

ALKALI-AGGREGATE REACTIVITY IN NEW ZEALAND

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SUMMARY

The reactivity of New Zealand aggregates with cement alkalis is discussed in terms of mineral composition, behaviour in laboratory tests and performance in structures. Attention is drawn to occurrences of cracking where a high-alkali cement was inadvertently used with a glassy andesite. Petrographic evidence is cited confirming that a moderate alkali-silica reaction had occurred. Measures which have proved effective in controlling alkali-aggregate reaction in practice are given.

INTRODUCTION

Attention was first drawn by Hutton (1945) to the possibility that certain potentially useful aggregate materials in New Zealand could react deleteriously with cement alkalis. Those considered to be potentially

^x Presented by B. Mather.

reactive were andesite, obsidian and possibly those greywackes which consist predominantly of volcanic fragments. Watters (1969) discussed the reactivity of minerals present in New Zealand aggregates and stated that the main reactive constituent present in commonly used aggregates was volcanic glass. This substance is widespread, occurring in moderate amount (generally less than 15% by weight), in andesites of the Taranaki and Tongariro-Ruapehu areas and in other volcanic rocks of the North Island central volcanic region.

It has been in this latter region that a series of hydro-electric stations, involving relatively large concrete dams has been built on the Waikato River. The absence of cracking due to alkali-aggregate reaction after 10 - 20 years service in these and associated structures has been due to the avoidance, wherever possible, of excessively reactive aggregates, and the consistent use of low-alkali cement, that is, with alkali content less than 0.6% soda equivalent. In many instances a pozzolan has been included in major concrete works even although low-alkali cement has been used. The pozzolan has provided additional protection against

Note: In each case where the alkali content of a cement is quoted in this paper it is expressed as soda equivalent.

- (a) the possibility that the alkali content of the cement might exceed the specification limit, and
- (b) possible expansion which might otherwise occur even where cement alkalis are below 0.6% since in the 1950s it was believed that such expansion might occur.

Cracking of concrete has occurred in Taranaki where a high-alkali cement was inadvertently used with an andesite aggregate. This cracking was reported by Kennerley and St John (1969) who considered it to be the result of alkali-aggregate reaction. Petrographic evidence in support of this claim has been provided (St John, 1975).

NATURE OF AGGREGATE MATERIALS IN NEW ZEALAND

The most widely used concrete aggregate is greywacke. This rock, which constitutes the axial ranges of New Zealand (Fig. 1) is a hard, well-indurated, medium-grained, well-jointed, unsorted sandstone. It consists mainly of angular fragments of quartz, feldspar (potash feldspar, sodic plagioclase and (rare) more basic plagioclase) and biotite (approximately 5%) with some muscovite. Expanding lattice minerals, such as vermiculite, which may have contributed to alkali-aggregate expansion of greywackes and phyllites of Nova Scotia (Gillott et al., 1973), appear to be absent.

