Learning to Live With a Reactive Carbonate Rock

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Faced with building a four-lane concrete highway for 30 miles west of Kingston, Ont., where the local dolomitic-limestone aggregates might show expansive reactivity in concrete in the presence of alkali, an investigation was made to determine the safest and most economical way of doing this. Selection of aggregates proved possible on the basis that they showed little expansion in concrete prisms made with high alkali cement and cured under standard conditions.

Confirmatory data were obtained in the laboratory on the factors that influence the degree of expansion and the effect of alkalies from a source other than the cement. Also described are precautions taken to insure that only non-reactive aggregates were used and that the other factors favoring expansion were minimized.

•WHEN serious notice was first taken in 1956-57 of the expansive reactivity of concrete in and about Kingston, Ont., the Department of Highways had almost completed the construction of the structures for part of a four-lane controlled-access highway which formed a bypass to that city. A close look at culverts and bridges constructed only a few months previously showed that there were traces already of the telltale pattern of map cracking that typified the appearance of older concrete in the area. The early observations of Swenson (1, 2) indicated that dolomitic-limestone aggregate from certain local quarries was an essential ingredient of affected concrete. It was therefore decided to import a gravel aggregate of known good performance from Brighton, 75 miles away, for the 325- by 90-ft concrete deck of the bridge over the River Cataraqui which remained to be placed. (Fortunately, considering the circumstances, a bituminous pavement had been already selected for the bypass.)

Although this was a satisfactory emergency solution to the problem, it was not a very economical one. Future plans called for the extension of the highway east and west of Kingston. Traffic, engineering, and economic considerations suggested that under normal circumstances the pavement for some 30 miles west of Kingston should be in portland cement concrete. To do this would involve concreting 24 major structures and 800,000 sq yd of 9-in. thick reinforced concrete pavement. All told, 250,000 cu yd of concrete requiring 275,000 tons of coarse aggregate would be needed. All commercially operating quarries within reach were in, or adjacent to, the Black River formation of Ordovician limestone, certain strata of which were known to be reactive. In addition, along the whole right-of-way itself, bedrock of the same suspect formation was only a few feet below ground level. Inasmuch as the extent of the reactive strata was not yet established, all working and potential aggregate sources (Fig. 1) had therefore to be regarded as suspect. The cements normally used in the area all have high alkali contents. Therefore a choice between the following alternatives was necessary.

1. Ignore the problem; switch to a bituminous pavement and import small quantities of aggregates for the concrete structures only.

