

Investigation of the Alkali-Reactivity Potential of Limestone Aggregates from the Quebec City Area (Canada)

Benoit Fournier and Marc-André Bérubé

Département de Géologie
Université Laval
Québec, Qué., Canada

Daniel Vézina

Ministère des Transports du Québec
Laboratoire Central, Complexe Scientifique
Sainte-Foy, Qué., Canada

ABSTRACT

The project began with the stratigraphic study and the bed-by-bed sampling of four limestone quarries of the Quebec City area. The samples collected were submitted to laboratory tests in order to evaluate their potential of alkali-reactivity in concrete. In parallel, the condition survey of some 300 concrete structures has been undertaken. The structures showing megascopic signs of deterioration commonly associated to alkali-aggregate reactions were cored and the samples investigated in detail.

INTRODUCTION

In Quebec (Canada), the (Paleozoic) Trenton limestones are the main source of concrete aggregates. Some varieties from the Montreal and the Trois-Rivières areas have already been recognized as alkali-silica reactive in concrete (Durand and Bérard 1974, Bérard and Roux 1986). The project investigated this problem for the Quebec City area and was conducted in two parts: 1) laboratory tests on samples from regional limestone quarries, and 2) condition survey of some 300 concrete structures of the area.

GEOLOGY AND PETROGRAPHY

Four representative quarries covering, with some overlapping (Fig. 1), the regional stratigraphic sequence of limestones, were geologically mapped and bed-by-bed sampled. Two types of samples were collected: 1) 85 "composite-samples", each of them corresponding at the most to a 3 meter thick rock sequence, and 2) 108 "block-samples" representative of the major petrographic rock types found in each "composite-sample". The limestones have been petrographically divided in three facies (Fournier et al. 1985):

Facies I: light grey to beige sparry limestones, rich in fossil fragments and usually containing more than 95% CaCO₃. They are mainly located in the basal part of the regional limestone sequence.

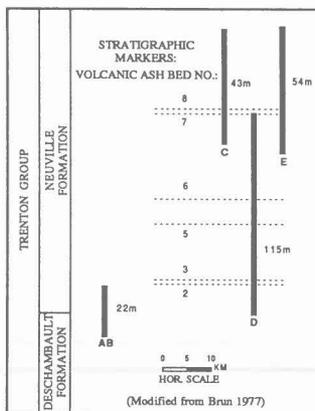


FIGURE 1. Stratigraphic correlations between the quarries.

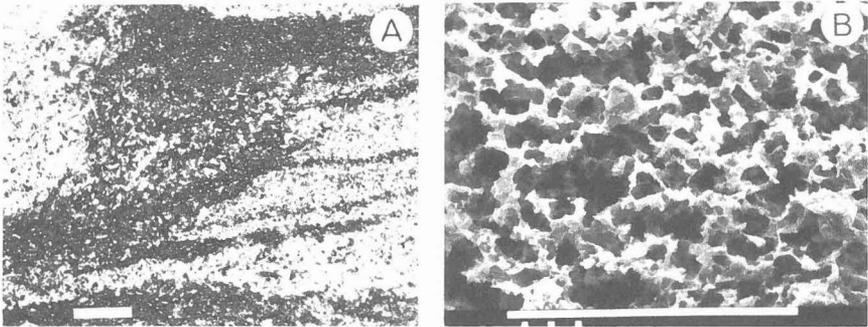


FIGURE 2. Typical composition of facies II limestones. A) Mixture of light areas of small fossil fragments cemented by calcite, and dark brown areas of calcite grains embedded in an argillaceous and siliceous insoluble matrix. (Thin section micrograph, scale = 1mm). B) Alveolar microtexture of this insoluble matrix after acid etching. (SEM micrograph, scale = 100 μ m).

Facies II: medium to dark-grey fine-grained limestones showing, in thin section, a mixture of two principal microfacies (Fig. 2A): i) light areas containing small fossil fragments cemented by crystalline calcite, and ii) dark-brown areas constituted by calcite grains (<10 μ m) embedded in a siliceous and argillaceous matrix (cryptocrystalline quartz, illite and inter-layered illite-smectite) (Fig. 2B). Within the rock sequence corresponding to a given composite-sample, the relative amounts of these two microfacies vary largely from bed to bed. The block-samples however could be divided in two "subfacies" according to the relative amounts of the siliceous microfacies (II-1: <50%, II-2: 50-90%). Rocks of facies II contain 4 to 24% of insoluble residues and are the major constituent of the regional limestone sequence.

Facies III: end-member of facies II rocks, being constituted by more than 90% of the siliceous microfacies just described. These rocks present a typical massive texture, a conchoidal fracture and a homogeneous chemical composition characterized by 10 to 15% of total insoluble residues. The beds of these limestones are usually not abundant and are sparsely dispersed and interbedded within facies II limestone beds. However, they form a continuous rock sequence of about 35 meter thick in one quarry.

