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Alkali-aggregate reaction in Nova Scotia. II. Field and petrographic studies

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ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
[Part] II. FIELD AND PETROGRAPHIC STUDIES

ANALYZED

by

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ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
II. FIELD AND PETROGRAPHIC STUDIES

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(Communicated by G. M. Idorn)

ABSTRACT

Certain siliceous and sedimentary rocks in Nova Scotia, when used as aggregate with high alkali cement, have produced excessive expansion of concrete. Laboratory studies showed a type of alkali-aggregate reaction to be responsible. Rock types in structures and in aggregate sources were identified by petrographic examination, the main types being selected for study of alkali-reactivity.

SOMMAIRE

En Nouvelle-Écosse, l'utilisation de certaines roches siliceuses et sédimentaires comme granulats avec du ciment riche en alcali a produit une dilatation excessive du béton. Des analyses en laboratoire en rendent responsable une sorte de réaction entre l'alcali et le granulats. On a identifié ces types de roches dans des structures et sources de granulats au moyen d'examen pétrographiques, et on en a choisi les types principaux pour étude de réactivité de l'alcali.

Introduction

An investigation of the alkali-aggregate reaction occurring in Nova Scotia has already been described (1, 2). This paper describes in brief the geology of Nova Scotia, the extensive field examination of structures and the detailed petrographic analysis of concrete cores and rocks from aggregate sources in the Province. An important phase of this investigation was the selection of rock types for length change studies, based on field and petrographic examination of affected and nonaffected structures as well as on aggregate sources.

Field evidence of excessive expansion of concrete had been observed over some 35 years and several investigations had been made without pinpointing the cause. Alkali-aggregate reaction had been suspected but the extreme slowness of the expansion and the complex geology of the area made this supposition difficult to demonstrate by laboratory experiment.

Preliminary microscopic examination of concrete cores and rock samplings were made at the Nova Scotia Technical College (3). More detailed petrographic analysis was done at the National Research Council of Canada, Division of Building Research.

Geological Background

The rocks of the Maritime Provinces of Eastern Canada are part of the Appalachian province which extends from central Alabama to Newfoundland. In Nova Scotia the rocks are mainly of Palaeozoic age and were folded and regionally metamorphosed during mountain building movements in the later part of that period. There are also Mesozoic rocks and surficial deposits formed during the Pleistocene; these have since been redistributed and eroded to some extent.

Lower Ordovician sedimentaries and metasedimentaries belong to the Meguma group which is divided into the older Goldenville Formation, and the younger Halifax Formation. The older rocks consist predominantly of grey-wacke with minor slate, schist and conglomerate. The overlaying Halifax Formation consists mainly of thinly bedded slates, argillites, siltstones and quartzites.

In much of south-central Nova Scotia there are Lower or Middle Devonian granites. There are also basic intrusions. In north-central Nova Scotia the sedimentary rocks are mainly of Mississippian and Pennsylvanian age. They consist of shales, sandstones, conglomerates, limestones, coal measures, gypsum, anhydrite and salt. The Mesozoic rocks occupy a fault trough from the Bay of Fundy to Chedabucto Bay. They are composed of conglomerates, sandstones, shales, amygdaloidal basaltic lavas and small outcroppings of arenaceous limestone and calcareous sandstone at the top. The harder and more resistant basalts form the ridge of North Mountain.

In the Pleistocene, till or boulder clay and drumlins blanket the bedrock. Deposits of this sort are generally less satisfactory sources of concrete aggregate because of the high percentage of fines.

Glacio-fluvial deposits which include outwash plains, eskers and kames are also widespread in Nova Scotia and are more satisfactory sources of fine and coarse aggregate for concrete. (Maps of these deposits are being prepared by the Nova Scotia Research Foundation.) Beaches in Nova Scotia are the result of recent redeposition of glacial deposits and postglacial erosion of bedrock.

In summary, the southern half of the Province is underlain by greywackes, quartzites, slates and phyllites, invaded by granites of at least two ages and by minor basic intrusives; the northern half is underlain by rocks of the Appalachian type on which were deposited alternating terre till and marine sediments. Surficial deposits of sands, gravels and till were deposited by fluvio-glacial action and in many cases consist of materials from widely separated sources.

Field Concrete

Evidence of excessive expansion in field concretes in Nova Scotia could be detected only after some 12 to 15 years of service. Usual manifestations were horizontal off-setting, squeezing out of expansion joint filler, warping of structural components, and misalignment of machinery. Measurements in early studies showed clearly that expansion in some hydraulic structures was continuing at a significant rate after 30 or more years. Map cracking

ALKALI AGGREGATE REACTION, FIELD STUDIES, PETROGRAPHY

and other forms of deterioration were consequences of excessive expansion but could not be used as direct evidence because of other destructive mechanisms that might have been present.

Frost action had clearly been responsible for considerable damage to concrete and its action in many structures tended to obscure expansion due to alkali-aggregate reaction. Most of the structures were built before air-entrainment was widely used, making it certain that much deterioration was caused by frequent freeze-thaw cycling prevalent in this region.