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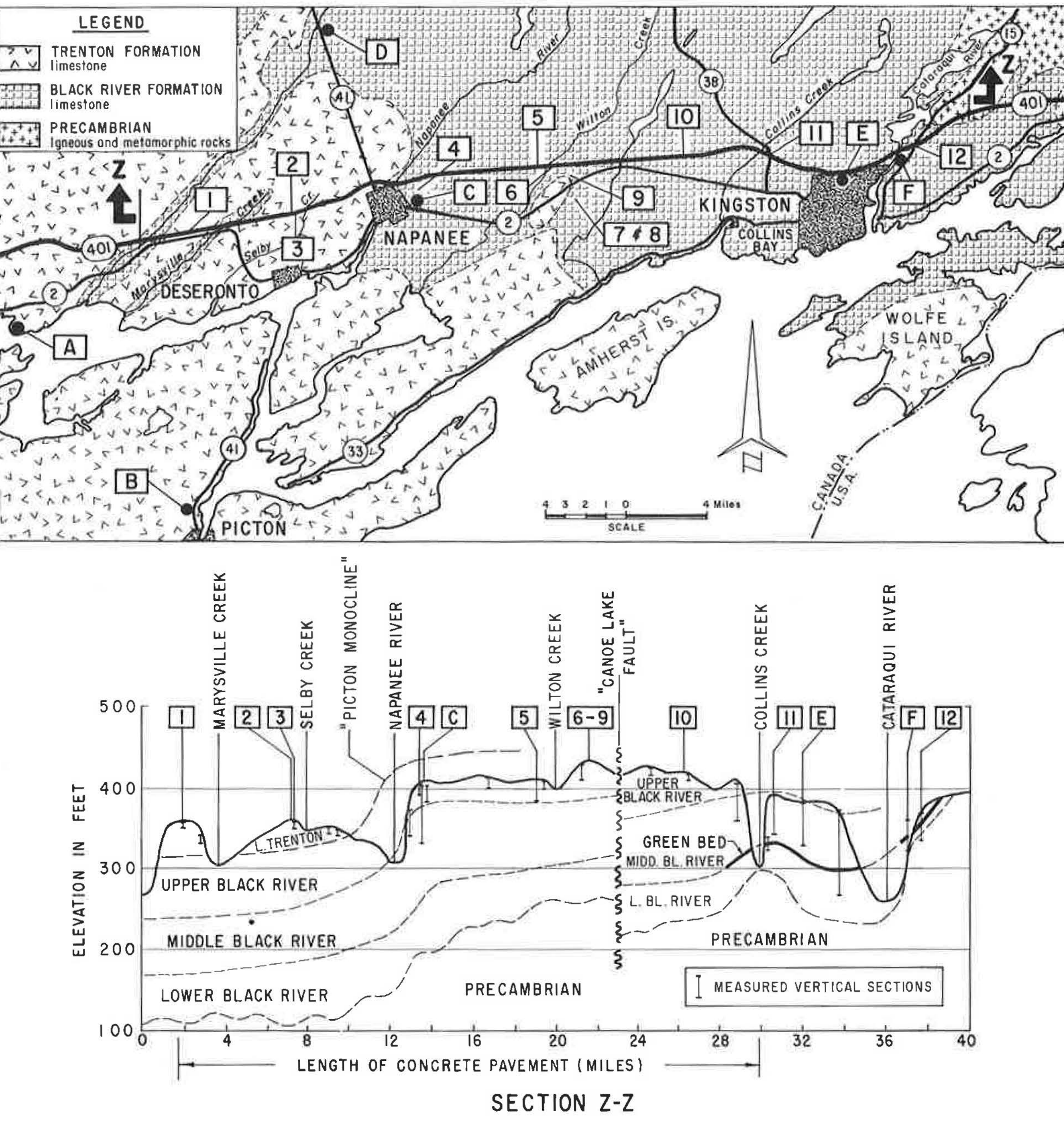

Figure 1. Highway 401, Kingston to Marysville Ont., showing geology of area and working or potential aggregate sources.

2. Import, at extra cost, large quantities of aggregate of known good quality for the concrete pavement and structures.

3. Use a low alkali cement at extra cost with any of the local dolomitic-limestone aggregates.

4. Select non-reactive local aggregates for use with the available cements of high alkali content.

This paper is concerned with the investigations that led to the adoption of the last choice, the method of aggregate selection employed and other precautionary measures which have permitted the successful and economical construction of a concrete highway through an area where previously concrete has been known to expand 6 in. in 100 ft, or to look like the bottom of a dried-out pond in summer.

FIELD SURVEY OF QUARRIES AND STRUCTURES

The commercially worked limestones of Ontario have been very thoroughly described (3). From this source and the information already accumulated in the contract records and inventory of granular deposits and aggregate sources maintained by the Department of Highways, it was possible to plan a survey to try to pin down the extent of the problem in geographical and geological terms.

The known quarries in the Kingston to Marysville area (Fig. 1) were each examined and the different strata identified. Where possible, information was gathered on how and when each quarry bed had been worked, and which structures had been built with the stone. Ledge samples of rock were secured from each different bed, together with samples of current aggregate production for subsequent examination and testing. In some quarries the whole face was being worked indiscriminately, in others the face was already benched either to facilitate quarrying operations, or because some beds were not acceptable for certain uses on the basis of usual quality tests. It was suggested to quarry operators early in the investigation that selective working might prove advantageous later on, because only certain beds, if any, were likely to be reactive.

A survey was also made of existing concrete pavements and structures, not only in the Kingston area but also over a wide part of Ontario where aggregates might have been obtained from limestones of the Trenton, Black River, Beekmantown groups of the Ordovician system. Although evidence of pattern cracking, expansion and poor durability in service was found outside the Kingston area, these could not at the time unhesitatingly be ascribed to alkali-carbonate reactivity. It was concluded from the survey that the major problem was confined to concrete containing aggregate from certain strata in the Black River formation in the Kingston area. It therefore remained to determine which beds were involved and where these were likely to outcrop as possible aggregate sources for the new highway.

