NRC Publications Archive
Archives des publications du CNRC

Alkali-aggregate reaction in Nova Scotia. Part 1. Summary of a 5-year study

Duncan, M. A. G.; Swenson, E. G.; Gillott, J. E.; Foran, M. R.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. / La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.
For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1016/0008-8846(73)90061-6
Cement and Concrete Research, 3, 1, pp. 55-70, 1973-01

NRC Publications Record / Notice d'Archives des publications de CNRC:
https://nrc-publications.canada.ca/eng/view/object/?id=f82a4fa2-811c-4c73-ae62-8d84e522156b
https://publications-cnrc.canada.ca/fra/voir/objet/?id=f82a4fa2-811c-4c73-ae62-8d84e522156b

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada
Conseil national de recherches Canada

Ser.
TH1
N21r2
no. 549

2879

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
PART I - SUMMARY OF 5-YEAR STUDY

ANALYZED

by
M.A.G. Duncan, E.G. Swenson, J.E. Gillott and M.R. Foran

Reprinted from

CEMENT AND CONCRETE RESEARCH

An International Journal

Vol. 3, No. 1, January 1973
pp. 55-70

[6] p.

50581

BUILDING RESEARCH
- LIBRARY -
JUN 20 1973
NATIONAL RESEARCH COUNCIL

Research Paper No. 549
of the
Division of Building Research

OTTAWA

JANUARY 1973

Price 25 cents

NRCC 13018

This publication is being distributed by the Division of Building Research of the National Research Council of Canada. It should not be reproduced in whole or in part without permission of the original publisher. The Division would be glad to be of assistance in obtaining such permission.

Publications of the Division may be obtained by mailing the appropriate remittance (a Bank, Express, or Post Office Money Order, or a cheque, made payable to the Receiver General of Canada, credit NRC) to the National Research Council of Canada, Ottawa. KIA 0R6. Stamps are not acceptable.

A list of all publications of the Division is available and may be obtained from the Publications Section, Division of Building Research, National Research Council of Canada, Ottawa. KIA 0R6.

CISTI / ICIST
3 1809 00211 3394

CEMENT and CONCRETE RESEARCH. Vol. 3, pp. 55-69, 1973. Pergamon Press, Inc.
Printed in the United States.

ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
I. SUMMARY OF A FIVE-YEAR STUDY

M. A. G. Duncan, Atlantic Industrial Research Institute, Halifax; now with Ministry of Roads, Salisbury, Rhodesia.

E. G. Swenson, Div. of Building Research, Nat. Res. Council of Canada.

J. E. Gillott, Div. of Building Research, Nat. Res. Council of Canada; now with Univ. of Calgary, Calgary, Alberta.

M. R. Foran, Nova Scotia Technical College, Halifax, (Dean of Graduate Studies); now retired.

(Communicated by G. M. Idorn)

ABSTRACT

Laboratory experiments confirmed that alkali-aggregate reaction caused excessive expansion of some Nova Scotia concrete. Major rock types were tested as aggregates in mortar bars and concrete prisms and as rock cylinders immersed in alkali solution. Greywackes, argillites, phyllites, and some quartzites, schists and rhyolites were identified as highly reactive through petrographic studies and length change tests.

SOMMAIRE

Des expériences en laboratoire confirment que la dilatation excessive de certains bétons en Nouvelle Ecosse est due à une réaction alcali-granulat. Les principaux genres de roche furent mis à l'essai comme granulats dans des barres de mortier et des prismes de béton, et sous forme de cylindres de roche plongés dans une solution alcaline. Les grauwackes, argilites, phyllites et certains quartzites, schistes et rhyolites furent identifiés comme des roches très réactives, au moyen d'études pétrographiques et d'essais de changement de longueur.

Introduction

An extensive investigation was begun in 1965 to determine the nature of and solution to a concrete problem in the Province of Nova Scotia. Excessive displacement and cracking of concrete had been observed over many years by the Nova Scotia Power Commission in their hydraulic structures. Several independent investigations had been made but the cause remained uncertain. The actual expansion was measured in the field over many years by the Commission and was observed to be exceedingly slow. Except for the clear-cut cases, the resultant deterioration of concrete often could not be distinguished from, for example, frost action. Petrographic and other evidence indicated that an alkali-aggregate reaction was probably responsible. To some degree the slowness of the field reaction could be attributed to fairly low annual average temperatures.

