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SOME UNUSUAL ALKALI-EXPANSIVE AGGREGATES

BY

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AGREGATS EXPANSIFS A L'ALCOLI PEU COMMUNS

SOMMAIRE

Les sous-grès shisteux de la carrière à Alert, Ile Ellesmere, T.N.O., Canada, possèdent, on a trouvé au moyen d'essais de changement de longueur, un potentiel réel pour provoquer la dilatation du béton par un genre de réaction alcali-agrégat. Ces roches sont physiquement saines mais démontrent des affinités pétrographiques avec des roches expansibles à l'alcali connues des provinces maritimes. Les roches de cette espèce peuvent être identifiées par un pétrographe familier avec ce genre de problème.

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SOME UNUSUAL ALKALI-EXPANSIVE AGGREGATES*

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ABSTRACT

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The subgrey wackes from the quarry at Alert, Ellesmere Island, N.W.T., Canada, have been found by length-change tests to have a definite potential for causing expansion of concrete by a type of alkali-aggregate reaction. The rocks are physically sound but have petrographic affinities with known alkali-expansive rocks in the maritime provinces. Rocks of this sort may be recognized by a petrographer familiar with this type of problem.

INTRODUCTION

A problem with concrete at Alert, Ellesmere Island, N.W.T., Canada, appeared to be caused by the aggregate at this northern military base. A request came initially from the department of National Defence to determine the cause of the concrete deterioration, particularly because some major construction was being planned with concrete as an important component. A co-operative program was undertaken between the University of Calgary and the Division of Building Research, National Research Council, to study the problem.

A preliminary petrographic examination of a rock sample from the quarry at Alert showed it to be a metagreywacke that had affinities with some of the alkali-expansive rocks in the Appalachians (Duncan et al., 1973 b). For this reason, although other characteristics of the rock were examined, emphasis was placed on determining the degree of alkali-expansivity.

The problem of concrete disintegration due to alkali-aggregate reactions, has been studied for over thirty years. In Canada different sorts of alkali-aggregate reactions have been investigated in the neighborhood of Kingston,

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Ontario (Swenson and Gillott, 1960; Gillott and Swenson, 1969), in the Appalachians (Swenson, 1957; Duncan et al., 1973 a), in the Canadian Shield (Dolar-Mantuani, 1969), on the Prairies (Price, 1961; Chakrabarti, 1968), and to a lesser extent in other locations. Rock types involved mainly are certain dolomitic limestones, greywackes, phyllites, argillites, opaline shales, rhyolites, and cherts. The degree of severity of alkali-aggregate reactions may vary from innocuous to rapidly destructive.

In July 1971 the two authors visited Alert to examine existing concretes, rocks in the quarry, and other possible aggregate sources and to obtain samples for a test program. Sufficient material for extensive engineering tests was obtained from the quarry and two additional localities. Hand samples for petrographic examination were collected from other outcrops.

At Alert, and for several miles surrounding that location, upper Silurian strata belonging to the Cape Rawson Group are exposed (Christie, 1964). These beds have suffered only low-grade metamorphism and in lithology are greywackes, impure sandstones, phyllites, cherts and argillaceous limestones. The rocks examined during the present investigation are subgreywackes, phyllites and cherts. Samples of subgreywacke and phyllite were obtained from the quarry near the military base. In the quarry the rocks are moderately steep dipping, jointed, grey to greenish-grey impure sandstones or greywackes with thin bands of slate or phyllite. The strata are cut by quartz and quartz-carbonate veins. The cherts were collected about 3½ miles from the camp just west of the road to Pullen Mountain at elevated topographic features, formed because of the superior resistance of the cherts to weathering. These sources appeared to be fairly accessible to the base, and the comparatively favourable weathering resistance of the cherts, barring any serious alkali-reactivity, made them more promising as aggregate than other outcrops along this route. At these locations the cherts fracture into blocky hand specimens which are dark grey to black sometimes with a surface sheen due to graphitic material.

Surface salts deposited by evaporation of upward moving groundwaters were not observed though various sulphate salts have been reported in the area (Christie, 1964; 1967). Above certain concentrations such salts can adversely affect durability of concrete.

An engineering report by the two authors will become available on limited distribution at the time of publication of this paper. This report* provides more detailed data and other information pertaining to the study.