IDENTIFICATION OF REACTIVE AGGREGATES

When the investigation started in 1957, the only known and certain way of detecting reactivity was to incorporate the suspect aggregates in concretes containing a cement of relatively high alkali content and measure the subsequent expansions. The test method used and the reference aggregates were essentially the same as those of Swenson and his co-workers at the National Research Council, Ottawa (1, 2, 4). This allowed a direct comparison to be made with their results throughout the investigation.

For each rock or aggregate under test, 3- x 4- x 16-in. concrete prisms were made with the aggregate at 3/4-in. maximum nominal size, standard laboratory sand, and normal portland cement with a total alkali content of approximately 1.1 percent expressed as equivalent Na_2O. The mixture was proportioned for 3,000 psi at 28 days with a fixed cement factor of 525 lb per cu yd, 3 in. slump and 6 percent air. The prisms were cured in a moist room at 70 F and 100 percent relative humidity, and length change was measured with a comparator initially at weekly and later at monthly intervals. All results are based on the average of three specimens.

From examination of the expansions of concrete containing aggregates from the working quarries surveyed, the corresponding data obtained by the National Research Coun-

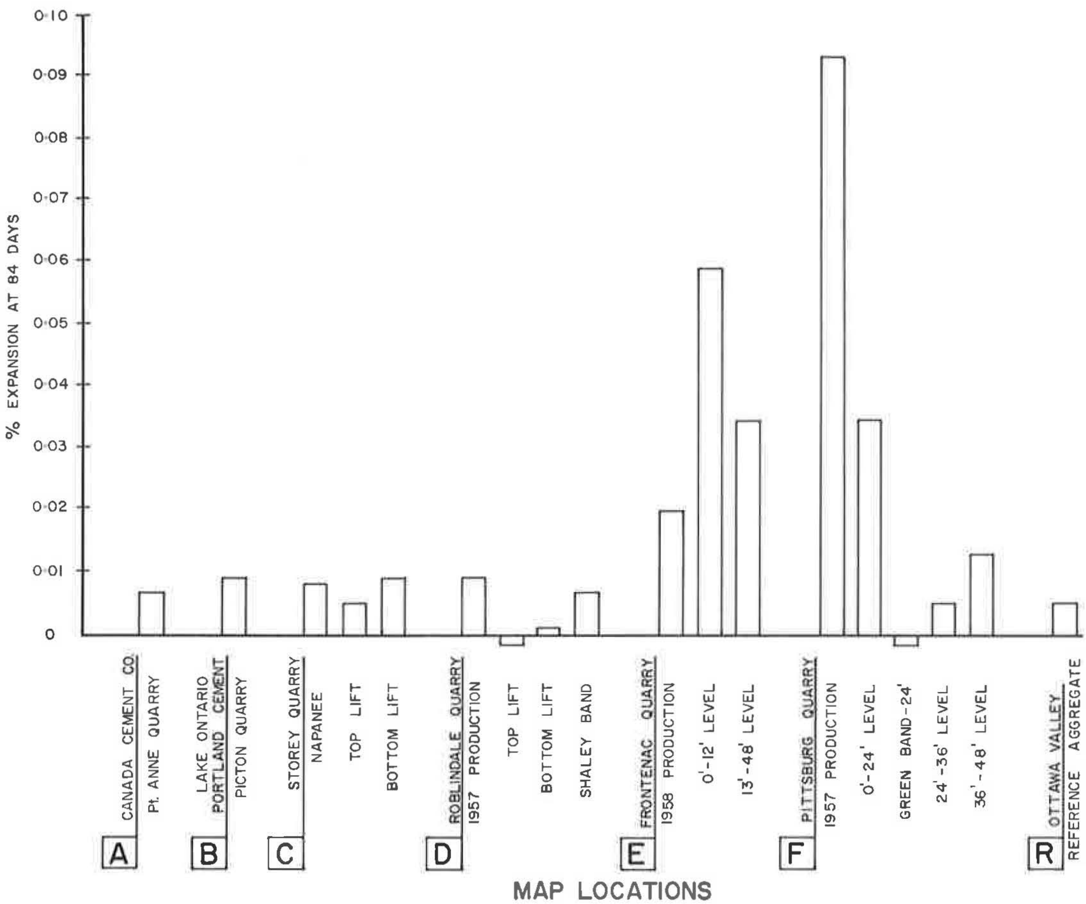

Figure 2. Expansions at 84 days of concretes containing aggregates from working quarries in Kingston to Marysville area.