The objects of the present study were to determine: (a) whether it was an alkali-aggregate reaction, (b) the rock type or types responsible, (c) the preventive measures, (d) the extent of the problem, and (e) the mechanism.

This paper is the first of four papers that describe in condensed form the five-year study and follows an earlier, preliminary report on progress during the investigation (1). The subsequent papers will describe field and petrographic studies, laboratory studies of volume change, and character of the reaction.

Materials and Methods

The rock types selected for study were mainly those that were found to predominate in field concretes as determined from cores and from known sources of concrete aggregate. The origin, nature, and relative abundance of these rock types are described in a second paper. A total of 75 concrete cores were taken from field structures; 48 rocks, 5 ballasts and 6 sands from across mainland Nova Scotia were studied. Rocks and sands that were of doubtful quality as concrete aggregate, from the point of view of conventional tests, were not included in the sampling. Two reference coarse aggregates and two reference fine aggregates from outside the Appalachian region, and with known performance records, were included as controls. The scope of the project did not permit evaluation of new sources of concrete aggregate considered to be nonreactive.

The alkali contents of the three normal portland cements used in the study are given in Table I. To obtain alkali contents exceeding the 0.88 percent maximum in these cements, extra alkali, usually sodium hydroxide, was added to the mixing water, using the medium alkali cement as the base in most cases.

Table I

Alkali Contents of Cements - As Percentage by Weight of Cement

Cement	Na_2O	K_2O	Total, calculated as Na_2O
Low alkali	0.14	0.30	0.34
Medium alkali	0.20	0.78	0.71
High alkali	0.27	0.93	0.88

Expansivity was determined by three length change methods: a modified form of the ASTM C227 mortar bar test (2), a modified form of the ASTM C586 rock cylinder test (3), and a concrete prism test (4). The modifications involved mainly methods of acceleration necessitated by the extreme slowness of the reaction. This added acceleration was achieved by higher conditioning temperature, increased alkali content to supplement that in the cement, and increased concentration of potentially reactive rock types in each test aggregate. Special tests were carried out with KOH instead of NaOH.

Besides the main test program involving variations in temperature, alkali content, and concentration of reactive rock type, other factors were studied, including the effect of fly ash and pozzolan, restraining steel, and cycles of wetting and drying. Studies were made of physical properties such as internal surface area, porosity, and specific gravity. Use was made of x-ray and electron microscope techniques. Not all of the test data can be reported because of space limitations.

Typical Test Results

Of the numerous rock types present in the Appalachian region, of which Nova Scotia is a part, those shown by length change tests to be alkali-expansive are shown in Table II along with those showing no expansivity. Within each group and within each rock type were considerable variations in degree of alkali-expansivity. The last three shown occurred in both categories. Concurrent studies of concrete field cores indicated, on the basis of cracking and other evidence, good agreement with results of length change studies in determining the above classification.

Table II

General Classification of Nova Scotia Rock Types Investigated

Highly Alkali Expansive	Non-Alkali Expansive
greywackes argillites phyllites	pink graphitic granites basalts arkoses sandstones dolomitic limestone syenite xenoliths in an acid intrusive massive milky quartz amphibolite
quartzites schists rhyolites	

It is important to note that a rock classified as a greywacke or a phyllite, for example, contains many rock types in varying proportions, some alkali-expansive and some not. Examples of compositional characteristics are given in the second paper in this series.

