# Alkali-Aggregate Reactions in Ontario

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ABSTRACT

Over 130 concrete structures in Ontario are affected by alkali-aggregate reactions. Three different types of reaction are found: alkali-silica, alkali-carbonate and the so-called alkali-silicate reaction.

## INTRODUCTION

The alkali-silica and silicate reactions found in Ontario are relatively slow and have not resulted in an immediate need to replace affected parts of structures. The cracking caused by these reactions has generally increased the cost of maintaining and repairing pavements and structures as well as reducing the overall life of the concrete. In the case of the far more serious alkali-carbonate reaction, life of concrete has sometimes been reduced to less than five years.

The presence of a reaction in a structure has seldom been the sole cause of demolition. Of the 130 structures where A.A.R. (Alkali Aggregate Reaction) has been recognized, about 125 are still in service. The climate of Ontario is severe with many cycles of freezing and thawing. Temperatures as low as -40° C are not uncommon, with an average January temperature of -15° C over much of the Province. Cracking initially caused by A.A.R. allows greater moisture and chloride ion penetration which accelerates damage caused by these agents. The problem is not so much the initial cracking and the resultant reduction in strength but rather the increased rates of deterioration by other agents that accompany cracking caused by A.A.R. Those structures affected by A.A.R. generally have far higher maintenance and repair costs than other structures of the same age.

## ALKALI-CARBONATE REACTION

Palaeozoic Carbonate Rocks of the Gull River Formation (Lake Ontario basin) (Swenson and Gillott, 1960) and the Ottawa Limestone (Ottawa-St. Lawrence Lowlands) are alkali reactive (Rogers, 1986). The general area of occurrence of these rocks is shown in Figure 1. Only certain beds are reactive. These are beds of fine grained dolomitic limestone with a significant clay mineral content. These beds are found in the lower member of the Gull River Formation, also known as the Pamelia Formation. The rocks are reasonably durable when used as building stone or in asphalt, but when they are used in Portland cement concrete, they expand and cause cracking and deterioration of the concrete. In a recent example, concrete sidewalks expanded up to 1.2 percent after 3 years and were replaced after 7 years.

If a quarry is suspected of containing alkali-carbonate reactive rock, a number of different techniques may be used to identify the reactive beds and those beds that may be safely used in concrete. The quarry face is sampled at about 0.3 m intervals and examined microscopically to see if the texture characteristic of reactive rock is present. The rock cylinder expansion test (ASTM C586) is also conducted. Expansion in excess of 0.1% after 4 weeks or 0.2% after 16 weeks usually indicates potentially deleterious expansion (Rogers, 1986).

When the non-reactive beds have been identified and a suitable working face established, aggregate is tested in the concrete prism expansion test (CSA A23.2-14A). Concrete prisms are stored in a moist room for a period of at least one year and the expansion measured. Most concrete used by the Ministry of Transportation and Communications (MTC) is in a moist environment, exposed to de-icing salts. Aggregate for use in this environment is tested with normal Portland cement fortified by the addition of NaOH to give a cement alkali content of 1.25% $Na_2O$ equivalent. An expansion of the concrete, of greater than 0.025% at 1 year is considered excessive. Waiting a year for approval to use an aggregate is regarded by many engineers as unreasonable. As a result, a quick chemical test has been developed in Ontario (Rogers, 1986).

When alkali-carbonate reactive rock has been identified, the usual solution is to exclude the reactive beds from use by selective quarrying. It is possible to use a low alkali cement (less than 0.4% $Na_2O$) to slow the reaction. De-icing salt (NaCl) will add alkalies to the concrete and increase the rate of expansion (Smith, 1964).

No cases of alkali-carbonate reactivity have been found with gravel aggregates. Extensive investigations in the 1960's on gravel aggregates in the area of outcrop of the alkali-carbonate reactive bedrock found low percentages (1-2%) of the reactive rock type, which was insufficient to cause excessive expansion of the gravels in laboratory tests. A possible reason for this phenomenon is the apparent low resistance of these rocks to freezing and thawing. Rogers (1986) found that alkali-carbonate reactive rock gave high losses in laboratory freeze-thaw tests. Remarkably, the same rocks were not significantly affected by the magnesium sulphate soundness test. Transportation of fragments of bedrock by glacio-fluvial action would presumably lead to breakdown of the frost sensitive varieties into small sizes (less than 2 mm). The residual gravel having been naturally beneficiated is non-expansive.

