AN APPRAISAL OF UK GREYWACKE DEPOSITS AND CURRENT METHODS OF AVOIDING AAR

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ABSTRACT

AAR involving greywacke aggregates has been known world-wide for sometime. However, problems related to this aggregate type have only recently been generally recognised and accepted within the UK. This paper presents the findings of a regional survey of UK greywacke deposits, using laboratory and field studies, which was undertaken to establish the likely potential for and extent of further problems. The results from this survey show that about half of the deposits tested would be considered potentially reactive in use. The report also presents findings, continuing the theme from the previous conference, which show that fly ash and ggbs have continued to suppress the deleterious effects of ASR when compared to equivalent opc only concretes, although final evaluation of these materials is not yet possible as expansion continues.

keywords asr, fly ash, ggbs, greywacke, UK.

INTRODUCTION

Greywacke, that ill-defined and highly variable rock of generic type, falls within the marginal areas of sandstone classification. It is essentially composed of a 'compositional jumble' of quartz and reworked rock fragments as clastic material set within a recrystallised clay and microcrystalline quartz matrix.

In common with other generic types of aggregates, such as silicified limestones or flint-based gravels, it is found that greywacke tends to have a reaction characteristic peculiar to its type (CAMNET ed Fourier 1991). Early theories that certain clay minerals within the rock matrix were the reactive constituents have largely been found inapplicable to the majority of reactive greywackes and there is now sufficient evidence to support the view that the reactive constituent is the matrix microcrystalline quartz.

The first recorded field case in the UK of greywacke alkali reactivity was identified in a small dam in the 1970's (Palmer 1978). Little attention was paid at that time to this isolated case as the main concern about AAR in the UK was focused on a number of affected structures which contained flint-based sand and gravels. Therefore, much of the UK guidance on AAR avoidance measures was based and demonstrated using the experience of field and laboratory concretes which contained flint. However, it was the discovery more recently of AAR in a number of older structures (pre -1975), located across the UK (figure 1), and containing reactive greywacke aggregates, which promoted this present investigation. This integrated investigation was undertaken to establish whether UK guidance and avoidance measures would need modification in light of the widening problems relating to greywacke.

Greywacke deposits (which in this study excludes those found as sands and gravels) have a wide geologic and geographic spread within the UK (figure 1) and tend to occur in the less populated areas of the country. Much of the production from the 20-30 quarries in England, Scotland and Wales and another 40 in Northern Ireland, is used as a good quality road surfacing material in asphalt/macadam. However, some greywacke is used in concretes, mainly in mass concrete structures such as dams constructed in the area of outcrop, where there may be few alternative sources of aggregates. For this reason it is important to ensure safe use of this aggregate type.

This paper reports firstly, on the findings of a regional study using standard aggregate testing techniques to establish an overview of the potential problem within the UK. Secondly, the paper updates the results presented at the previous conference (Blackwell et al. 1992) concerning the use of fly ash, and presents new results concerning the use of ggbs to mitigate the effects of AAR. The major structures shown in figure 1 have been discussed in detail elsewhere (Palmer, 1978, Blackwell and Pettifer 1992, Thomas and Blackwell 1992).

REGIONAL OVERVIEW

To obtain an overview of the potential AAR problem within the UK a 'low density' study of UK greywacke deposits has been undertaken. Greywacke samples were collected from sites indicated in figure 2. Most of the collection sites were either working or disused quarries, although occasionally material was collected from exposures such as road cuttings. These samples were subjected to a number of laboratory tests, including: the ASTM C289-87 Quick Chemical Test for potential alkali reactivity, expansion testing using the BS 812 pt 123(draft) (now DD218:1995) ASR-Concrete Prism Test, the ASTM P214 (draft) Accelerated Mortar Bar Test. As previous laboratory testing (Blackwell et al., (1992), Blackwell and Pettifer, 1992) had shown that measured expansion was broadly proportional to greywacke content i.e. no pessimum, all experimentation was undertaken using 100% test aggregate.