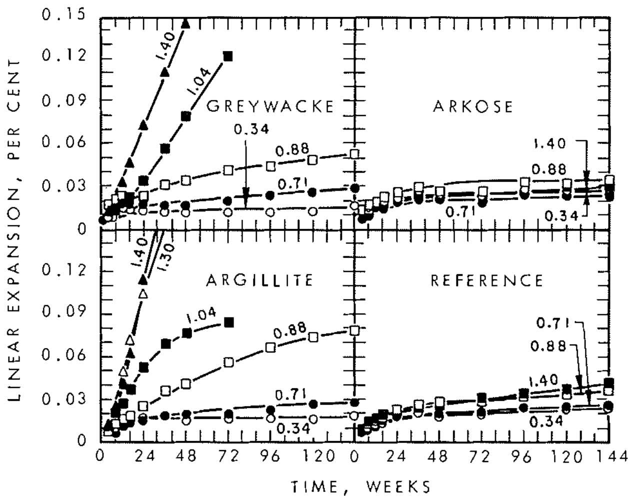
1. Mortar Bar Tests

Some 2000 mortar bars, made to ASTM bar dimensions (1 by 1 by $11\frac{1}{4}$ in. (25 by 25 by 285 mm)), were conditioned in various ways and measured for length change, in some cases for as long as four years. Triplicate samples were used in most tests. Expansion was considered to be excessive when it reached or exceeded 0. 05 percent (linear). The slowness of the reaction compared with most alkali-silica reactions described in the literature required different criteria of time versus degree of expansion. Final selection was based on performance in laboratory and field.

Figure 1 shows typical expansion results for mortar bars cured over water in sealed containers. The curves show that greywacke and argillite

FIG. 1

Typical mortar bar expansion at 100° F (38° C) (ASTM C227) with Nova Scotia rocks as aggregate and low alkali cement (0. 34%), medium alkali cement (0. 71%), high alkali cement (0. 88%), and the medium alkali cement plus additions of NaOH. (Total alkalis calculated as percent Na_2O.) Moist-cured in sealed containers.



produce significantly high alkali-expansivity with the higher alkali concentrations, as against no significant expansions for the arkose or reference aggregate.

Figure 2 shows typical expansion versus time curves with temperature as a variable. The change in rate and degree of expansion from 100° F (37. 8° C) to 125° F (51. 7° C) was generally quite pronounced for rock types shown to be alkali-expansive in other tests. Except for small increases in a few cases, expansions were not excessive when low alkali cement was used, even at 150° F (64. 4° C). Studies of this nature made it possible to develop time-length change criteria for test purposes.

Mortar bar tests were carried out in which the percentages of Nova Scotia (N. S.) rock in the total aggregate (made up with a non-alkali expansive sand) were 100, 65, 35 and 4. Twenty-six rock samples were studied. In 3 cases the maximum expansion, 0. 05 percent or more at 48 weeks, occurred with 35 percent N. S. aggregate (an impure granular quartzite, a rhyolite and a heterogeneous mixture). In 8 cases the maximum expansion occurred

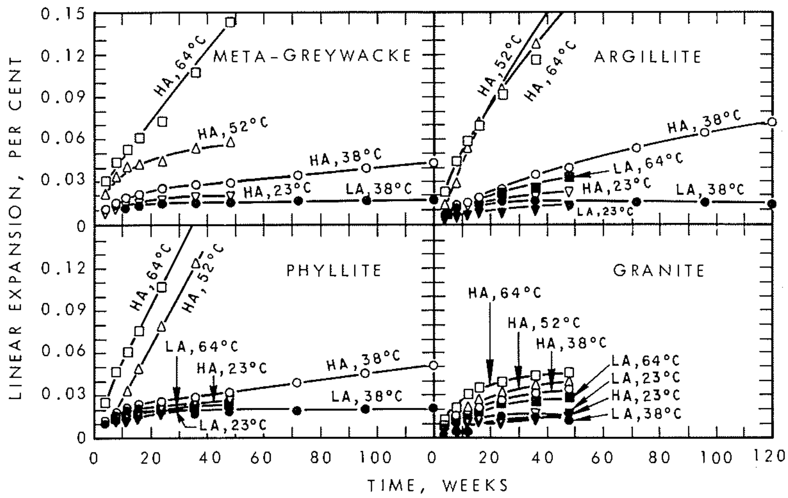


FIG. 2

Effect of curing temperature on expansion of mortar bars made with Nova Scotia aggregates; with low alkali cement (LA, 0.34%) and high alkali cement (HA, 0.88%). Moist-cured in sealed containers at temperatures stated.

with 65 percent N.S. aggregate (a phyllite, an argillite, a heterogeneous combination, 3 greywackes and 2 quartzites). In 7 cases the maximum expansion occurred with 100 percent N.S. rock (a phyllite, a rhyolite, 3 greywackes, and 2 quartzites). A cherty agate produced maximum expansion when present as 4 percent of total aggregate. The remaining 7 samples did not produce excessive expansion when present in any of these proportions.

Mortar bar studies showed that in general the expansion rate increases with increase in average particle size of alkali-expansive rocks. The effect is not considered sufficient to use a grading different to that of ASTM C227.