Records of sources of cement and aggregate, of mix proportions, and other information on concrete used were rarely available. As often as not, aggregates used in the original construction were transported over considerable distances. Aggregates were commonly made from gravel and beach deposits and invariably contained a heterogeneous mixture of rock types as can be expected from the geology of this part of the Appalachians.

Structures which showed the clearest evidence of excessive expansion, and which could be expected to be susceptible because of the availability of excessive moisture, included gravity dam walls, spillways, powerhouses, canals and bridges.

Among the several field surveys made during this investigation was a systematic "condition survey" of 176 concrete structures. Of the 117 that predated 1940, 101 were judged unsound and of these 63 appeared to have suffered excessive expansion, presumed to be due to alkali-aggregate reaction. Of the 59 structures postdating 1940, 30 were judged to be unsound and of these 15 appeared to be affected by alkali-aggregate reaction. Figure 1 shows an example of a type of deterioration associated with the Nova Scotia reaction.

Petrography of Concretes

Seventy-five cores were taken mainly from affected field structures, but also some from structures judged to have been unaffected by alkali-aggregate reaction. The cores were examined microscopically for evidence of alkali-aggregate or other reaction and to determine the rock types present as aggregates. Subsequently 45 of these cores were subjected to more detailed

FIG. 1

Pattern cracking in concrete of a buttress pier in a Nova Scotia dam.

petrographic analysis, using mated thin and polished sections. Table I shows typical examples of analyses of rock types present in five concrete cores taken from widely separated structures in the province.

TABLE I

Aggregate Analyses of Five Cores Showing Typical Distribution of Rock Types in Nova Scotia Concretes

Rock Type	Percent of each Rock Type Present (Particle count in brackets)				
	1 (161)	2 (136)	3 (288)	4 (124)	5 (190)
Greywackes	34.8	18.4	30.2	25.0	
Argillites	4.4		9.4	19.4	
Phyllites	3.1				
Quartzites	26.7	34.6	30.4	22.6	28.4
Feldspathic Quartzites				22.6	
Rhyolite				5.6	
Arkose		4.4			36.3
Plutonics		16.9		2.4	8.4
Metamorphic fragments	28.6		28.5		
Volcanics	1.2	5.9			12.6
Tuffs	0.6	16.2	1.4		10.5
Lamprophyres	0.6				
Syenites					3.7
Carbonates				0.5	
Slates		3.6		1.1	
Total percent	100.0	100.0	99.9	99.2	99.9

The core examinations, independent of the more definite confirmation obtained in subsequent length-change studies, showed that one or more of certain rock types were always present where expansion and cracking had occurred and the cause appeared to be due to an internal reaction. These rock types were mainly the greywackes, argillites and phyllites, with other rock types such as schists, rhyolites and some quartzites also involved in reaction and expansion. Later volume change data confirmed and more clearly pinpointed the rock types that were alkali-expansive to an excessive degree.

Initial microscopic evidence for the presence of alkali-aggregate reaction was sought in terms of that previously found in cases of alkali-silica reactions; this was the presence of known deleteriously reactive minerals and rock types, the degree of gel formation, the presence of reaction rims on aggregates, and certain types of microfracture in the rock particle and cement paste. It was found that potentially alkali-silica reactive minerals and rock types such as opal and chert, and silica-rich cryptocrystalline and glassy volcanic rocks, e.g., silica-rich rhyolites, andesites, and their tuffs, were present only in relatively small amounts and in only a few instances.

Gel formations in concrete are generally products of reaction between alkali hydroxides and siliceous phases in the aggregates. These silicate products tend to imbibe water and swell, producing pressures that can produce rupture of the concrete under extreme conditions. When the concrete is dried or partially dried, these silicates form a ceramic-like deposit in voids. Their relative abundance has been considered as proof of alkali-silica reaction and observed displacement and cracking. In the Nova Scotia concretes, gels were abundant in some concretes and almost lacking in others. No correlation was found between length-change results on test mortars and concretes and the amount of gel associated with the rock types. Gels were not usually abundant even in concretes which had expanded excessively, except where rhyolites and tuffs were present in significant amounts.

Reaction rims were detectable on some Nova Scotia rock particles in aged concretes. They were present, however, both in concretes that were seriously affected by alkali-aggregate reaction and those that were not. In laboratory specimens containing expansive rock types, reaction rims, when

they occurred, were present with high alkali cement and to a lesser extent with low alkali cement. It was clear that rim formation, like gel formation, was not in itself reliable evidence of alkali-expansivity in these rocks.

Apart from a few isolated instances of so-called "classical" alkali-silica reactivity, as with some of the rhyolites, the relationship between microfractures and alkali-aggregate reaction in the sedimentary and metasedimentary rocks in aged Nova Scotia concretes was found to be difficult to assess. The extremely slow reaction had in all probability allowed creep, plastic flow, and autogenous healing to accommodate and obscure microfractures within the mortar. Characteristic internal peripheral cracks and transverse cracks could frequently be observed, however, within the larger suspect particles.