The ASTM C289-87 test requires no introduction. Similarly, the ASTM P214 (draft) method was, until final publication as ASTM 1260-94, used widely across the world. Briefly, in this test, expansion measurements are undertaken after mortar specimens have been stored in 1N NaOH for 14 days. The BS 812 pt 123 prism test uses 75 x 75 x (200-300mm) concrete prisms, cast using 700 kg/m^3 cement content with 20,10, & 5mm test aggregate. The required alkali level is 7 kg/m^3 Na_2O_e supplied from a high alkali cement (approx. 1% Na_2O_e). The prisms are wrapped in damp towelling, further wrapped in polythene and sealed over water in screw top polypropylene containers. The specimens are stored at 38°C/100% RH and measured periodically for 1 year. For purposes of this study the prisms were continued on test after 1 year.

EVALUATION OF FLY ASH (EQUIVALENT TO CLASS F) AND GGBS TO MITIGATE THE EFFECTS OF ASR

Current UK guidance for the avoidance of AAR (The Concrete Society, 1987) recommends that the risk of AAR could be minimised by **A) Limiting the <u>mix alkali</u> levels to 3 kg/m^3** by (i) use of a cement with relatively low alkali content , or, (ii) use of OPC/fly ash or ggbs combinations, in which 25 % or more by mass of cement is replaced. **B) Use of a *low alkali* cement** which is either an OPC with <0.6% Na_2O_e or OPC/ggbs combination, where 50% or more ggbs is used.

The aim of this part of the study is to assess the applicability of these recommendations to greywacke aggregates. Concrete mixes have been prepared using two greywacke aggregate samples previously shown to be alkali reactive in the

Maentwrog Dam (Maent) and Northern Irish road bridge (N.I.)respectively. Concrete prisms of a similar size to those used in the BS Prism Test (previously described), have been cast using OPC only, and using 25% & 35% fly ash and 50% and 70% ggbs partial cement replacement. The fly ash was selected to have a high alkali content (4% Na_2O_e) and therefore potentially represents the worst case for fly ash. A cementitious content of 450 kg/m^3 was used in all mixes and the water content controlled to produce a 'slump' of 30-60mm. This resulted in some water reduction in the fly ash concretes of between 7-10%.

Three sources of opc with varying alkali contents were blended to give mix alkali contents in the opc-only specimens in the range 3-5.18 kg/m^3. Higher alkali contents, up to 7 kg/m^3 Na_2O_e, were produced by dosing the mix water with K_2SO_4.
Where K_2SO_4 had been added to the opc-only mix the same level of addition was made to the corresponding mixes containing cement replacement materials. Full chemical analyses of these materials has been previously presented (Blackwell et al. 1992). The storage conditions were identical to those described previously for the BS 812 pt123 prism test.

RESULTS

The results from the standard tests in the regional study are presented in Table 1. The limits placed on the ASTM P214 method are: <0.1% expansion at 14 days (innocuous), 0.1-0.2% (inconclusive) and >0.2% (reactive). At the present time there are currently no officially published limits relating to the BS 812 pt123 (draft). However, a recent discussion document (presented to BSI B/502/6 1995) provides suggested criteria for interpretation of results; In summary these are: <0.05% at one year (non-expansive), >0.05-<0.1% (probably non-expansive), >0.1-<0.2% (possibly expansive) and >0.2%(expansive).

The latest expansion results from the evaluation of cement replacement materials, ranging in time from between 44-56 months for the prism tests, are presented in figures 3,4,5 and 6. The figures are plotted so that only the alkali from the opc (and salts where added in all specimens) is considered As this is an ad hoc test guidance on interpretation of results is not available. Traditionally, expansion values at the termination of expansion of >0.1% are considered *deleterious*, although values between 0.05 - 1% would be considered *significant*, as these values denote the onset of microcracking detectable in thin section. Expansion values <0.05% would be considered innocuous. If the curve of (significant) expansion against alkali level for the concrete containing the cement replacement material lies on the high alkali side of the opc-only curve the cement replacement material can be considered to be inert or 'consuming' alkalis. Conversely, if they lie on the lower alkali side of the opc-only curve they are contributing alkalis. The principles of this approach of appraising the effectiveness of cement replacement materials is explained in greater detail elsewhere (Hobbs, 1988).