LABORATORY TESTS ON SAMPLES FROM QUARRIES

Standard (ASTM C289) and Modified Chemical Tests

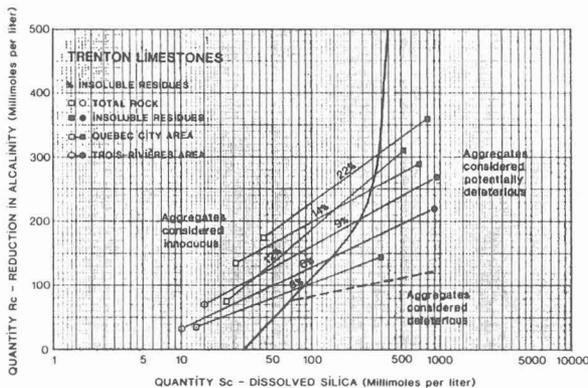


FIGURE 3. Results for the Standard Chemical Method (ASTM C289) and for the modified chemical test on insoluble residues.

The standard ASTM C289 Chemical Method has been applied. It is however not appropriate for carbonate rocks (Mielenz and Benton 1958, Bérard and Roux 1986). The modified test proposed by Bérard and Roux (1986) has also been performed on the insoluble residues obtained after elimination of the carbonates with HCl. The results indicate that these residues are chemically unstable in basic and alkaline solutions (Fig. 3), thus confirming data from Bérard and Roux (1986) for the limestones from the Trois-Rivières area.

Rock Cylinder Test (ASTM C586)

Rock cylinders were cored from the block-samples. After a stable behavior during the first 21 to 24 weeks in NaOH solutions (Fig. 4), most of the cylinders belonging to facies II and III began to expand, but at different rates. Microcracks and deposits of characteristic siliceous gels appeared on many of them, mainly parallel to the rock bedding (Fig. 5). The results indicate higher expansions for rock cylinders containing large amounts of the siliceous microfacies previously described. When considering expansions greater than 0.1% as indicative of chemical reactivity (ASTM Standard C586-81), rocks of facies II-2 and III appear as chemically unstable in basic and alkaline environments (Table 1).

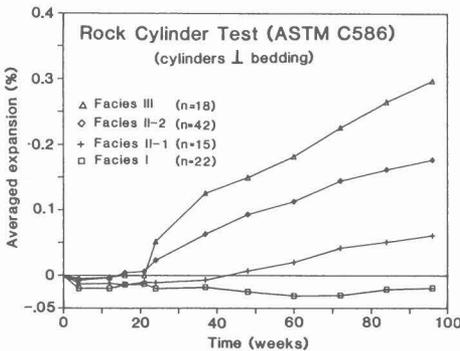


FIGURE 4. Results for the Rock Cylinder Test.

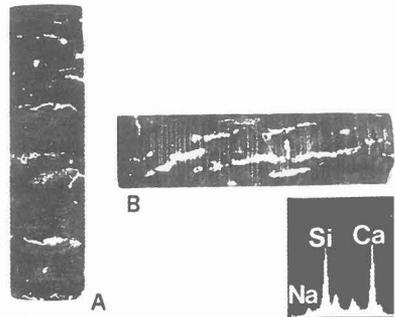


FIGURE 5. Siliceous gels on rock cylinders. (Core A: ⊥ to bedding; core B: // to bedding).

TABLE 1. Expansion of rock cylinders in NaOH solutions.

PETROGRAPHIC FACIES	NUMBER OF CYLINDERS	TIME YEARS	% EXPANSION		% OF CYL. WITH EXPANSION >0.1%
			Avg.	Std.dev.	
I	22	1	-0.025	0.021	0
		(2)	(-0.018)	(0.026)	(0)
II-1	15	1	0.006	0.032	0
		(2)	(0.061)	(0.078)	(20)
II-2	42	1	0.095	0.085	50
		(2)	(0.179)	(0.142)	(74)
III	18	1	0.149	0.120	78
		(2)	(0.295)	(0.177)	(89)

Mortar Bar Test (ASTM C227)

Mortar bars were made with limestone aggregates (composite-samples) and a type 10 high alkali cement (1.20% Na₂O eq.). Again, the three limestone facies performed quite differently (Fig. 6). The observed expansions (Table 2) may be considered as marginal in comparison with the specified ASTM

limits (0.05% and 0.1% at 3 and 6 months, respectively). However, such limits have already proved to be unrealistic for certain types of reactive aggregates (Grattan-Bellew 1981). Moreover, microcracks and spots of siliceous gels were observed on numerous bars which expanded more than 0.05%. The results indicate again that rocks containing large amounts of the siliceous microfascies may be slowly expansive in alkaline environments.