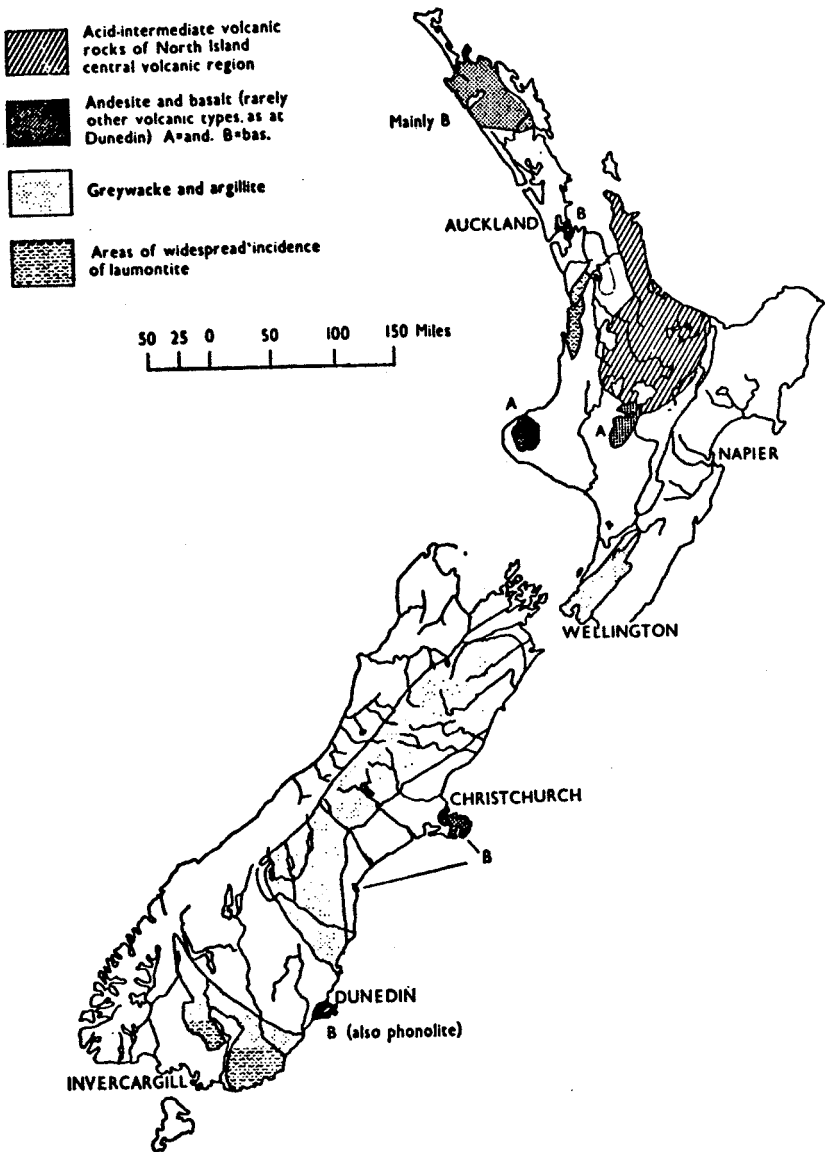


Fig.1 - Main aggregate-producing rock types in New Zealand

This greywacke has been used extensively in concrete, mostly with cements of low alkali contents (0.4-0.6%), but during 1960-62 it was used with one brand of cement containing over 1% alkalis, without evidence of cracking due to an alkali-aggregate reaction.

Certain New Zealand aggregates contain small amounts of laumontite which can cause the aggregate to breakdown in stockpiles due to the action of wetting and drying. The presence of this zeolite mineral provides a possible source of sodium ions which could be released by base exchange, but experiments have shown the amount of alkali from this source to be negligible.

Volcanic greywackes occur in certain localised areas but are not used as aggregate. The presence of devitrified glass in the groundmass of some of the volcanic fragments in the rock suggests that they could react expansively with cement alkalis.

Argillite is often interbedded with greywacke in New Zealand and, as far as possible, it is avoided or removed in the quarries. No evidence has been found to suggest that the type of argillite commonly found in New Zealand would react deleteriously with cement alkalis in a way similar to the argillite from the Canadian Shield (Dolar-Mantuani, 1969) or as mentioned by Gillott et al. (1973). There is considerable

interest in the extent to which aggregate intermediate in composition between greywacke and argillite can be used in concrete. Although future use will be determined by the mechanical properties of the aggregate, the possibility of interaction with cement alkalis should not be overlooked. Reed (1957) has found that the predominant form of clay in the argillite present in a range of lower Mesozoic rocks from the Wellington region is illite.

Andesite from Mount Egmont is the sole source of aggregate in Taranaki. Andesite has been used as aggregate to a lesser extent in the Bay of Plenty, and recently, in association with greywacke, in a central North Island power development project. Volcanic glass, generally devitrified, is present, sometimes with minor cristobolite and tridymite in a glassy matrix which varies in amount from 30% to 80% of the rock.

Andesite and rhyolitic fragments, including pumice, are present in sand from the Waikato River whose headwaters are in the central volcanic region of the North Island. This sand has been used with other aggregates such as rhyolite, basalt and greywacke in concrete dams. Pyroxene andesites, with little or no glass, have been used with immunity.

Basalt is used in Auckland and certain other areas and is usually free from glassy areas which might cause

it to react with cement alkalis. Dacite has been used as a minor aggregate, and phonolite is a major aggregate in Dunedin.