DISCUSSION

Preliminary surveys of aggregate deposits using low density sampling on a regional scale, such as the one reported here, have been undertaken in other countries

(Oberholster et al 1978, Gratten-Bellew, 1990) where reactive greywacke aggregates occur. In such studies it is not the intention, and indeed it would not possible, to provide detailed analyses on individual quarries. Similarly, the results presented in table 1 should not be used in that manner. However, these studies do provide a basis for an overview of a rock type recognised only relatively recently in the UK as being potentially reactive. The results from laboratory testing clearly show that approximately half the greywacke deposits surveyed would be classed as 'potentially expansive' in use. There is some discordance between the results of the accelerated mortar bar test and BS prism test method. In general, the mortar bar test has proved a harsher test, classifying some greywacke as 'reactive' or 'inconclusive' which are classed 'non- or probably non-reactive' in use, by the prism method. There is no easy resolution to this discrepancy. Experiments reported from Canada suggest that the accelerated mortar bar test is perhaps too harsh and that its use should be restricted to a method for preliminary screening of aggregates rather than as a definitive method of test. Additionally, there are a few greywackes judged 'non-reactive' in the prism test at 12 months but which have subsequently continued to expand slowly so that at 30 or 42 month the expansion value would be of concern. This phenomenon of slowly expanding greywacke has previously been well documented in Canada (CANMET- ed Fournier 1991) and therefore some caution must be applied when interpreting results . Notwithstanding this, both test methods have correctly classified the material used in structures identified as being affected by AAR as being 'potentially reactive' This clearly provides a degree of confidence in these methods of test. The C289-87 Quick Chemical Test has indicated that all the greywacke tested, including where there has been field occurrence of AAR, would be classed as 'innocuous'. This test method should therefore be considered unsound with this rock type.

Our study of the geographical spread of structures, with good supporting evidence to confirm that the source of the greywacke aggregates was within the locality, supports the findings of the regional study that greywacke alkali reactivity is not related to one geographic area of the UK. However, reactivity also appears not to be related to any easily recognisable geologic or petrographic criteria of the greywacke and in this respect is somewhat of a enigma.

Results from the prism expansion tests on greywacke aggregates broadly support current UK guidance measures for minimising the risk of AAR. However, it should be noted that the alkali threshold for the onset of expansion at 4-4.5 kg/m ^{3} Na_2O_e is significantly less than the threshold for aggregates containing flint-bearing sands and gravels. This might have significance where concrete is placed in extreme conditions. However, it is apparent that to date a low alkali cement ($<0.6\%$ Na_2O_e) would have prevented deleterious effects of AAR.

The results from the trials using cement replacement materials show that these materials are so far having a beneficial effect. *Significant* expansions were only observed when these materials were used to replace opc in concretes where the opc equivalents mixes had alkali values of 6 kg/m^3. The only *deleterious* expansion has been found in cement replacement mixes where opc-only equivalent mixes had alkali values of about 7kg/m^3 (ie fly ash replacing a 450kg/m^3 cement content mix using a cement with 1.15% Na_2O_e with additional K_2SO_4). However, as expansion was first observed in cement replacement specimens after about three years, and as expansions are still continuing some caution is required in interpreting these results.

The data from this study therefore continues to support the current guidance regarding the use of ggbs and fly ash outlined in the Concrete Societies' document[6]. In common with other countries there is only limited field evidence in the UK to validate such laboratory findings. However, the Nant-y-Moch dam as previously reported (Thomas et al. 1992) contains fly ash concrete with a 'reactive' greywacke aggregate combination and even after 35 years, 25% fly ash replacement was sufficient to prevent deleterious AAR. No structures with a ggbs concrete containing a 'reactive' greywacke aggregate has yet been identified.