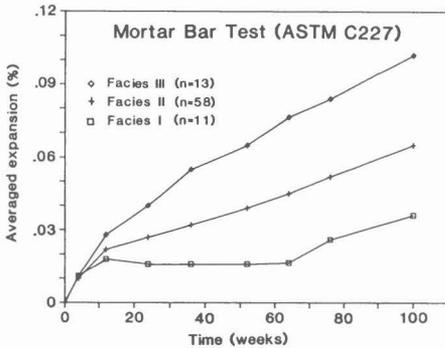


FIGURE 6. Results for the Mortar Bar Test.

TABLE 2. Expansion of mortar bars stored at 38°C and 100% R.H.

PETROGRAPHIC FACIES	NUMBER OF TESTS	TIME YEARS	% EXPANSION		% OF BARS WITH EXPANSION	
			Avg.	Std.dev.	>0.05%	>0.1%
I	11	1	0.016	0.017	9	0
		(2)	(0.036)	(0.034)	(9)	(9)
II	58	1	0.039	0.025	26	7
		(2)	(0.065)	(0.031)	(66)	(16)
III	13	1	0.065	0.021	77	8
		(2)	(0.102)	(0.026)	(100)	(54)

Concrete Prism Test (CSA A23.2-14A)

Concrete prisms (100mm x 75mm x 400mm) were made with a type 10 high alkali cement (1.20% Na₂O eq.), a local innocuous sand (according to standards ASTM C289 and C227), and the limestone aggregates (composite-samples). They were stored in a fog room maintained at 23°C. No expansion values greater than the proposed limit of 0.03% (CSA Standards, CAN A23.2-M77, App. B3.5) are observed after 2.5 years, which suggests that the aggregates are non expansive, or at the most very slowly expansive. However, the amount of water available in the fog room may have contributed to reduce the alkalis in the concrete pore solution, thus reducing or eliminating expansion. Additional prisms has been recently made with the alkali content raised to 1.25% Na₂O eq. (Rogers 1985), and are maintained in sealed containers over water at 38°C and 100% relative humidity.

Conclusion on laboratory tests

According to the modified chemical test, the insoluble residues of the limestones from the Quebec City area are chemically unstable in basic alkaline solutions. The extent of chemical reactivity signs presented by these rocks (expansion, microcracks, gel formation, etc.) greatly depends upon the amount and the nature of these insoluble residues, as demonstrated by the results for the Mortar Bar and the Rock Cylinder Tests. However, the Mortar Bar and Concrete Prism Tests seem to indicate that the expansive behavior of these limestones is probably marginal or proceeds at a very slow rate.

CONDITION SURVEY

Visual examination

Some 275 concrete structures from the Quebec City district and 15 other from the neighbouring Lévis District, mainly viaducts and bridges, have been investigated in detail for defects (ACI 201.1R-68). Results from the survey (Fournier et al. 1987) indicate that the current deteriorations are generally modest, affecting almost exclusively parts of concrete components submitted to freezing and thawing, wetting and drying, and deicing salts.

Map cracking, a defect commonly associated to alkali-aggregate reactions, even if not characteristic, was frequently observed, but almost exclusively on girders (Fig. 7), sidewalks and abutments (Fournier et al. 1987), all made with limestone aggregates. This defect, which appeared early on many of these components, was not recognized on less exposed components of the same structures, or on structures made with greywacke aggregates (Lévis District) and subjected to as severe exposure conditions.

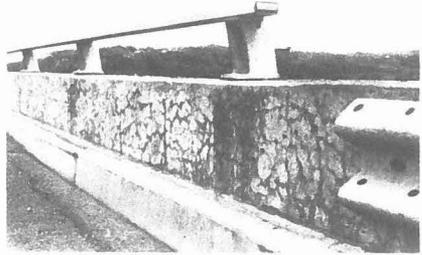


FIGURE 7. Map-cracking pattern on a girder.

Sampling and laboratory analyses

Sixty (60) concrete structures of the Quebec City District, selected with regard to their age and to the extent of map-cracking, were cored in one of their most deteriorated (and exposed) components. For comparison, core samples were also taken i) in less deteriorated components from five of these structures, and ii) from three 25 year old concrete structures of the Lévis District. The samples (100mm ϕ x 250mm) were submitted to the usual laboratory tests on hardened concrete (Fournier et al. 1987).