Opal and chert are present in altered volcanic rocks of the Coromandel Peninsula but these rocks have not been used for aggregate production.

EXAMINATION AND TESTING OF AGGREGATES

It has been normal practice to examine new materials petrographically, before they are used, to determine the presence or absence of volcanic glass.

Chemical Test

Where the petrographic examination has reported that glass is present, the potential reactivity, as indicated by the values for soluble silica (S_C) and reduction in alkalinity (R_C), has been determined chemically using ASTM Method C289-71.

This test has been useful as a means of establishing that such materials as rhyolite or dacite are reactive or that materials such as greywacke are unreactive. It has been of rather limited value when applied to andesites. Most glassy andesites have been classified, according to the chemical test, as reactive, but since the S_C value has not been as high as, for example,

for rhyolites, variations in results inherent in the test method have made it difficult to classify these marginally reactive materials with confidence.

Mortar Bar Tests

Mortar bar tests have been carried out on selected aggregates to establish whether they react expansively with cement alkalis. Aggregates intended for use in the Waikato River projects were tested using a method similar to ASTM Method C227-71 but with 50 x 50 x 305 mm (2 x 2 x 12 in) prisms. Three cements, having alkali contents of 0.40%, 0.67% and 0.96% were used, the first two being cements intended for use on the job and the third an imported cement. Significant expansion occurred only with the cement containing 0.96% alkalis, and here the rate of expansion was slower than anticipated. Appreciable shrinkage was recorded for specimens in this series and it was believed that, with the larger-than-standard-size specimens used, self-desiccation might have contributed to this effect. This observation is at variance with the results of Davis (1957) though his results were obtained on specimens stored at 17°C. Davis found that, although specimens of larger cross-section began to expand at a slightly later age, after the first 3 months they expanded at a greater rate than smaller bars and eventually expanded up to half as much again.

In further tests on aggregates for Waikato River projects, pozzolans, namely, finely-ground pumicite and

diatomaceous pumicite, were used to replace 25% and 12½% respectively of cement containing 0.89% alkalis. No expansion was observed.

In a later test series the expansion of various glassy aggregates was studied using 25 mm (1 in) mortar prisms and cement with 0.89% alkalis, and also, with selected aggregate samples using cements having effective alkali contents of 1.20% and 1.50% respectively (achieved by the addition of NaOH solution to the first cement). Using similar curing and storage conditions to those used previously, shrinkage was either very small or not apparent after one month. These tests showed that Egmont and Tongariro andesites were expansively reactive, but revealed a "pessimum" proportion for the Tongariro sample that increased approximately in proportion to the alkali content of the cement. Egmont andesite, which contains a smaller amount of glassy matrix than the Tongariro andesite sample considered, expanded at a slow rate and did not show a "pessimum" proportion, the amount of expansion at one year being proportional to the alkali content of the cement. Examples of the type of results obtained with andesite and dacite are given by Kennerley and St John (1969). Typical results of expansion of mortars containing selected aggregates are given in Table 1.

In view of the importance of volcanic glass as the reactive constituent in many New Zealand aggregates, it is of interest to consider the behaviour of the glass by

Table 1. - Expansion of ASTM C227 Mortars at 1 year

Aggregate		Chemical Reactivity ^a		% Total Aggregate	Expansion %		
Type	Source	S _c	R _c		Cement	Alkalis %	
						1.5	
						0.89	1.2
Greywacke (Typical)	Hutt River	19	73	100	0.018	0.022	0.025
Andesite (Egmont)	Stony River	167	71	100	0.080	0.218	0.248
" "	" "	-	-	10 ^b	0.010	0.020	0.076
Andesite (Tongariro)	R 4/1	78	83	100	0.099	-	-
Andesite (Tongariro)	R 9	531	136	100	0.231	0.255	0.339
" "	" "	-	-	10 ^b	0.100	0.194	0.292
Dacite	Tauhara	721	114	100	0.016	0.046	0.067
" "	" "	-	-	10 ^b	0.170	0.224	0.234
Rhyolite	Whakamaru	909	130	100	0.032	0.037	0.049
" "	" "	-	-	15 ^b	-	-	0.470
Rhyolitic pumice	Te Teko	212	103	10 ^b	-	-	0.003
Obsidian ^d	Taupo	106	11	100	0.022	0.028	0.050
" "	" "	-	-	15 ^b	-	-	0.067
Pitchstone ^e	Gebbies Pass	150	50	100	0.134	0.291	0.310