CONCLUSIONS

Low density regional studies using field and laboratory methods have shown that greywacke alkali reactivity is not restricted to one geographic or geologic province. The survey has shown that approximately half the UK greywacke deposits tested would be considered 'potentially' reactive in use. Results from prism expansion tests indicate that greywackes react at relatively low alkali levels compared to flint. However, use of low alkali cements or with ggbs or fly ash appears beneficial from the results to date but expansions are continuing and final evaluation is not yet possible.

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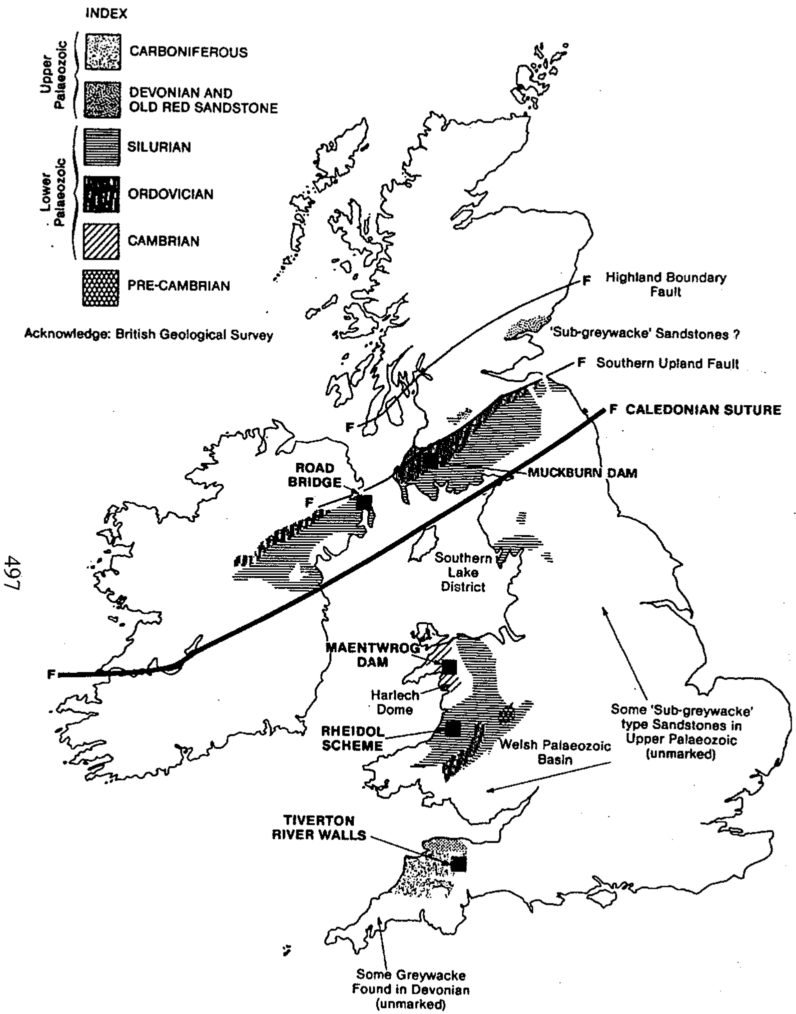

FIGURE 1: Geological map showing strata by geological age where greywacke are found in the UK. Also located are the greywacke containing structures which show distress due to AAR.

