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ALKALI-REACTIVITY POTENTIAL OF CARBONATE ROCKS FROM THE ST. LAWRENCE LOWLANDS (QUEBEC, CANADA)

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ABSTRACT

Results from an extensive laboratory research program are used to establish the alkali-reactivity potential of the carbonate aggregates produced in the St. Lawrence Lowlands (Quebec, Canada). A special attention was attributed to the development or the adaptation of quick and reliable testing methods for the evaluation of this potential on a routine basis.

1. INTRODUCTION

In the St.Lawrence Lowlands (Quebec, Canada), sedimentary rocks of Paleozoic age (Cambrian to Upper Ordovician) form the main source of concrete aggregates. These are exploited in more than fifty quarries located for the most in the vicinity of great urban centres. Some siliceous limestones exploited in the Montreal, Trois-Rivieres and Quebec city areas have already been recognized as alkali-silica reactive in concrete [1,2,3]. However, the degree of deterioration affecting concrete structures shows large variations from an area to another, but also within a particular area. This is mainly attributed to variations in the alkali-reactivity potential of aggregates, but also to the local exposure conditions (wetting/drying cycles, deicing salts applications, etc.). This paper summerizes the results of laboratory standard and experimental tests performed to investigate the alkali-reactivity potential of the carbonate concrete aggregates produced in the St. Lawrence Lowlands.

2. GEOLOGY AND PETROGRAPHY

The St. Lawrence Lowlands mainly consist of relatively unfolded and flat-lying beds of limestones, dolostones, sandstones and shales, extending on both sides of the St. Lawrence River. These are bordered to the northeast by the Precambrian Shield, along a series of normal faults, and to the southeast by the folded rocks of the Appalachian belt [4] (Fig.1). Twenty-two quarries were selected to cover the stratigraphic variations within this large structural domain. Lithostratigraphic correlations were mainly based on petrographic considerations, but also on stratigraphic markers consisting of beds of altered volcanic ashes called "K-Bentonites" [5]. Each quarry was geologically mapped and bed-by-bed sampled according to their constituing petrographic facies. 71 samples representing about 30 geological Formations of Members were collected (Fig. 1). These were crushed to produce aggregate particles between 5 and 20 mm in size, on which a series of petrographic, physico-mechanical and chemical tests (alkali-reactivity) were performed.