PHYSICAL PROPERTIES OF ROCKS, MORTARS AND CONCRETES

Conventional tests for concrete aggregates were carried out on the rocks from the three localities at which sufficient material was collected for this purpose (Canadian Standards Association, 1967; American Society for

*Gillott, J. E. and Swenson, E. G., 1973. An investigation of rocks from Alert, N.W.T., for concrete aggregates. Report to Defence Research Board of Canada.

Testing and Materials, 1971a). The rocks were found to be physically sound in the magnesium sulphate test and the freeze-thaw cycling test (700 cycles). In the latter, however, the quarry crushed rock sample required double the normal dosage of air-entraining agent because of the presence of an excess of the dust fraction. Compressive strengths of the concrete test samples at 28 days were 70–75% of a reference concrete made with high quality aggregates. This ratio was maintained at 90 days, and so the stone was considered acceptable for normal use.

In scratch hardness test the rocks from Alert gave values close to the average found for rocks commonly used as concrete aggregates. A fairly high percentage of elongated or slabby particles is produced by the crushing equipment at Alert. This probably accounted for the reduced concrete strengths but the aggregate was deemed satisfactory, considering the geographic location and providing that the mix design is suitably adjusted.

The grading of the aggregate obtained by the equipment in the quarry was poor but, again, usable on the basis of adjustment in mix design and dosage of air-entraining agent. No deleterious particles were present in significant amount though small quantities of shale or phyllite were represented. Surface rocks were coated with dead moss which had deleterious effects on strength; such material should not be used as concrete aggregate.

A non-standard wet-dry cycling test was carried out on both mortar bars and concrete prisms. This will usually cause excessive expansion and deterioration when shale or shale-like material is used as aggregate. The test specimens showed no deterioration after about 200 cycles.

In general, the conventional tests showed that both the subgreywacke rocks of the quarry and the cherts are satisfactory as concrete aggregates if the limitations noted above are taken into account in concrete manufacture.

ANALYSES OF THE ROCKS BY OPTICAL, ELECTRON OPTICAL AND X-RAY DIFFRACTION METHODS

General guidance for petrographic assessment by optical microscopy of rocks for use as aggregate is given in ASTM C295 (American Society for Testing and Materials, 1971b). Optical micrographs of the three rock types examined in the present study are shown in Fig.1.

The subgreywackes are composed of quartz, carbonates, rock fragments, feldspars and phyllosilicates. Cubes of pyrite and graphite stringers are common. The grain size of many samples is close to the boundary between fine-grained sandstone and siltstone. Sedimentary clay-grade constituents comprise about 10% of the rock while additional matrix material seems to have formed by secondary alteration due either to diagenesis or low grade metamorphism. Much of the carbonate originated as clasts but this is not now readily recognized since the micrite of which they were composed deformed and recrystallized under shear, commonly forming part of the matrix. Slate and phyllite are the most common lithic components though fragments of chert, quartzite and siltstone are sometimes present. X-ray

Fig.1. Optical micrographs of rocks from Ellesmere Island, N.W.T.

analysis of size-fractionated material showed that swelling chlorite is a constituent in some but not all of the subgreywackes (Fig.2). Fine fractions ($< 0.2 \mu\text{m}$) sometimes contain an expanding lattice mineral which is probably a random mixed-layer mica-montmorillonite. All samples contain 10 Å-mica and non-swelling chlorite.

Fig.2. X-ray diffractograms of impure sandstone, Alert, N.W.T. (< 2.0 μm saturated Mg).

The slates and phyllites contain fine quartz and carbonates in addition to phyllosilicates. X-ray analysis showed the latter to be 10 Å-mica and non-swelling chlorite in the samples examined.

The cherts are composed of microcrystalline silica showing varying degrees of recrystallization with carbonates, white mica and graphite. The carbonates sometimes form rhombs which are partially replaced by haematite and subsidiary limonite. Partially altered pyrite rhombs are also present. X-ray analysis confirmed the presence of 10 Å-mica but no chlorites or other phyllosilicates were detected.

Fracture surfaces were examined on the scanning electron microscope in the untreated condition and after immersion in 2M NaOH at 100°F.* Re-examinations were made at intervals of several hours to several days or weeks in alkali until the surface became unrecognizable. Mosaics were very

*Samples were coated with aluminium to minimize charging. This metal was used rather than Au/Pd, since it is readily removed when the sample is reimmersed in alkali.