Petrographic examination

In spite of more or less severe scaling and cracking on the concrete surface, samples with limestone aggregates were usually in a satisfactory condition. However, samples from components submitted to severe exposure conditions and generally showing map cracking on their surface, contained, in variable amounts, but quite frequently, large amounts of microcracked aggregate particles. The microcracks are usually thin (<0.1 to 0.3 mm), often partially or totally filled with insoluble products which form typical white "veinlets" (Fig. 8A), and frequently extend into the cement paste. These veinlets represent planes where fractures run preferentially when samples are broken and reveal (Fig. 8B) i) a dark rim at the periphery of the aggregate particles, which surrounds white deposits, and ii) gel deposits, sometimes filling pores adjacent to the aggregate particles, and covering more or less large areas of the cement matrix, depending on the extent of microcracking. Under the SEM, the dark rim appears to consist of massive gels (Fig. 9A) with various microtextures (Bérubé and Fournier 1986). These gels give way abruptly, but sometimes progressively, toward the centre of the aggregate particles, to rose-like crystals (Fig. 9B). Such typical petrographic features of alkali-silica reactivity are often presented in the literature (Bérubé and Fournier 1986). However, the actual mechanism of formation of the veinlets within the particles is not well known. They may result from progressive filling, by reaction products, of i) preexisting cracks (Davies and Oberholster 1986), or ii) "secondary" cracks formed by internal pressure (St-John 1985).

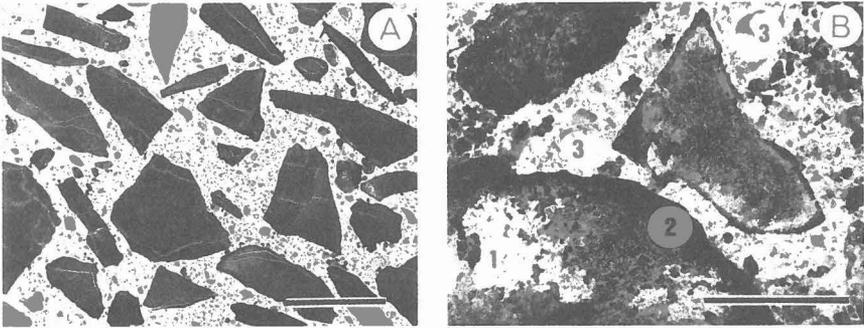


FIGURE 8. Internal concrete deterioration. A) Microcracks and veinlets in limestone particles. (Scale = 2 cm). B) White products (1) surrounded by dark rims (2) on fracture surfaces through limestone particles, and white gels in pores (3) of the cement matrix. (Scale = 5 mm).

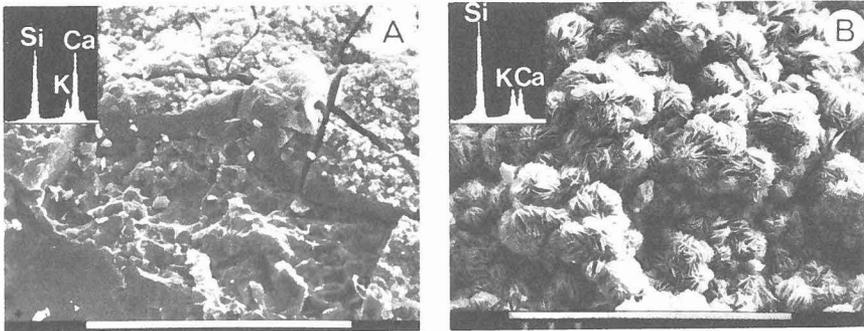


FIGURE 9. Typical SEM micrographs and EDXA spectra of gels from the dark rim (A) and of white crystalline products (B) found on fracture surfaces through aggregate particles. (Scales = 100 μm).

In fact, more than 70% of the examined core samples showed characteristic signs of alkali-aggregate reactivity, however mostly of a low degree. Superficial etching with diluted HCl of polished concrete sections revealed that most of the aggregate particles showing white veinlets correspond to the facies II and III limestones previously described.

No direct correlation was observed between the extent of the petrographic signs of alkali-silica reactivity and the age of the concrete structures, thus confirming that many factors are involved in the deterioration processes.

Conclusion from the field survey

Deterioration observed on concrete structures in the Quebec City area does not presently affect their serviceability, but will necessitate more or less important periodical repairs. Superficial map cracking and microcracking of the aggregate particles (at least over the total thickness of the concrete core samples) occur almost exclusively on components built with limestone aggregates and submitted to the combined effects of freezing

and thawing, wetting and drying, and deicing salts. Limestones have already shown to be sensitive to such conditions (Hudec 1980).

Signs of alkali-silica reactivity were present in many core samples, but some petrographic observations suggest that this single phenomenon is probably not the only factor nor the major one, responsible for the early development of map-cracking on the exposed components.

CONCLUSION

Laboratory tests on quarry samples and petrographic examination of concrete cores revealed a marginal potential of alkali-silica reactivity for the limestone aggregates produced in the Quebec City area. The early occurrence of superficial map-cracking and the internal particle microcracking which affect the exposed concrete components seem to involve deterioration mechanisms which imply the presence of limestone aggregates in combination with wetting and drying cycles, freezing and thawing cycles, and deicing salts. More research is needed to explain these behaviors.

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