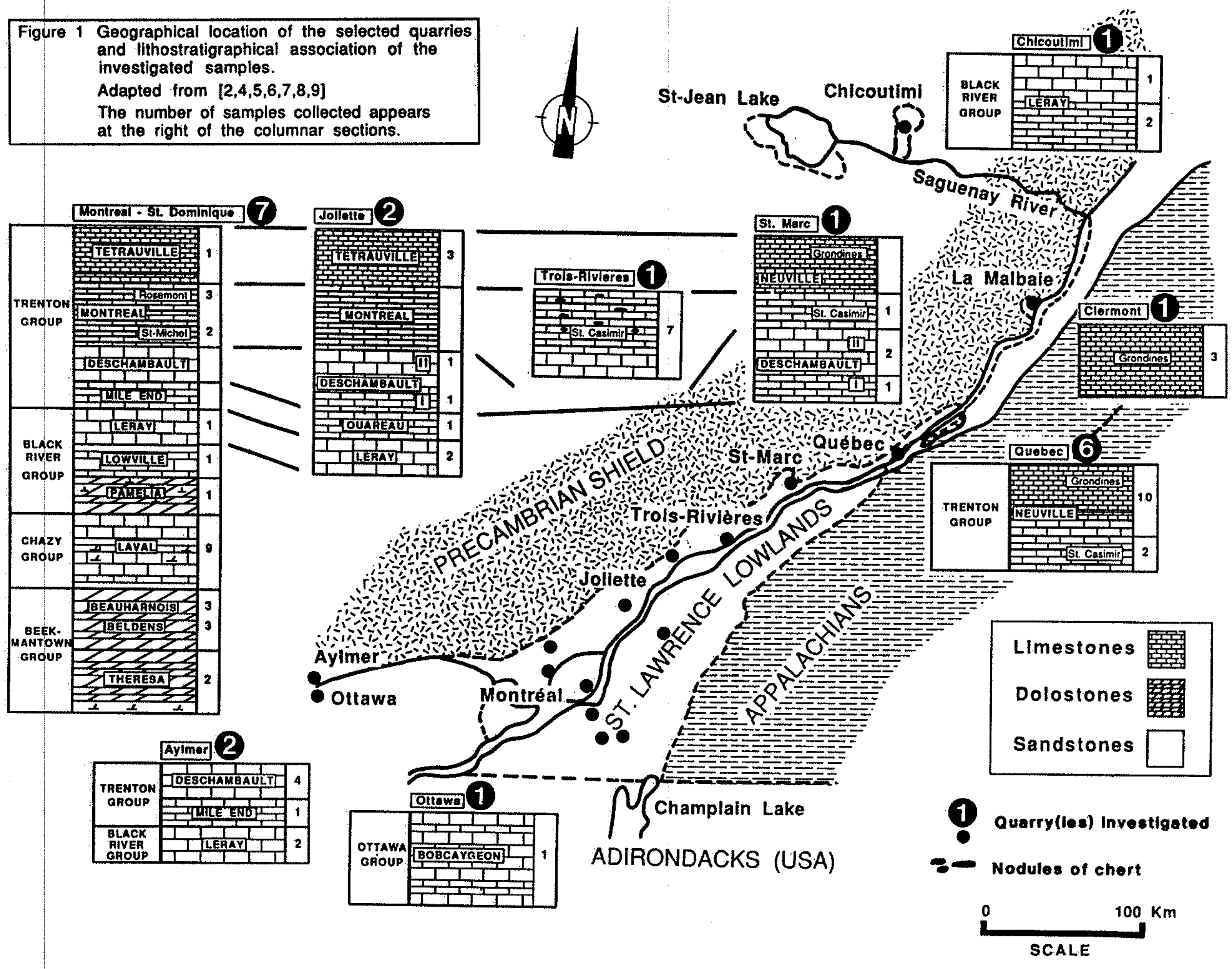

Figure 1 Geographical location of the selected quarries and lithostratigraphical association of the investigated samples.
Adapted from [2,4,5,6,7,8,9]
The number of samples collected appears at the right of the columnar sections.

3. EXPERIMENTAL

On a reference basis for the accelerated tests, concrete prisms were made (75mm x 75mm x 300mm) using a type 10 high alkali cement (1,0 Na_2O equiv), and an innocuous granitic sand. The mixes had an aggregate:sand:cement:water ratio of 3,18 : 2,19 : 1 : 0,50, with a cement content of 350 kg/m^3. The total alkali content of the mix was increased to 1,25% (Na_2O equiv.) by the addition of NaOH. The concrete prisms were stored at 38^{o}C and 100% R.H. with length change measurements made at specified times using a vertical comparator readable to 0,001mm (CSA Standards). Petrographic examinations were realized to monitor the development of cracking at the surface of the samples.

The effectiveness of the Modified Chemical Method (on insoluble residues) has been already evaluated [2,10]. For each samples, 1,5 to 2 kg of 150-300 um material were produced by progressively crushing 5 kg of coarse aggregate particles (-20 + 5mm). The insoluble residue (-300 um) was obtained after leaching of carbonates with concentrated HCl (12N) at room temperature. For dolostone and dolomitic limestone aggregates, hot acid treatment insured complete dissolution of the dolomite. The residues were then tested in accordance with ASTM C289, at the exception that 25 gr of residue were used (2 x 12,5 gr) instead of 75 gr (3 x 25 gr), because of the high porosity of the material. "Corrected" Sc values were calculated by multiplying the bulk Sc values by the percent of insoluble residues in the samples, since the test is performed on 100% insoluble residues [10]. Mortar bars were prepared in accordance with ASTM C227, using the same high alkali cement (1% Na_2O equiv.), but at a fixed w/c ratio of 0,5. The bars were then tested under the South African Test conditions [11]. However, the 24 hour temperature conditioning in water was replaced by a 24 hour curing period at 23^{o}C and 100% R.H., and a 24 hour temperature conditioning in NaOH prior to the zero reading. The expansion of bars in the NaOH solution was then monitored over a 14 days period.

4. RESULTS AND DISCUSSION

Average expansions of concrete prisms at 6 months are presented in Table 1. A preliminary expansion limit of 0,04% is chosen to distinguish reactive or potentially reactive aggregates from the non reactive ones. It is noted that this expansion value generally corresponds to the detection of visible cracking on concrete prisms. All siliceous or massive dolostones, dolomitic/sandy limestones and quartzitic sandstones associated to the Beekmantown, Chazy and Black River (Pamelia Formation) Groups show expansion values less 0,04% at 6 months. This suggest that such aggregates, largely used in the Montreal area, can be considered as innocuous in concrete. Dolostones are even considered as high performance aggregates.