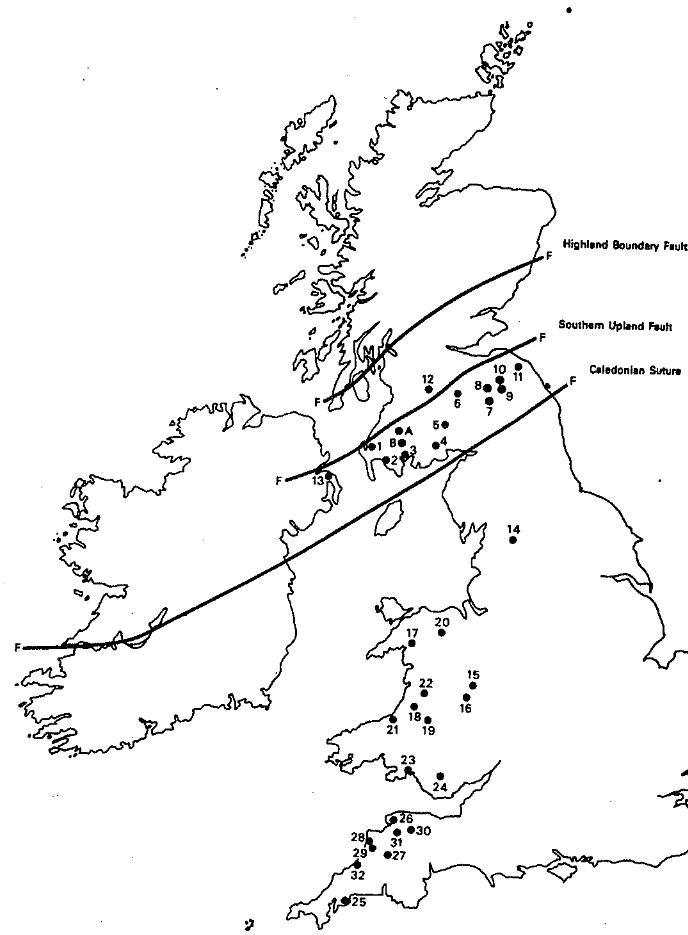

FIGURE 2: Regional survey of UK greywacke, showing sample collection locations (results of laboratory testing of these samples are shown in table 1.)

Sample	ASTM P214 Exp %	BS Prism Test			C289-87	Classification				
		12 m Exp %	30 m Exp %	42 m Exp %	RC:SC	ASTM P214	BS Prism Test			C289-87
							12 m	30 m	42 m	
Scotland and Northern Ireland										
A*1	N/A	0.31	N/A	N/A	N/A	N/A	E	E	E	N/A
B	N/A	0.12	N/A	N/A	N/A	N/A	PE	-	-	N/A
1	0.21	0.19	0.28	0.3	N/A	R	PE	E	E	N/A
2	0.26	0.22	0.35	0.35	N/A	R	E	E	E	N/A
3	0.45	0.18	0.19	0.20	N/A	R	PE	PE	E	N/A
4	0.32	0.15	0.18	0.19	N/A	R	PE	PE	PE	N/A
5	0.15	0.02	0.04	0.05	N/A	I	NE	NE	PN	N/A
6	0.19	0.05	0.008	0.09	N/A	I	NE	PN	PN	N/A
7	0.14	0.06	0.10	0.11	N/A	I	PN	PE	PE	N/A
8	0.11	0.01	0.01	0.02	N/A	I	NE	NE	NE	N/A
9	0.15	0.01	0.04	0.05	N/A	I	NE	NE	PN	N/A
10	0.10	0.005	0.02	0.03	N/A	I	NE	NE	NE	N/A
11	0.13	0.005	0.02	0.03	N/A	I	NE	NE	NE	N/A
12	0.16	0.005	0.03	0.04	N/A	I	NE	NE	NE	N/A
13*2	0.49	0.20	N/A	N/A	113:30.4	R	E	E	E	In
N England and Wales										
14	0.47	0.18	0.18	0.18	44:26.7	R	PE	PE	PE	In
15	0.19	0.04	0.09	0.11	55:32.9	I	NE	PN	PE	In
16	0.20	0.11	0.20	0.21	79:29.4	R	PE	E	E	In
17*3	0.25	0.16	0.16	N/A	36:24.6	R	PE	PE	PE	In
18*4	0.28	0.22	0.25	N/A	51:34.4	R	E	E	E	In
19	0.38	0.25	0.27	0.29	38:33.0	R	E	E	E	?
20	0.27	0.08	0.18	0.19	46:44.3	R	PN	PE	PE	?
21	0.25	0.06	0.11	0.12	78:37.7	R	PN	PE	PE	In
22	0.32	0.20	0.24	0.26	59:48.6	R	E	E	E	?
23	0.18	0.07	0.11	0.12	225:16.7	I	PN	PE	PE	In
24	0.31	0.07	0.09	0.11	146:60.0	R	PN	PN	PE	In
Devon and Cornwall										
25	0.21	0.05	0.06	N/A	67:35.3	R	PN	PN	N/A	In
26	0.06	0.03	0.06	N/A	143:24.4	N/R	NE	PN	N/A	In
27	0.35	0.03	0.06	N/A	100:45.5	R	NE	PN	N/A	In
28	0.11	0.03	0.04	N/A	103:0.6	I	NE	PN	N/A	In
29	0.09	0.02	0.04	N/A	130:190	R	NE	PN	N/A	In
30	0.15	0.31	0.34	N/A	68:43.2	R	E	E	N/A	In
31	0.29	0.30	0.31	N/A	14:58.1	R	E	E	N/A	In
32	0.23	0.05	0.06	N/A	165:34.6	R	PN	PN	N/A	In