## ALKALI-SILICA REACTION

The main alkali-silica reactive minerals found in Ontario are chalcedony and optically strained quartz. Cherts, cherty limestones, sandstones and granites from Ontario have all been found to be deleteriously alkali-silica reactive. Artificial glass has also been found to be alkali-silica reactive.

In Ontario, concrete aggregates are subjected to detailed petrographic examination. This often requires study under a polarizing microscopic to look for chalcedony in cherts and cherty limestones or highly strained quartz in sandstones and granites. The mortar bar test (ASTM C227) is employed with aggregate suspected to be alkali-silica reactive. MTC practice is to test the aggregate with normal Portland cement fortified by the addition of NaOH to give a cement alkali content of 1.25% $Na_2O$ equivalent. An expansion of greater than 0.05% at three months or 0.1% at six months is considered excessive. The quick chemical test (ASTM C289) is not practical in Southern Ontario where the aggregates contain significant amounts of carbonate minerals. In Northern Ontario, where igneous gravels are often contaminated with small amounts of chert, with little or no carbonate, this test is more useful.

Sandstone and granites may be slowly alkali-silica reactive and may give unreliable mortar bar test results (ASTM C227). With these rock types, acceptance is based on petrographic examination and past field performance. For instance, aggregates containing large proportions of sandstone or granite, such as those obtained in quarrying operations, are not used unless there are many years of good field performance of concrete exposed under similar conditions to those intended. Alternatively, a thorough petrographic examination and exhaustive testing may show the aggregate to be innocuous.

## ALKALI-SILICATE REACTION

Argillites and greywackes of the Huronian Supergroup (Precambrian) are alkali-reactive (Dolar-Mantuani, 1969). These metamorphosed sedimentary rocks are found in Northern Ontario (Figure 1). Gravel deposits in this area may contain these rocks together with alkali-silica reactive sandstones of the same age. These rocks react with alkalies from cement paste to cause expansion and cracking of concrete.

The reaction of these rocks with alkalies is generally slow, and is not properly understood. Dolar-Mantuani (1969) showed that these rocks slowly expand in the rock cylinder expansion test (ASTM C586) usually used for alkali-carbonate reactive rocks. They also caused expansion of mortar bars (ASTM C227) with the generation of alkali-silica gel. Grattan-Bellew (1978) found that expansivity was related to porosity and the percentage of microcrystalline material present in the rock. The greater the amount of microcrystalline material, the greater the expansion. Argillites, which are very fined grained, are most expansive; the greywackes, which are coarser, are less expansive. Grattan-Bellew concluded that the expansion of concrete was mainly due to expansion of the individual rocks.

The expansion of these argillites and greywackes in concrete is termed the alkali-silicate reaction. While there are similarities with the alkali-silica reaction, the expansion of individual rock particles suggests adsorption of water on previously 'dry' alumino-silicate surfaces in the microcrystalline portion of the rock. Furthermore, the results of the diagnostic tests used for detecting the alkali-silica reaction may be misleading. Both the quick chemical test (ASTM C289) and the mortar bar test (ASTM C227) may give unreliable results (Grattan-Bellew, 1978).

Current MTC practice, in the area of Ontario where these rocks are found, is to conduct petrographic examination of the coarse aggregate. If the quantity of potentially reactive rock types (argillite, greywacke, sandstone and/or arkose) is less than about 15%, the aggregate may be used in concrete without further testing. If there is greater than 15% reactive particles, then the aggregate should not be used until testing shows it to be satisfactory. At the present time, a high temperature concrete prism expansion test (CSA A23.2-14A) is the best method of evaluation. The prisms are stored in a 100 percent humidity atmosphere at 38°C rather than the 23°C normally used for the alkali-carbonate reaction. Unfortunately, reliable maximum expansion values to separate deleterious from satisfactory aggregates have not been developed.

Work by Sturrup et al (1983) has shown that the use of low alkali cement or fly ash replacement of the cement considerably reduces expansion due to this reaction. At the Lower Notch Dam on the Montreal River, 20% fly ash replacement was used successfully to prevent cracking of concrete containing argillite and greywacke.

## CORRECTIVE MEASURES

Once an alkali reactive rock has been identified, the use of a low alkali cement or other corrective measures are possible. The Ontario Ministry of Transportation and Communications has seldom adopted this solution. Low alkali cement is of limited availability and is more expensive. In view of the generally small amounts of concrete required on any highway contract (5-4000 $m^3$), the use of non-reactive aggregates has been cheaper and easier to control. The specification of low alkali cement in an area of high alkali cement requires a separate silo for storage. This is not a practical solution unless large quantities of concrete are called for. Further, there are problems of ensuring that the concrete delivered on the site contains the low alkali cement or pozzolan. The risk of using a reactive or a potentially reactive concrete aggregate is usually too great considering the small cost of aggregate compared to the value of the structure in which it is used.