Tested limestones from the Black River and the Trenton Groups globally present high expansion values (> 0,04%, Table 1), thus indicating potentially alkali-reactive rocks. However, high standard deviation values reflect important variations in their expansive behaviors, in accordance with lateral and vertical stratigraphic variations observed in these Groups. The high-calcium limestones from the Deschambault II and the Lowville Formations can however be considered as non reactive in concrete since they present very low expansions (average expansion < 0,04%, Table 1). The siliceous limestones exploited in the Quebec City (St-Casimir and Grondines Members) and the Trois-Rivieres areas (St-Casimir Member) produced high expansions in this laboratory study, as well as numerous signs of reactivity in concrete structures [1,2,3,12]. This behavior is mainly attributed to cryptocrystalline quartz, which is closely associated with various amounts of illite, interlayed illite/smectite and chlorite (XRD, SEM-EDXA observations) within the matrix of these rocks [2,10].

Figure 2 presents the "corrected" Sc values (at the Modified Chemical Method) as a function of the concrete expansions at 6 months (Concrete Prism Test). Despite large dispersion of data, a 10 mmoles/liter limit criteria may be drawn. This criteria can only be used as an acceptation limit since the rocks from the Beekmantown and the Chazy Groups often exceed this limit while proved to be non reactive at the Concrete Prism Test. The expansion values at 14 days (for the Accelerated South African Mortar Bar Test) are plotted against those at 6 months (for the Concrete Prism Test) for the investigated carbonate aggregates (Fig. 3). An acceptation limit criteria of 0,10% can be drawn since lower mortar bar expansion values correspond to concrete expansions less than 0,04%. Rocks from the Quebec City and the Trois-Rivieres areas which are known to be reactive in concrete structures [1,2,3,12] globally give mortar bars expansions greater than 0,2% at 14 days. However, the 0,10% criteria can only be used as an acceptation limit since some very slowly reactive massive and argillaceous aggregates from the Clermont area give excessive expansion at this rapid mortar bar test (0,35%). Expansions greater than the proposed limit should require further testing through the Concrete Prism Test.

Table 1. Expansion data for the Concrete Prism Test at 6 months (A: Average; STD: Standard deviation). The number in parentheses indicates the amount of sample tested.

GROUP	Formation (Member) \ Area	AYLMER OTTAWA A STD	MONTREAL St. Dominique A STD	TR. RIVIERES JOLIETTE A STD	ST. MARC A STD	QUEBEC A STD	CHICOUTIMI CLERMONT A STD
TRENTON	Tetrauville Neuville (Grondines)		0,069 (1)	0,064 0,007 (3)		0,092 0,036 (10)	0,060 0,035 (3)
	(St-Casimir) (St-Michel)		0,048 0,004 (2)	0,224 0,087 (7)	0,008 (1)	0,121 0,024 (2)	
	Montreal (Rosemont)		0,083 0,032 (3)				
	Deschambault II	0,009 0,005 (4)		0,007 (1)	0,011 0,000 (2)		
	Deschambault I			0,158 (1)	0,195 (1)		
	Mile End Ouareau	0,011 (1)		0,073 (1)			
BLACK RIVER	Leray	0,024 0,008 (2)	0,027 (1)	0,140 0,050 (2)			0,017 0,014 (3)
	Bobcaygeon	0,274 (1)					
	Lowville		0,011 (1)				
	Pamelia		0,019 (1)				
CHAZY	Laval		0,016 0,005 (9)				
BEEKMANTOWN	Beauharnois		0,021 0,000 (3)				
	Beldens		0,014 0,009 (3)				
	Theresa		0,015 0,003 (2)				

4. CONCLUSION AND RECOMMANDATIONS

Despite high bulk and corrected Sc values, the investigated siliceous dolostones and sandy/dolomitic limestones from the Beekmantown and the Chazy Groups globally present low expansion at the Concrete Prism Test and the Accelerated South African Mortar Bar Test. Further testing may however be necessary for the Beekmantown Group rocks which present important stratigraphic variations in the Montreal area. The present study indicated that the Modified Chemical Method (on insoluble residues) is unsuitable for the routine evaluation of such rocks. It is then recommanded to first use the South-African rapid mortar bar test with a 14 day expansion criteria of 0,10%. Expansions in excess of this limit should involve further testing on concrete.