From an examination of field concretes, a deduction must be based on evidence of mechanical displacement, supported in some cases by other factors such as rims and gels. Such mechanical displacement may be on a microscopic scale in the laboratory or on a megascopic scale in the field. Thus the interpretation of diagnostic features generally associated with the better known alkali-silica reaction should be re-examined in the case of affected Nova Scotia concretes. Three previously reported cases (4, 5, 6), two of which involved Appalachian rocks, appear to be related to the Nova Scotia phenomenon described in the present study.

Petrography of Rocks

The greywackes examined are dark, fine-to-medium-grained, massive rocks which often weather to a lighter grey or greenish color sometimes showing iron staining. The sand-size constituents are commonly in the 0.1 to 0.2 mm size range and are generally quartz and feldspar with accessory amounts of rock fragments. They tend to elongate parallel to the shear-induced alignment of the platy minerals in the matrix. The matrix constituents are less than 20 μ m and generally comprise quartz, feldspar, mica, chlorite and iron minerals such as leucoxene, pyrrhotite, magnetite and limonite. Microfractures are fairly common. Graphitic material is present in some of the rocks.

Many of the greywackes contain porphyroblasts of a brown mica-type mineral which shows pleochroism from light to dark brown. X-ray exami-

nation indicates that this mineral is more closely related to vermiculite than biotite. Vermiculite is known to form at the expense of biotite by weathering or hydro-thermal action. In some of the greywackes the brown layer structure silicates are partly altered to pale green chlorite.

Argillites and phyllites are not the dominant rock type in Nova Scotia concrete aggregates selected for study. Nonetheless, they are frequently present. The argillites contain anhedral quartz and feldspar grains of silt-size in a fine matrix of sericite and subhedral laths of muscovite. Approximately 1 mm porphyroblasts of the vermiculite-type mineral similar to those found in the greywackes, are present. Pyrite sometimes occurs as an accessory. The fine micas in the groundmass often show some recrystallization and preferred orientation indicating a gradation into phyllite. The phyllites are similar but more strongly metamorphosed than the argillites. In some samples there are porphyroblasts of the brown layer-structure silicate.

Hand samples of Nova Scotia quartzites are fine-to-medium grained, massive, have good coherence and are generally light grey but sometimes are brownish. Iron stains are common on weathered surfaces and around fractures. The quartz crystals are commonly less than 1 mm in diameter and frequently have interlocking boundaries with their neighbors. In some rocks the crystals are clear but in others inclusions and boundary intergrowths with mica are common; many of the crystals show strain. Feldspar is common in the same approximate size range as the quartz. Brown mica, muscovite and chlorite are important accessories. The matrix varies from 1 or 2 percent to 10 or 15 percent. It is generally composed of fine quartz and feldspar crystals with muscovite, chlorite and sometimes biotite laths. Accessory amounts of tourmaline, pyrite, hematite, leucoxene and limonite are common. Quartzites were not generally found to be alkali-expansive but there were some notable exceptions. Micas, clay minerals and feldspars are alkali-containing minerals. Deer, Howie and Zussman (7) report an average content of 1.2% Na_2O and 7.1% K_2O for illites with smectites and chlorites containing smaller quantities. It is possible that in the Ca-rich environment of hydrating cement paste some small quantities of alkalis may be released from the phyllosilicates by cation exchange.

Only a few samples of volcanic rocks were examined; these included basalt, rhyolite, trachyte and tuff.

Selection of Rock Types for Expansion Studies

A total of 54 local rocks and sands suitable for concrete were sampled from various parts of the province. The rock types were selected on the basis of occurrence in concrete field cores and in current sources of concrete aggregate in the province. These rocks were used as aggregates in mortars and concrete for studies of expansion characteristics and mechanical and other properties. The scope of this investigation did not permit an evaluation of new sources of potentially non-reactive aggregate.

Fourteen of the bedrock samples were obtained from four quarries of the Nova Scotia Power Commission who initiated these studies because of problems with concrete in its hydraulic structures. These rocks consisted mainly of argillites, greywackes, subgreywackes, quartzites, phyllites and schists. Samples were taken from marine-worked glacial tills comprising boulders, cobbles and sands. The samples were various mixtures of arkoses, sandstones, greywackes, subgreywackes, argillites, schists, phyllites, quartzites, basalts, rhyolites and granites. Inland glacial tills sampled included sands, natural ballast and crushed rocks from eskers, kames, outwash plains and drumlins. Outcrop samples consisted of some of the above varieties of rock. Figure 2 shows the location of the test aggregate sources.

FIG. 2
Location of test aggregate sources in Nova Scotia

Concluding Statement

Rocks used as concrete aggregate are of the type to be expected from the geology of Nova Scotia - a glaciated portion of the Appalachian province. Microscopic examinations of concrete cores from many structures, and rock and sand samplings from widely separated parts of Nova Scotia show that gravel and beach deposits have frequently been used as aggregate sources; hence many of the concretes contain a heterogeneous mixture of Appalachian rock types. The field surveys along with petrographic examinations indicate concrete distress caused by an alkali-aggregate reaction in widely separated parts of the Province. The most common rocks in affected cases are greywackes, argillites, phyllites, and some quartzites and schists. These findings were confirmed by length change experiments on mortar bars, concrete prisms and rock cylinders.

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