Fig.3. Scanning electron micrographs of impure sandstone from Alert, N.W.T. before and after treatment with 2M NaOH at 100° F.

Fig.4. Scanning electron micrographs of phyllite from Alert, N.W.T. before and after treatment with 2M NaOH at 100° F.

helpful in the relocation of the same area of surface. This makes it possible to assess the effect of increasing periods in alkali by visual comparison (Gillott, 1970).

Some of the progressive changes to the surface of the subgreywacke are shown in Fig.3. The corrosion of a carbonate mineral is clearly shown, the original smooth crystal planes being etched into an acicular pattern. On the flat surface of the mineral showing the river pattern, there was growth of new material, presumably deposited from solution. The material for the new crystals appears to have been derived at least in part at the expense of the neighbouring carbonate grains so the ions must only have migrated through solution for a few micrometres before being reprecipitated. Layer structure minerals did not exfoliate (Gillott et al., 1973) but many showed relatively rapid dissolution. In some instances the smooth cleavage planes became coated with precipitates.

In the case of the phyllites most of the crystals developed a granular appearance. This seemed to be a precipitated coating of reaction products some of the material being apparently derived by dissolution from elsewhere in the surface. A curious semi-transparent skin developed after 36 h in alkali (Fig.4). Thorough washing in distilled water did not remove this skin but it was completely removed by treatment in an ultrasonic bath for 30 sec. Similar deposits re-formed after successive periods of immersion in alkali and were similarly removed. Layer structure minerals did not exfoliate but instead cleavages became obscured by precipitate.

The scanning electron micrographs show the chert to be micro-crystalline with a dense texture of interlocking grains which sometimes develop euhedral quartz morphology (Fig.5). The progressive changes in appearance with increased time in 2M NaOH at 100° F are shown in Fig.6. The silica gradually became roughened and corroded. Angularities and asperities became rounded and material was redeposited on planes which were originally smooth giving to them a granular appearance somewhat reminiscent of portland cement grains at very early ages of hydration. A mineral with strong basal cleavage developed a rough texture and after 11 weeks of alkaline attack virtually no trace remained of the strong cleavage.

Samples of all three rock types as size-fractionated powders were soaked in 2M NaOH at 100° F for 10 weeks. Soluble salts and alkali were then removed by centrifugal rinsing and the samples were analyzed by X-ray diffraction. No significant shift in peak positions was detected though there were some indications of line broadening suggesting a decrease in the crystallinity of some minerals.

ALKALI-AGGREGATE INVESTIGATION

The most direct tests for the recognition of alkali-expansive aggregates involve the measurement of the dimensional change characteristics, under controlled conditions in the laboratory, of mortar bars, concrete prisms and rock cylinders. A standard test with mortar bars is described in ASTM C227 (American Society for Testing and Materials, 1971c). It involves the measurement of length change of mortar bars made with the suspected aggregate and a high and low alkali cement and held at 100% relative humidity and constant

Fig. 5. Mosaic of scanning electron micrographs of chert from Pullen Mt., Ellesmere Is., N.W.T.

Fig. 6. Scanning electron micrographs of chert from Pullen Mt., N.W. T. before and after treatment with 2M NaOH at 100° F.

Fig. 7. Length change data for mortar bars.

temperature for some months. The concrete prism test, requiring more materials and space, is a similar test for alkali-expansivity and is frequently used. Measurement of rock cylinders placed in alkali gives results somewhat more rapidly. The basic techniques are given in ASTM C586 (American Society for Testing and Materials, 1971d).

When the rate of expansion is slow it has been found necessary to accelerate the reaction by using higher temperatures and increased concentration of alkali (Duncan et al., 1973). Such procedures were followed in the present investigation. Dimensional change data were obtained for mortar bars, concrete prisms and rock cylinders.

Results of the tests on mortar bars show that the subgreywacke from the quarry is moderately alkali-expansive; the cherts also show mild alkali-expansivity. Under accelerated conditions both the subgreywackes and cherts show considerably greater alkali-expansivity than a reference aggregate similarly tested (Fig. 7).

Tests using concrete prisms confirm the significant degree of alkali-expansivity of the subgreywacke from the quarry. The cherts, however, do not show this property at the end of 400 days of conditioning (Fig. 8). It is probable that the reactivity indicated by the mortar bar test is so slow that

Fig.8. Length change data for rock cylinders and concrete prisms.

more time is required under conditions of the concrete test. On the other hand this would greatly reduce, if not eliminate, the danger of field problems.