cil and the field examination of structures and pavements containing aggregate from the same sources, a criterion was established that for acceptability the expansion must not exceed 0.05 percent at 84 days. (Subsequent consideration suggests that this might well be very much lower, about 0.02 percent.) The expansions at 84 days for concretes containing aggregates from the working quarries in the Kingston-Marysville area are shown in Figure 2. These indicated that the problem appeared to be limited to two quarries, Pittsburgh and Frontenac, in Kingston.

Because bedrock was at the surface along almost all the right-of-way, a contractor might well wish to open a new quarry adjacent to the highway to produce his concrete aggregates. It was obviously impractical to test every inch of the ground for alkali-carbonate aggregate reactivity during the pre-contract investigation, therefore attention was directed to those properties which had been acquired by the Department in order to obtain the right-of-way. Such potential quarry sites (Fig. 1) were core drilled, and after logging the recovered cores were subjected to testing for alkali-aggregate reactivity in addition to normal quality testing. Figure 3 shows the results of this phase of the investigation. Usually, the contracts for the concrete paving were let in the early fall for construction next year. If the contractor wished to produce aggregate from an untested location, of his own choice, it was thought that ample time was still available during the winter for testing, even though a 112-day minimum time of testing was involved.

PROBLEM OF SECONDARY ALKALIES AND POSSIBLE USE OF LOW ALKALI CEMENTS

Swenson (2, 4) and his co-workers have shown that the addition of alkali could be expected to increase the measured expansions of concrete containing reactive rocks in the same manner as if a cement of higher alkali content had been used. This appeared to be especially significant as far as a concrete pavement was concerned, inasmuch as there could be external sources of alkali present. Alkaline ground waters might reach the concrete and the use of sodium chloride as a de-icing chemical might generate additional sodium hydroxide within the concrete by reaction with the cement hydration products. To check the latter assumption, concrete prisms were immersed in a saturated salt solution at 70 F. As Figure 4 shows, greater expansions did occur in these circumstances.

Additional experiments were run with cements of different alkali contents, concretes of different compositions and under different curing conditions with aggregates from strata in the Pittsburgh quarry known to be reactive. The results bear out those of Swenson and his co-authors (2, 4) and show that other than possibly reducing the maximum size of the aggregate, the only factor capable of mitigating the expansion would be the use of a very low alkali cement. The 0.5 percent alkali content, which was the lowest in a cement then made in Ontario, did not appear to be low enough for safety. With time, prisms containing the most reactive aggregates and this cement still showed enough expansion to induce cracking.