a Test method ASTM C289-71

b Remainder of aggregate is Hutt River greywacke; size grading of both aggregates similar

c Remainder of aggregate is Hutt River greywacke; pumice fraction 300-150 μm (50-100 mesh)

d SiO₂ 75.6, Al₂O₃ 12.8, Na₂O 4.0, K₂O 3.6, H₂O 0.14%

e SiO₂ 76.5, Al₂O₃ 11.9, Na₂O 3.2, K₂O 4.6, H₂O 3.5%

itself. Obsidian and pitchstone were chosen for study. Obsidian was found to be not particularly reactive, presumably because of its low water content and dense structure; on the other hand, pitchstone, which has a similar chemical composition to obsidian but contains over 20 times more water, is much more soluble in alkali and reacts expansively in mortar. In an early series of tests the amount of pitchstone in mortars was varied in an attempt to establish a relationship between the ratio of volcanic glass to alkali and the amount of expansion, as found by Vivian (1950) for opal, but without success due to the use of cement of too low an alkali content.

Concrete Tests

Tests have been carried out to determine the behaviour of Egmont andesite in concrete (aggregate maximum size 20 mm) with cement having effective alkali contents 0.65%, 0.90% and 1.20% respectively. Three cement contents namely, 295, 445, 595 kg/m³ (500, 750, 1000 lb/yd³) were used and the water to cement ratios to give a constant slump of 100 mm (\pm 20 mm) were 0.82, 0.52 and 0.40 respectively. The specimens, 76 x 76 x 290 mm, were stored

1. continuously moist in fog at 21°C,
2. in fog at 21°C for 28 days, thence in a cabinet subject to daily cycles of 8 hours drying at 55°C and 16 hours soaking in water at 21°C (after Scholer, 1949),

3. outdoors just above ground level where average daily temperatures vary 13 - 21°C mid-summer and 5-12°C mid-winter; frost conditions applied about 40 days per year with a minimum of minus 7°C.

Measurements were made of compressive and tensile strengths, dynamic modulus and length change, the latter giving the earliest indication of alteration in physical properties. Results of expansion measurements are contained in Table 2.

The effect of combining Egmont andesite coarse aggregate (greater than 4.75 mm) with greywacke sand and Egmont andesite sand with greywacke coarse aggregate was examined with cement containing 1.2% alkalis and a cement content of 595 kg/m³. Expansion increased where the coarse aggregate was greywacke but decreased where the fine fraction (less than 4.75 mm) was greywacke.

In another series of tests, specimens of air-entrained concrete containing Egmont andesite, cement with 0.64% alkalis, cement content 382 kg/m³, were placed in seawater (maximum 16°C, minimum 11°C) between high and low water levels after 32 days curing in fog at 21°C. No significant expansion had occurred after 7 years.

EXPANSIVE CRACKING OF A STRUCTURE

The only instances of cracking of concrete due to alkali-aggregate reaction in structures in New Zealand have occurred in Taranaki where Egmont andesite aggregate was used in association with a cement of average alkali content 1.14% cement contents 385 - 445 kg/m³ (650 - 750 lb/yd³) and water to cement ratio 0.4. Three railway bridges are affected, but the structure which has attracted most attention is the Te Henui Bridge which is located in New Plymouth on the sea coast only 100 - 200

Table 2. - Percentage Expansion of Concrete Prisms containing Egmont Andesite
(Alkali content of cement and storage conditions as shown)