## APPROVAL OF CONCRETE AGGREGATES

The alkali-reactivity testing of concrete aggregates is time consuming and calls for specialized equipment. Some way had to be found to rapidly approve concrete aggregates. The approach taken by MTC has been to publish a list of approved concrete aggregate sources in each region of Ontario. For a source to be included on this list it has to either have passed all applicable tests or to have a good record of past field performance in highway structures. The aggregate source is placed on the list together with any restrictions. For instance, in quarries, the location of extraction is specified since other parts of the quarry may be alkali-reactive or non-durable for physical reasons.

The concrete aggregate sources list is used as part of the contract documents. The concrete aggregates used on the job must come from the approved sources. As a further check, samples are taken once or twice a year from the various deposits and tested to confirm that they meet the requirements. In 1986 there were about 270 approved sources of coarse and fine aggregate.

## INVESTIGATION OF AAR IN STRUCTURES

Starting in the late 1950's the Ontario Ministry of Transportation and Communications has carried out numerous studies on AAR in structures. The major highway structures in each of the administrative districts are described, with photographs, in about 30 volumes. These volumes are kept in the petrographic laboratory and are separate from the far larger inventory of Ontario highway structures. The description of each structure is oriented only toward the cracking observed due to frost action or AAR. Structural problems are not recorded. Every year an attempt is made to visit and revise the description of the condition of the structures in one area of the Province. New photographs are taken and changes in condition are noted. When, in the course of these inspections, unusual or suspicious cracking is observed, pieces of the concrete are taken and petrographic examination conducted to determine the cause. It is through this process that much of our knowledge of the incidence of AAR in Ontario has accumulated.

## STOCKPILES OF REACTIVE AGGREGATE

One of the problems encountered by researchers in alkali-reactivity is the location of a source of known and documented alkali reactive aggregate. MTC has purchased and stockpiled about 110 tonnes each of three different reactive aggregates. These are: alkali-carbonate reactive dolomitic limestone from Kingston; alkali-silica reactive cherty limestone from Ottawa;

and alkali-silicate reactive argillite, greywacke and sandstone from Sudbury. These materials are available, free of charge, for studies into alkali-aggregate reactions.

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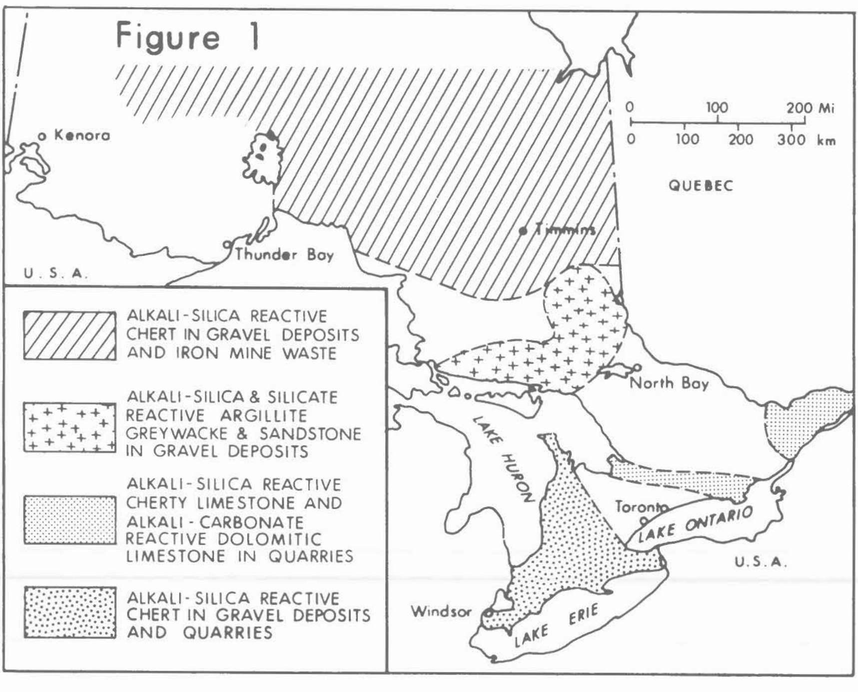


Figure 1