The high-calcium rocks from the Deschambault II and Lowville Formations show corrected Sc values under 5 mmoles/liter (Fig. 2), mortar bar expansions lower than 0,1% (Fig. 3), and concrete prisms expansions less than 0,04%. All these results confirm the innocuous

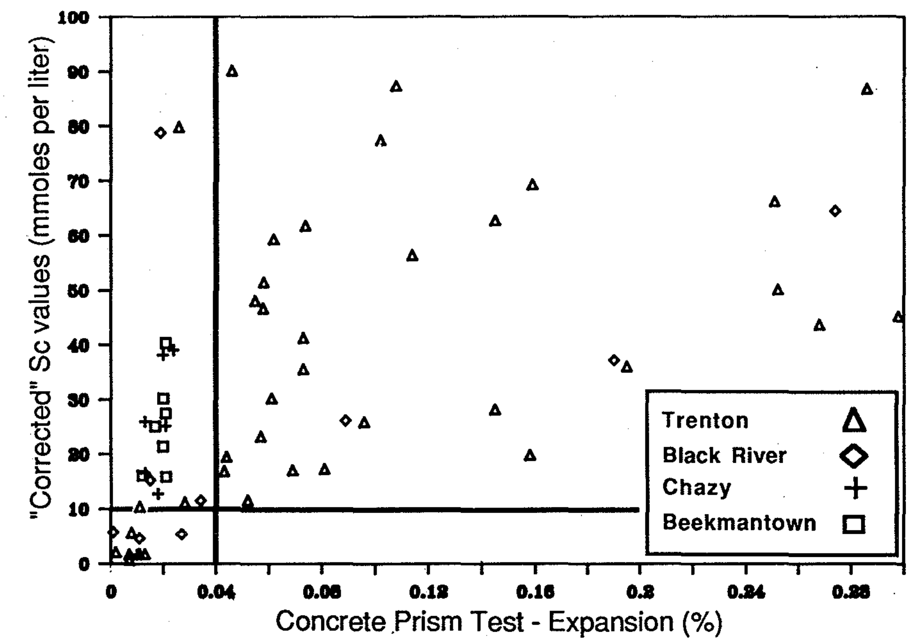

Figure 2. "Corrected" Sc values (mmoles per liter) as a function of the 6 month expansion values measured at the Concrete Prism Test.

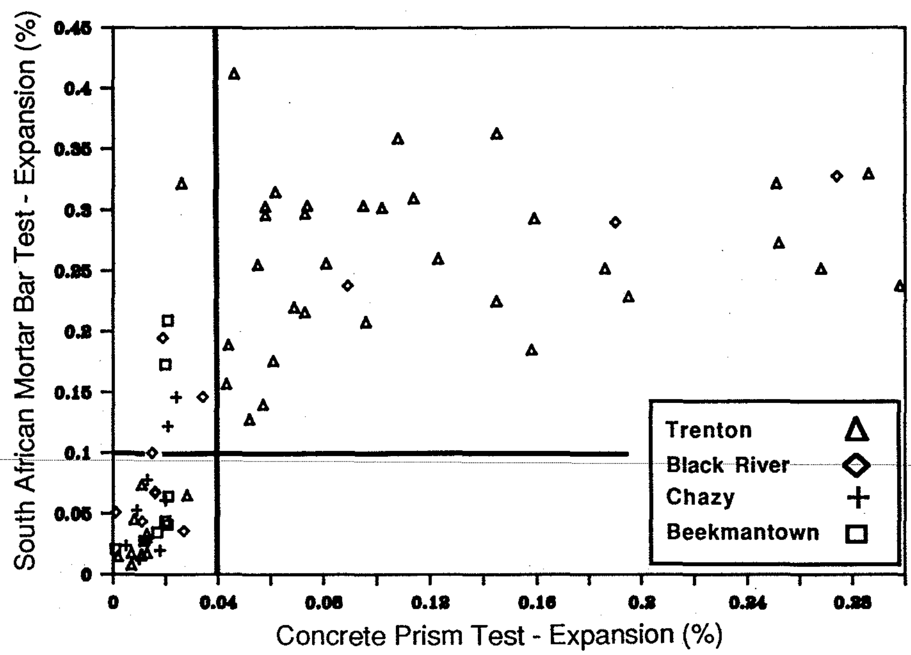

Figure 3. Expansion values at 14 days (Accelerated South African Mortar Bar Test) as a function of the expansions at 6 months (Concrete Prism Test)

nature of these rocks. In fact, within all the rocks investigated, none containing less than 5% of insoluble residues showed an expansive behavior at the Concrete Prism Test. Large variations in the alkali-reactivity behavior of the Trenton Group limestones were observed. The exact reasons for such a behavior are still under investigation. Various factors may be invoked, especially variations in nature, mineral composition and texture of the insoluble residues (ratio clay minerals / free silica, type of silica, etc.), and in the permeability and porosity of the rocks. A corrected Sc value of 10 mmoles/liter (Modified Chemical Method), or a 14 day expansion value of 0,10% (South African Accelerated Mortar Bar Test) can be used as acceptation limits for the preliminary or routine investigation of these rocks. Results in excess of these limits should require further testing through the Concrete Prism Test. It is noted that these conclusions are mostly based on laboratory test results and may be revised after concrete structure inspections which are presently under investigation.

5. ACKNOWLEGMENTS

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