Cement Content (kg/m ³)	Age (years)	Fog at 21°C			Wetting and Drying 21°/55°C after 28 days fog at 21°C			Outdoors in Temperate climate after 28 days fog at 21°C		
		0.65	0.90	1.20	0.65	0.90	1.20	0.65	0.90	1.20
295	7	0.010	0.018	0.015	-0.007	-0.006	0.018	-0.032	-0.032	-0.027
445	1	0.010	0.016	0.017	-0.015	-0.007	0.004	-0.019	-0.018	-0.009
	1½	0.011	0.015	0.017	-0.024	-0.015	-0.010	-0.018	-0.012	-0.007
595	1	0.016	0.021	0.050	-0.003	0.018	0.293	-0.013	-0.003	0.004
	5	0.021	0.033	0.110	0.022	0.091	0.367	-0.017	0.008	0.110
	6½	0.023	0.036	0.113	0.039	0.156	0.372	-0.021	0.006	0.179

meters from the high water mark. Cracks in the concrete were first noted 5 years after completion. Concrete cores (diameter 100 mm) were obtained from the piers (nominal cement content 385 kg/m^3) and these were examined microscopically by St John (1975). Gel deposits somewhat similar in composition to those reported by Idorn (undated) were visible, but although numerous andesite particles were seen to be disintegrating, the extent to which alkalis had attacked the aggregate appeared small in relation to the amount of cracking. It was suggested that, initially, highly reactive aggregates expand and crack the concrete and thus allow the establishment of concentration gradients towards cracked areas thereby facilitating the movement of mobile alkali ions. Less reactive particles in the same area then become attacked and a highly expansive zone is formed.

Compared with reports of affected structures overseas alkali-aggregate reactivity in this bridge is only moderate. It is not surprising that the cracking should be found to be due to alkali-aggregate reactivity since the cement had a high alkali content and the aggregate was a glassy andesite. Subsequently it was ascertained that the specification for the bridge required that a cement with an alkali content not greater than 0.60% be used. It is noted that Mather (1975) states that failure to ensure that specifications are complied with is a major reason for significant deterioration of concrete in service.

PREVENTIVE MEASURES

The main safeguard against possible alkali-aggregate reaction in New Zealand has been the use of low-alkali cement. In New Zealand the alkali contents of cements from its four works have generally been and are now almost

without exception below 0.6%. It is fortunate indeed that even before the existence of an alkali-silica reaction was recognised, the only cement readily available in the area where reactive aggregates prevail was low in alkalis (0.4%). Thus the absence of expansive cracking in early structures where reactive aggregates have been used must be due to the use of low-alkali cement.

A further safeguard has been the avoidance of reactive aggregates or reactive combinations where this has been feasible.

Extensive use has been made, in major structures, of a pozzolan, namely, a diatomaceous pumicite from Whirinaki, to give added protection, as there had been reports of cracking overseas due to alkali-aggregate reactivity where cement containing less than 0.6% alkalis had supposedly been used (e.g. Jansen, 1967). The above pozzolan consists of about 55% pumicite, 30% diatomite and 15% clay by weight (Kennerley, 1959) and has been dried and ball-milled before use. In concrete it is used to replace 12½% by weight of cement. Tests to determine its effectiveness in preventing expansion of concrete due to alkali-aggregate reaction (as described in ASTM Method C441-69, but using 50 mm prisms in place of 25 mm prisms) showed an average reduction in mortar expansion (R_e) value of 85%. Pumicite occurs more widely in areas adjacent to reactive aggregates and is more uniform in composition than the Whirinaki material, but tests where the pumicite was used to replace 20% cement gave R_e values of only 47 - 63 (Kennerley and Clelland, 1959) which is less than the value of 75% specified by ASTM C618-71, although the latter test would require that 30.5% by weight of cement be replaced by the pumicite. Thus diatomaceous pumicite was preferred because of its greater reactivity.

It is now accepted in New Zealand that concrete

deterioration due to alkali-aggregate reaction does not occur where the alkali content of the cement used does not exceed 0.6%. Experience elsewhere confirms this acceptance (Mather, 1967). Nevertheless pozzolan has continued to be used in major construction in the central North Island where reactive aggregates are used, even although the cements being used have alkali contents below 0.6% and frequently below 0.5%. Justification for continued use is the improvement in plastic properties of the fresh concrete, ease of finishing and water-tightness.