Measurement of rock cylinders indicates that the subgreywackes are highly expansive whereas the cherts are not significantly alkali-expansive when data are compared with a reference sample (Fig.8).

The conclusion from this phase of the investigation is that the quarry rock samples all showed alkali-expansivity. The cherts can be judged as only mildly alkali-expansive, if at all, when used in concrete as coarse and fine aggregate.

DISCUSSION

The alkali-expansivity of the subgreywacke rocks at Alert is of sufficient magnitude to require recognition and attention to concrete practice. Even the cherts, although only mildly reactive, are known to produce excessive expansion of concrete when they constitute certain proportions of the total aggregate. In other respects these rocks, apparently abundant in this area, were shown to be satisfactory for concrete.

In heavily settled regions, particularly where depletion of high quality materials has taken place, it is not unusual to make use of aggregates of marginal quality. Such a procedure requires no justification in a unique geographic location such as Alert. Furthermore the absence of paved roads makes it more than usually necessary to exploit sources of aggregates that are close to the construction site. Proper evaluation and usually only minor adjustments in concrete practice are necessary with such borderline aggregates, normally with little or no extra cost. On the basis of a recent review (Swenson, 1972), and having regard to the geology, other areas of the north may face similar problems in concrete construction.

Excessive expansion of concrete made with the aggregates from Alert was successfully prevented in laboratory tests by the use of a low alkali cement (in this case, 0.59% equivalent Na_2O). Two such cements are being produced in Canada at the time of writing. A low-alkali cement normally contains less than 0.60% equivalent Na_2O . This limit can be somewhat exceeded where the reaction is mild and slow and where temperature and moisture conditions are unfavourable to the reaction.

All known alkali-aggregate reactions are accelerated by increase in temperature. The lower temperatures in the far north and the cold regimes in permafrost would tend to reduce or entirely prevent excessive expansion. This is particularly true since the rocks from Alert caused only a slow expansion that may be accommodated by creep. Concretes inside heated buildings would, however, be subject to more rapid reaction if relative humidity is high. Moisture is also necessary to the reaction. Thus an exposed concrete element inside a normally heated room would tend to dry out whereas the same situation with the concrete protected from drying by a coating would be more susceptible to expansion where alkali-reactive aggregates are used.

Rapid strength gain of concrete is normally considered important in far northern construction. Usually a high early strength cement or the accelerator, calcium chloride, is used. Low-alkali high-early-strength cements are not manufactured at this time in Canada but could be made. The response of a low-alkali cement to calcium chloride is not always high and, if contemplated, should be tested.

Extra cement is often used primarily to give added strength. In massive concrete sections benefit of extra exothermic heat is thus obtained. On the other hand, if some expansion does occur due to alkali-aggregate reaction, extra cement content will aggravate this situation. Pozzolanic additives would not be suitable under northern conditions.

Where expansions are relatively moderate and cause only minor damage other adverse reactions may then find the concrete more vulnerable. Much northern concrete is liable to attack by sulphates from saline soils or sea-water and also to damage by frost action. Thus measures intended to prevent damage by one agency should be considered in relation to their possible effect on the others. Magnesium salts are also present in saline soils and sea-water and may damage concrete in time. Such salts tend to migrate when a temperature gradient exists in the concrete.

Where alkali-expansive aggregates are used excessive expansions can sometimes be prevented by attention to design features that take account of temperature and moisture effects, without using a low-alkali cement. The latter however may be necessary.

CONCLUSIONS

The subgreywackes at Alert have petrographic affinities with the alkali-expansive greywackes from the Appalachians. Rocks from both localities contain expanding lattice phyllosilicates but the rocks at Alert do not contain the brown pleochroic porphyroblasts of vermiculite-type mineral. Studies with the scanning electron microscope failed to detect exfoliation of layer structure minerals though considerable changes in mineral morphology were caused by treatment in 2M NaOH at 100° F. Also different from the findings in Nova Scotia was the absence of any shift in peak position on X-ray diffractograms of alkali-treated rock-powders. The cherts have a dense, interlocking, microcrystalline texture which is no doubt in large measure responsible for the extreme slowness of the alkali-aggregate reaction found in the studies of the cherts.

In far northern construction involving concrete, petrographic examination of aggregate sources is shown to have added importance.

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