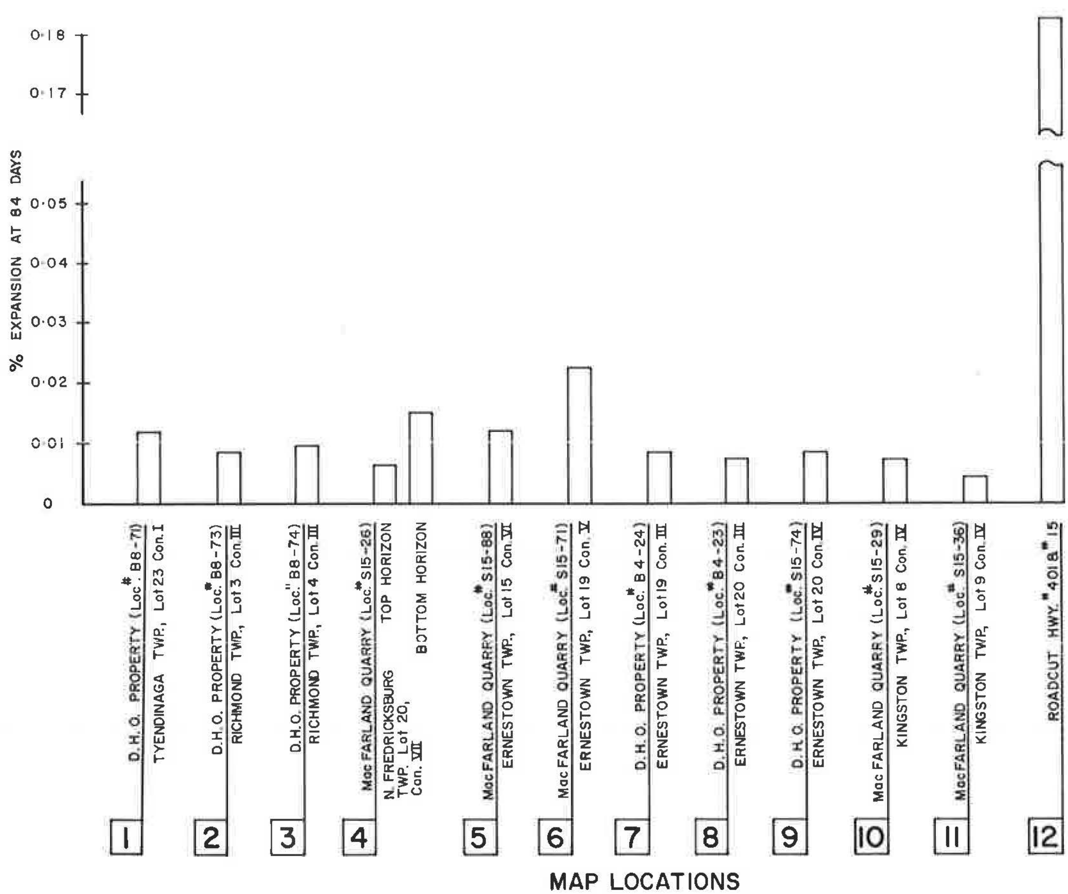

Figure 3. Expansions at 84 days of concretes containing aggregates from potential quarry sites in Kingston-Marysville area.

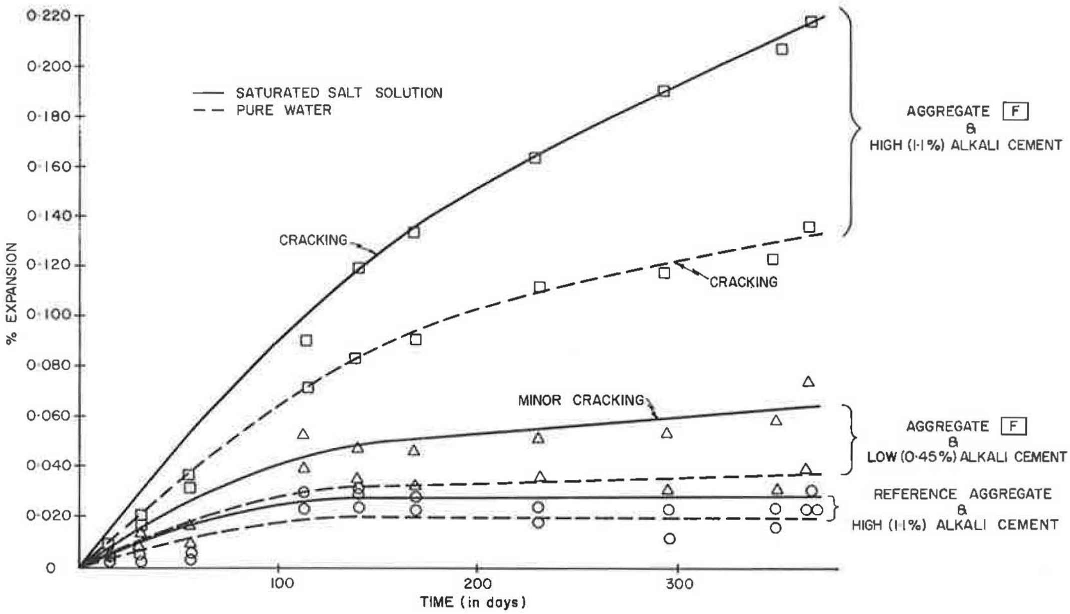

Figure 4. Effect of sodium chloride on alkali-carbonate expansive reactivity of concrete.