CONCLUSIONS

1. Certain New Zealand aggregates, particularly glassy andesite, rhyolite and dacite, react expansively with cement alkalis.
2. The good performance of concrete containing potentially reactive aggregates in service is due mainly to the use of low-alkali cement.
3. At a time when there were doubts regarding the occurrence of expansion of concrete containing reactive aggregate and low-alkali cement, additional protection was provided by the use of a pozzolan.
4. The only known instances of cracking due to alkali-silica reaction in New Zealand have occurred where, contrary to a specification, a high-alkali cement was inadvertently used with a glassy andesite.
5. The period required for significant expansion to occur depends on the storage or exposure conditions. In tests on concrete specimens containing Egmont andesite, expansion greater than 0.05% occurred after 3 years outdoors in a temperate climate, 1 year

in fog at 21°C or 2 months exposure to daily cycles of wetting (21°C) and drying (55°C) using a cement containing 1.20% alkalis and a cement content of 595 kg/m³. Expansion was not significant at 445 kg/m³ after 1½ years.

6. The contribution of alkali ions from seawater during marine exposure for 7 years has not caused a significant increase in the expansion of concrete of moderate cement and alkali contents and containing Egmont andesite aggregate.

REFERENCES

- Davis, C.E.S., 1957, Studies in Cement-Aggregate Reaction. XXV Comparison of the Expansions of Mortar and Concrete, Aust. J. Applied Science, 8, 222 - 234.
- Dolar-Mantuani, L., 1969, Alkali-Silica-Reactive Rocks in the Canadian Shield. Highway Research Record 268.
- ✓ Gillott, J.E., M.A.G. Duncan, E.G. Swenson, 1973 Alkali-Aggregate Reaction in Nova Scotia. IV Character of the Reaction. Cement and Concrete Research 3, 521 - 535.
- Hutton, C.O., 1945, The Problem of Reaction between Aggregate Materials and High Alkali Cement. New Zealand J. Sci. Tech. 26B, 191 - 200.
- Idorn, G.M., Undated, Studies of Disintegrated Concrete, Pt I-V. DINBR/ATV Progress Report N2 - N6. Danish National Institute of Building Research.
- Jansen, Robert B., Behaviour and Deterioration of Dams in California. Proceedings of Ninth International Congress on Large Dams, Istanbul, III, 435 - 475.
- Kennerley, R.A., 1959. Evaluation of Whirinaki Diatomite Processed for Use as Pozzolan. New Zealand DSIR Dominion Laboratory Report No.2016.
- Kennerley, R.A., J. Clelland, 1959, An Investigation of New Zealand Pozzolans. New Zealand DSIR Bulletin 133.

- Kennerley, R.A., D.A. St John, 1969, Reactivity of Aggregates with Cement Alkalis. Proc. Nat. Conf. on Concrete Aggregates, Hamilton, New Zealand, 35 - 47, 200 - 204.
- Mather, B., 1967, Factors which Influence the Deterioration of Concrete in Dams, and Measures for Prevention of Deterioration. Proceedings of Ninth International Congress on Large Dams, Istanbul, III, 419 - 433.
- Mather, B., 1975, New Concern over Alkali-Aggregate Reaction. National Sand and Gravel Association Circular No. 122, National Ready Mixed Concrete Association Publication No. 149, Maryland, U.S.A.
- Reed, J.J. 1957, Petrology of the Lower Mesozoic Rocks of the Wellington District, New Zealand Geological Survey Bulletin n.s. 57.
- St John, D.A., 1975, Confirmation of Alkali-Aggregate Reaction in the Te Henui Bridge. New Zealand J. Sci. 18, No. 3
- Scholer, C.H., 1949, A Wetting-and-Drying Test for Predicting Cement-Aggregate Reaction. Proc. Amer. Soc. Test. Mat. 49, 942 - 953.
- Vivian, H.E., 1950, Studies in Cement-Aggregate Reaction. X The Effect on Mortar Expansion of Amount of Reactive Component, CSIRO Australia Bulletin No. 256 13-20.
- Watters, W.A. 1969, Petrological Examination of Concrete Aggregates. Proceedings of National Conference on Concrete Aggregates, Hamilton, New Zealand, 48 - 54, 204.