Mortar bar tests were made to study such factors as effect of type of alkali and effect of moist-dry cycling. Low alkali cement was used with added KOH and with added NaOH to bring the total alkali contents to that of a high alkali cement (1.00% as Na_2O). In these two cases there was no essential difference in rate and degree of expansion of alkali-expansive Nova Scotia rocks. This is not in agreement with findings of the rock cylinder test, noted in section (3).

Intermittent drying during moist curing greatly retarded the expansion and in this regard the reaction is similar to other alkali-aggregate reactions. In these many tests only rarely did the mortar bars exhibit exudations or popouts.

2. Concrete Prism Tests

About 380 concrete prisms, 3 by 3 by 11 in. (75 by 75 by 275 mm), were made with rocks suspected of alkali-expansivity when used as coarse aggregate and a sand free from reactivity. In each case, an additional sample was made in which the suspected alkali-expansive rock constituted both the coarse and the fine aggregate. These results are not reported as they were of the same general order as those made with the neutral sand.

Twenty-six rock types were studied in one series; control samples made with imported, non-expansive aggregate were used in each set of tests. The mix was designed for 3500 psi at 28 days; slump was 2 to 3 in. (50 to 75 mm), maximum size coarse aggregate was 3/4 in. (19mm), and water-cement ratio 0.60 ±0.02. Duplicate or triplicate samples were subjected to test. Among the variables were alkali content, temperature, pozzolan or fly ash admixture, and restraining steel. Changes in length and elastic properties (the latter determined by nondestructive sonic tests), were observed on most of the samples. Destructive strength tests were performed on one series.

Figure 3 shows typical expansion curves of concrete prisms made with 4 different coarse aggregates. Low, medium, and high alkali cements were used and conditioning was done at 73 and 100°F (23 and 38°C). The concretes made with greywacke and argillite coarse aggregate show a high degree of alkali-expansivity as against no significant expansion for those made with the heterogeneous rock. The results of these concrete prism tests correlated well with those of the mortar bar series.

Twenty-four concrete mixes were made in which 25% by weight of the cement was replaced by fly ash and by a proven, active pozzolan. Alkalinity was increased by using the medium alkali cement and adding sodium hydroxide to give a total alkali of 1.00 percent, calculated as Na_2O. In one set of mixes only the admixture replacement was made; in the other the admixture replacement was accompanied by an addition of sodium hydroxide to a value

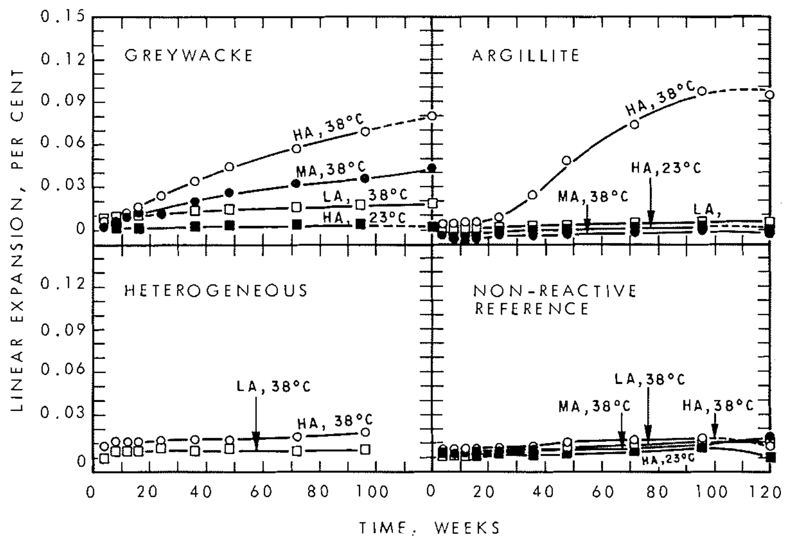


FIG. 3

Linear expansion of 3 by 3 by 11 in. (75 by 75 by 275 mm) concrete prisms made with Nova Scotia rocks as coarse aggregate with low alkali cement (LA, 0.34%), medium alkali (MA, 0.71%) and high alkali (MA, 0.71% with added NaOH to 1.00% total alkali calculated as Na_2O). Fog room at 73°F (23°C) or 100°F (38°C) in sealed containers.

equivalent to 1.00 percent by weight of alkali, based on cement plus pozzolan or fly ash. Figure 4 shows length change results for an alkali-expansive greywacke. The very effective suppression of expansion by the mineral admixtures shown here was also demonstrated for a number of other alkali-expansive rock types used in this series.