N/A = Not Available; I = Inconclusive; N/R = Non-reactive; R = Reactive; In = Innocuous; E = Expansive in use;
PE = Possibly expansive in use; PN = Probably Non-Expansive in use; NE = Non Expansive in use
*1 = Muckburn Dam; *2 = N. I. Road Bridge; *3 = Maentwrog Dam; *4 = Dinas Dam and Nant-Y-Moch Dam (fly ash)

Table 1 Summary of the laboratory test data for the UK Regional Survey of greywacke deposits

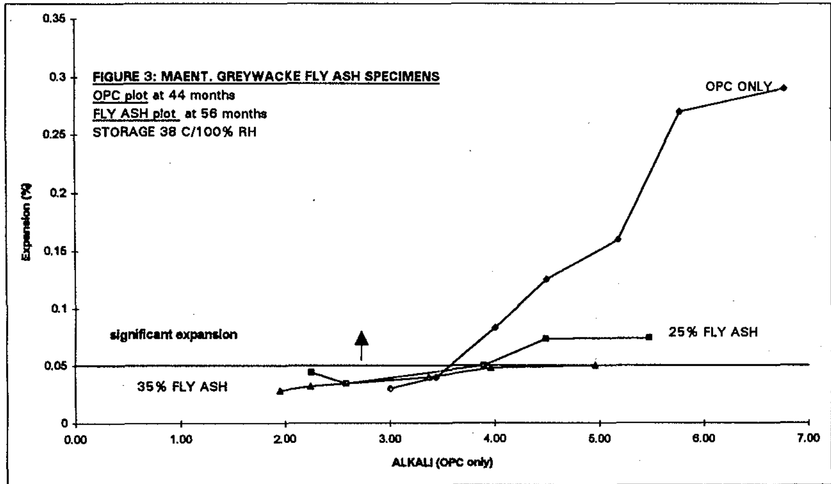
FIGURE 3: MAENT. GREYWACKE FLY ASH SPECIMENS
OPC plot at 44 months
FLY ASH plot at 56 months
STORAGE 38 C/100% RH
OPC ONLY
25% FLY ASH
35% FLY ASH
significant expansion
Expansion (%)
ALKALI (OPC only)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

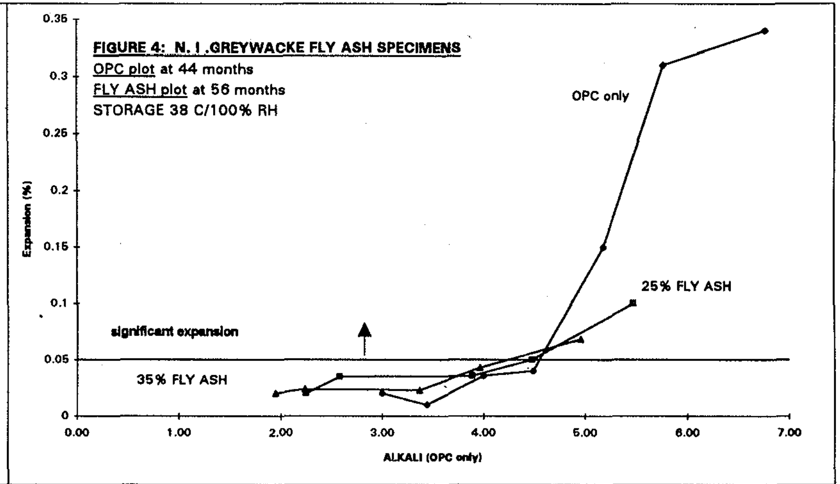
FIGURE 4: N. I .GREYWACKE FLY ASH SPECIMENS
OPC plot at 44 months
FLY ASH plot at 56 months
STORAGE 38 C/100% RH
OPC only
25% FLY ASH
35% FLY ASH
significant expansion
Expansion (%)
ALKALI (OPC only)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