Considering the danger of secondary alkalies and the extra cost of the low alkali cement which would in any case be needed, it was concluded that the indiscriminate use of local dolomitic-limestone aggregates without regard for their potential reactivity was neither a safe nor an economical way to build a concrete pavement.

PRECAUTIONS SPECIFIED

As a result of the investigation, and taking into account engineering and cost considerations, it was decided to still build a concrete pavement but to use selected aggregates, while taking precautions to exclude secondary alkalies and allowing for some "warning" expansion in the pavement. Therefore, in each contract concerned, the following precautionary measures were required.

Aggregates

1. From existing commercial sources. The strata currently opened and being worked, from which acceptable non-reactive aggregates might be obtained, were designated. All unacceptable material above this had to be removed first before the acceptable material was worked, and a restriction was also placed on the production at the same time, of aggregate from reactive strata for other purposes, in order to avoid confusion and possible contamination of stockpiles.
2. Those potential quarry sites along the right-of-way which had been tested, were designated in the same manner.
3. For unworked strata in existing commercial quarries, and unexplored potential quarry sites, the contractor, if he chose to use these, was required to open the quarry to the full depth he proposed to work and permit the material to be tested prior to use.

A testing period of 112 days was specified, which included the actual expansion measuring time of 84 days. A limiting expansion of 0.05 percent was set when the aggregate in question was incorporated in a concrete prism with a cement of alkali content greater than 1.1 percent. If the contractor wished to process aggregates while waiting out the testing period, he was at liberty to do so at his own risk, provided aggregate from each different lithological sequence was separately processed and stockpiled, on the understanding that it would only be acceptable if results of the testing were satisfactory.

4. Those strata in two commercial quarries (Frontenac and Pittsburgh) known to be unacceptable together with the local deposits already known to be reactive (mainly in the Collins Bay area and east of Highway 38 and south of Highway 2 in the Kingston area (see Fig. 1)), were excluded outright from consideration as concrete aggregates.

Use of Moisture Vapor Barrier Under Pavement

Four-mil. polyethylene sheeting was specified as a moisture vapor underlay for the pavement to reduce upward migration of ground water which might be alkaline.

Provision of Expansion Joints in Pavement

Expansion joints were specified throughout the pavement, irrespective of the time of construction, instead of the customary practice of only providing these in early spring and late fall at intervals of 350 ft.

PRACTICAL RESULTS

Construction of structures on the highway started in 1959, and laying of the concrete pavement commenced in 1961. Examination of both structures and pavement so far reveals no trace of pattern cracking or excess expansions such as had been noted in earlier work only a few months after construction.

The coarse aggregates were in fact obtained from quarries C, D and 10 shown in Figure 1.

CONCLUSION

By prior geological exploration of existing and potential quarry sites and subsequently testing the different strata therein for alkali-carbonate reactivity by incorporating the rock in concrete prisms, the expansion of which was measured, it has proved possible to safely select aggregates which will be non-reactive. Taking into account the dangers of secondary alkalies and the extra cost of using low alkali cement or importing aggregate from outside, this appears to have been the most realistic and economical way to build a major concrete highway through the area of Black River dolomitic-limestones around Kingston, Ont.

Detection of reactivity by the expansion of concrete prisms is a somewhat laborious and lengthy process. Later work as reviewed by Hadley (5) on the known cases of alkali-carbonate reactivity has suggested that characteristics of the rock itself such as texture, calcite-dolomite ratio, clay minerals, and expansion of small rock prisms in alkaline solutions, may provide more rapid identification. Undoubtedly the petrologist can thus be of the greatest assistance to the engineer by examining and identifying the characteristics of rocks as to their potential reactivity. But pending greater certainty that all such cases of reactivity can be so detected, and there is now preliminary evidence that at least one reactive aggregate originating from a quarry in the Black River group in Ontario does not fit the postulated petrological pattern, the expansion of concrete prisms must remain as the ultimate criterion for aggregate acceptability where alkali-carbonate reactivity of the expansive type is suspected.

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