3. Rock Cylinder Tests

An extensive investigation was made to determine if the ASTM C586 test, developed for alkali-carbonate rock reactions, would be equally useful in assessing the type of alkali-aggregate reaction occurring in Nova Scotia. This was shown to be the case. About 1200 rock cylinders, cored from Nova Scotia rocks and from reference rocks, were immersed in sodium hydroxide solutions of various concentrations at different temperatures and measured periodically for length change.

A special micrometer was developed to minimize inaccuracies that might develop over the lengthy test periods. Wherever possible, rock samples were cored in three mutually orthogonal directions. Expansion results usually differed because of anisotropy but the average of the expansions in

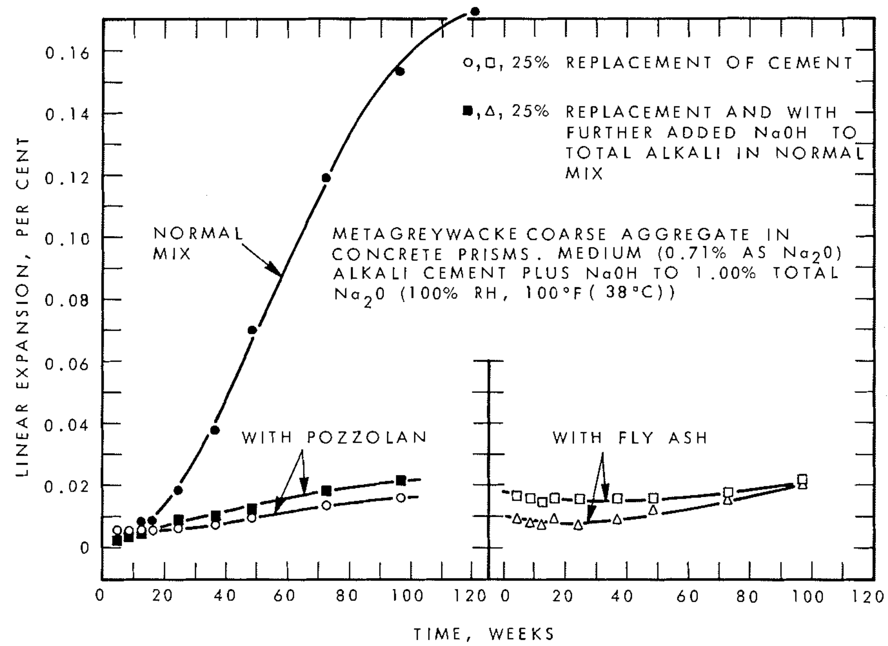


FIG. 4

Effect of linear expansion of concrete prisms made with a metagreywacke coarse aggregate with 25% of cement replaced by a calcined volcanic tuff pozzolan or a fly ash.

the three directions was taken to be the significant value. All expansion data reported have been corrected for the small, normal expansions due to soaking in water. Comparison of test results with those from other length change tests led to the adoption of 0.056 percent volumetric expansion as the critical value.

Figure 5 shows typical volume change results for rock cylinders at two temperatures for several concentrations of sodium hydroxide. The greywacke here exhibits a high degree of alkali-expansivity; the rhyolite does not under these conditions of test. The extensive data of this type developed in these tests showed good correlation with those from mortar bars and concrete prisms.

In experiments where rock cylinders were immersed in KOH instead of NaOH, expansions were very much less. This was contrary to the experiments with mortar bars already described.