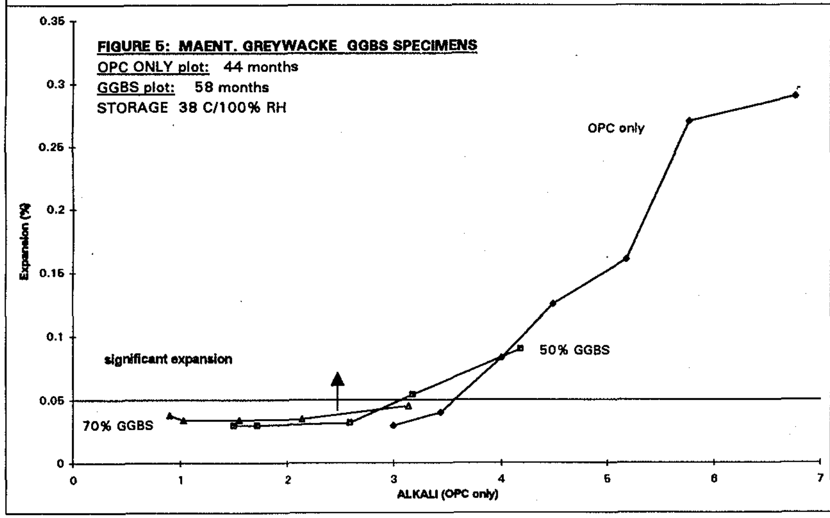
FIGURE 5: MAENT. GREYWACKE GGBS SPECIMENS
OPC ONLY plot: 44 months
GGBS plot: 58 months
STORAGE 38 C/100% RH
OPC only
50% GGBS
70% GGBS
significant expansion
Expansion (%)
ALKALI (OPC only)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7

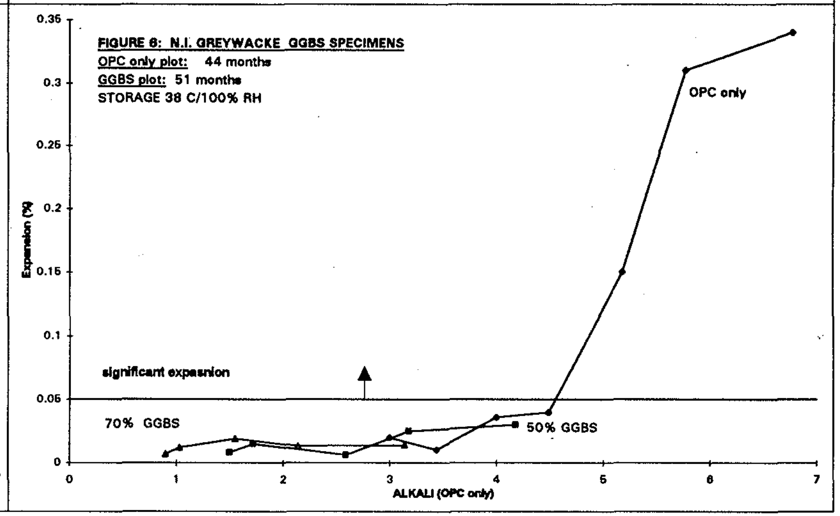
FIGURE 6: N.I. GREYWACKE GGBS SPECIMENS
OPC only plot: 44 months
GGBS plot: 51 months
STORAGE 38 C/100% RH
OPC only
50% GGBS
70% GGBS
significant expasnion
Expansion (%)
ALKALI (OPC only)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7