4. Other Tests

Fourteen rock samples that had been shown by other tests to be

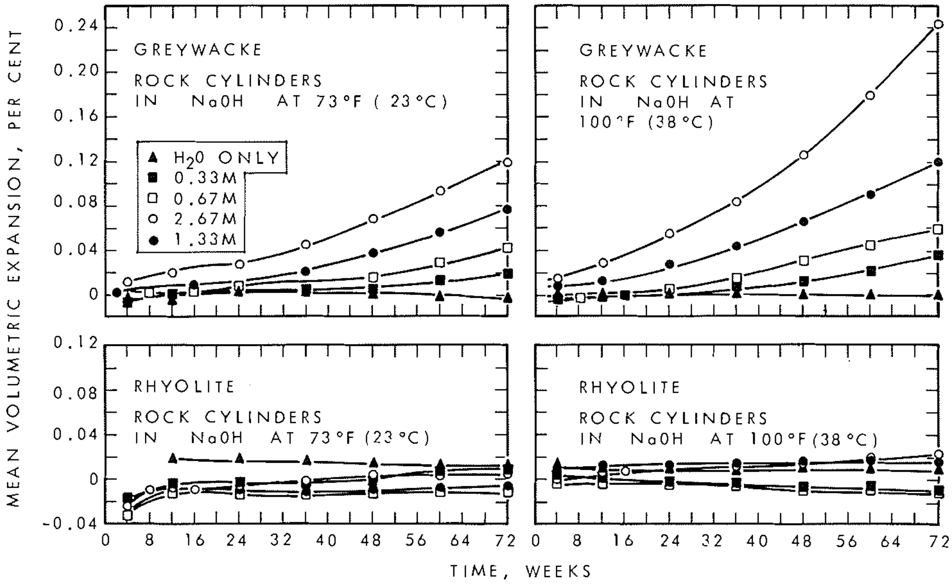


FIG. 5

Typical expansions of rock cylinders in various concentrations of NaOH at 73° F (23° C) and 100° F (38° C)

alkali-expansive were subjected to the ASTM Quick Chemical Test, C289-66. On the basis of this test, about half would be classed as alkali-reactive, the other half as innocuous, indicating the inapplicability of this test for the Nova Scotia rocks. The Conrow test, ASTM C342-67, also carried out on reactive samples, did not produce response. Rim formation was rare and gel exudation did not often occur in large amounts in cases of excessive expansion of the concrete or mortar. These and other results to be discussed in subsequent papers suggested strongly that the Nova Scotia reaction is different in some important respects from the classical alkali-silica reaction.

Discussion

Thorough analyses were made of the length-change data from the mortar bar, concrete prism, and rock cylinder studies to determine the degree of correlation and the reliability of the various procedures used. Of particular importance were the factors of temperature, alkali content, concentration of rock type, and variable composition within each rocktype. Agreement between the three types of tests in rating a rock as alkali-expansive or not was about 80 percent (see Appendix A). The most consistent results were obtained for greywackes, argillites and phyllites; agreement was not as good for the quartzites, micaceous schists and rhyolites. Heterogeneous rocks (those with no predominating rock type) behaved consistently in relation to the total of alkali-expansive rock types present. In assessing reliability, extra weight was given to results obtained under only moderately accelerating conditions.

The procedure recommended for evaluating an aggregate source in Nova Scotia, based on this investigation, can be summarized as follows:

(a) Examination of the performance of field concrete in area in question; such evaluation would indicate to what degree special testing for alkali-aggregate reactivity need be considered.

(b) Conventional aggregate tests to ensure that normal specification requirements are met.

(c) Petrographic examination and interpretation by a petrographer with experience with alkali-aggregate reactions.

(d) If petrographic analyses indicate a high percentage of rock types designated in this study as potentially alkali-expansive, no further testing need be done, and one or more of the recommended preventive measures should be taken.

(e) If petrographic analyses indicate little or no such reactive rocks present, the usual concrete practice may be followed.

(f) If analyses leave doubt as to alkali-reactivity, length change testing should be done to determine extent of preventive action to be taken.

A preliminary probe test of various strata in a quarry that can be recommended to give an assessment in a minimum amount of time is:

(i) 16-week rock cylinder test at 125° F (52°C) in a 2.67M NaOH solution, with a critical mean expansion limit of 0.056 percent, or,

(ii) 16-week mortar bar test at 150° F (64°C) with a high alkali cement containing not less than 0.90 percent total alkali calculated as Na_2O (critical expansion limit of 0.05 percent).

For greater reliability but requiring more time, the following procedure is recommended:

(iii) 72-week mortar bar test at 100°F (38°C) with 1.00 percent total alkali and a critical length change limit of 0.05 percent, or,

(iv) 120-week concrete prism test at 100°F (38°C) with a high alkali cement of total alkali (as Na_2O) not less than 0.90 percent (critical length change limit of 0.05 percent). An essential factor in any of these tests is the use of at least one carefully chosen, non-alkali-expansive control aggregate.

Preventive measures to be used in the field, as shown in this study, are the same as for the well-known alkali-silica reaction. These are:

(a) low alkali cement of not more than 0.60 percent alkali, calculated as Na_2O.

(b) substitution of part of normal high alkali cement by a fly ash or a proven pozzolan, or,

(c) where possible, design of structure to permit drying of concrete after curing.

Summary and Conclusions

Certain rock types in Nova Scotia, otherwise acceptable for concrete aggregate, were shown to be alkali-expansive to an excessive degree when used in conjunction with a high alkali cement. The length-change expansion tests confirmed field observations and results of examination of field concretes. Culprit rocks were greywackes, argillites, phyllites, and some of the quartzites, schists and rhyolites. A highly moist environment was shown to be necessary for this reaction to develop to any serious extent.

Accelerated methods of evaluation were developed because of the very slow reaction. Preventive measures, demonstrated in the laboratory, are the use of a low alkali cement or a pozzolan or fly ash.

Acknowledgement

This investigation was initiated by the Nova Scotia Power Commission which has, with added financial support from other provincial agencies, been the main sponsor. Most of the studies were carried out at the Nova Scotia Technical College by the first author. The Division of Building Research of the National Research Council of Canada carried out the detailed petrographic analyses and was responsible for continuing advice and assistance.

The project was administered by, successively, the Nova Scotia Research Foundation and the Atlantic Industrial Research Institute. The research results are being published through courtesy of the Nova Scotia Project Committee on Concrete.

References

1. M. A. G. Duncan and E. G. Swenson, Investigation of Concrete Expansion in Nova Scotia. The Prof. Eng. in Nova Scotia, Vol. 10, No. 2, May 1969, p. 16-19.

2. P. K. Mukherjee, M. A. G. Duncan, M. R. Foran and A. Samanta. The Expansive Behaviour of Mortar Bars Prepared from Alkali-Sensitive Nova Scotia Concrete Aggregates. Atlantic Ind. Res. Inst., Halifax, Sept. 1970, p. 1-28.

3. M. A. G. Duncan, Correlation of Field and Laboratory Evidence of Alkali-Silica Reactivity in Nova Scotia Concrete. Ph. D. Thesis, Nova Scotia Tech. Coll., 1970, p. 1-544.

4. S. S. Gurjar, M. A. G. Duncan, and P. K. Mukherjee. Performance of Concrete Prisms made from Alkali-Expansive Nova Scotia Aggregates. Atlantic Ind. Res. Inst., Halifax, Sept. 1970, p. 1-27.

APPENDIX A

ALKALI - EXPANSIVITY OF NOVA SCOTIA AGGREGATES AS DETERMINED BY TEST METHODS AND CONDITIONS SELECTED FOR EVALUATION PURPOSES (CRITICAL TIME-EXPANSION VALUES IN EACH CASE GIVEN IN TEXT)

* Mixtures of Test Sand and Neutral Sand giving Maximum Expansion

EXPANSION: E = Excessive, B = Borderline, N = Not Excessive.

AGGREGATE		MORTAR BARS						CONCRETE PRISMS			ROCK CYL.
	ALK. %	0.88	0.88	1.04	1.42	0.88	1.00*	0.71	1.00	1.00	2.67M
	°C	38	38	38	38	64	38	38	38	38	52°C
	WEEKS	72	144	72	36	16	48	120	72	96	
META-SUBGREYWACKE		N	N	E	E	-	E	-	B	B	E
META-GREYWACKE		N	E	N	E	E	E	N	B	B	N
QUARTZITIC GREYWACKE		N	B	E	E	-	B	B	E	E	E
META-GREYWACKE		N	N	E	E	-	N	N	E	E	E
GREYWACKE		N	N	E	E	E	-	-	E	E	E
META-GREYWACKE		E	E	E	E	-	E	-	E	E	E
GREYWACKE		E	-	E	E	-	-	E	E	E	E
GREYWACKE AND SILTSTONE		-	-	-	-	-	-	B	E	E	E
META-FELDS GREYWACKE		B	E	E	E	-	-	-	-	-	N
QUARTZITIC GREYWACKE		N	N	-	N	-	-	-	-	-	N
PYRITIFEROUS ARGILLITE		N	N	E	E	-	-	-	-	-	E
PYRITIFEROUS ARGILLITE		N	N	-	E	-	-	-	-	-	-
CALCAREOUS ARGILLITE		E	E	E	E	E	E	N	E	E	E
PYRITIFEROUS PHYLLITE		E	E	E	E	E	E	N	N	N	E
PHYLLITE		E	E	E	N	E	E	E	E	E	E
MICACEOUS SCHIST		N	N	E	E	-	N	-	-	-	E
META-QUARTZITE		N	N	E	E	-	-	-	-	-	E
FELDSPATHIC QUARTZITE		N	N	E	E	-	-	-	-	-	E
MICACEOUS QUARTZITE		N	N	N	N	-	N	-	-	-	E
MICACEOUS QUARTZITE		N	N	N	E	E	B	-	-	-	E
FELDSPATHIC QUARTZITE		B	E	E	E	E	E	N	E	E	E
WHITE QUARTZITE		N	N	-	E	-	E	-	-	-	N
FELDSPATHIC QUARTZITE		E	-	E	E	-	-	N	N	N	E
META-FELDSP. QUARTZITE		E	-	E	E	-	E	E	E	E	B
FELDSPATHIC QUARTZITE		E	E	E	N	-	-	E	E	E	E
FELDSPATHIC QUARTZITE		E	-	B	E	E	E	B	E	E	N

Continued .....

APPENDIX A (Continued)

FELDS. QUARTZITE AND ARGILLITE	E	-	E	E	-	E	E	E	E	E
QUARTZITE	E	E	E	E	-	-	N	N	N	E
FELDSPATHIC QUARTZITE	B	E	-	E	-	N	-	-	-	N
MILKY QUARTZITE	N	N	-	N	-	N	-	-	-	N
MASSIVE MILKY QUARTZ	N	N	-	-	-	-	-	-	-	N
ARKOSIC SANDSTONE	N	N	-	N	-	-	-	-	-	E
FELDSPATHIC SANDSTONE	N	N	-	N	-	-	-	-	-	N
ARKOSE	N	N	-	N	-	-	-	-	-	E
PORPHYRITIC BASALT	N	N	-	-	-	-	-	-	-	N
AMYGDULCIDAL BASALT	N	N	-	N	-	N	-	-	-	N
SYEMITE XENOLITH IN ACID INTRUSIVE	N	N	-	N	-	-	-	-	-	N
DOLOMITIC LIMESTONE	N	N	-	N	-	-	-	-	-	N
PYRITIFEROUS SCHISTOSE	N	N	N	N	-	-	-	-	-	E
BANDED RHYOLITE (1)	E	-	E	E	E	E	N	N	N	-
PORPHYR. RHYOLITE (2)	E	-	E	E	-	E	-	N	N	-
SPHEROL RHYOLITE (2)	E	-	E	E	-	-	-	N	N	-
MIX OF (1), (2) AND (3) RHYOLITE	E	E	E	E	-	-	N	N	N	-
IMPURE GRANULAR QUARTZ	B	-	N	-	-	B	-	-	-	N
CHERTY AGATE	N	-	N	-	-	E	-	-	-	-
HETEROGENEOUS	N	N	N	E	-	E	-	-	-	N
HETEROGENEOUS	N	N	E	N	-	E	-	-	-	E
NEUTRAL CONTROL, DOLOMITE	N	-	-	-	-	-	N	N	N	-
NEUTRAL CONTROL, SILICEOUS BALLAST	N	-	N	-	-	-	N	N	N	-
SAND, BEACH, TILL	E	E	E	E	-	-	-	-	-	-
SAND, BEACH, TILL	E	E	E	-	E	-	-	-	-	-
SAND, INLAND, TILL	N	N	-	E	-	-	-	-	-	-
SAND, INLAND, TILL	N	N	-	N	-	-	-	-	-	-
SAND, INLAND, TILL	E	E	E	N	E	-	-	-	-	-
SAND, BEACH, TILL	N	N	E	E	-	-	-	-	-	-
SAND, NEUTRAL, CONTROL	N	N	-	N	-	-	-	-	-	-
SAND, NEUTRAL, CONTROL	N	N	-	-	-	-	-	-	-	-