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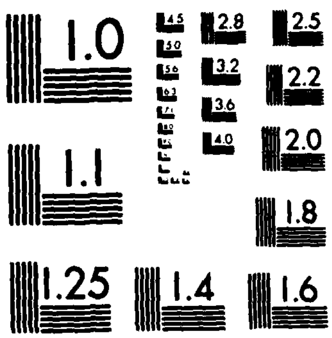

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ALKALI-SILICA REACTION IN CONCRETE FROM FONTANA DAM, NORTH CAROLINA, TENNESSEE VALLEY AUTHORITY

by

Alan D. Buck, Katharine Mather

Structures Laboratory

DEPARTMENT OF THE ARMY
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The Tennessee Valley Authority (TVA) in 1973 requested petrographic examination of several concrete cores from Fontana Dam located in North Carolina to determine whether an alkali-silica reaction had occurred. A petrographic examination was made, and the results of it showed that there was evidence of alkali-silica reaction. While the evidence of reaction was conventional (gel, rims on aggregate particles, cracks), the type of aggregate was not one usually then thought to be reactive. The reactivity of this rock, with one variety variously described as quartzite or feldspathic muscovite schist or metamorphic subgraywacke and another variety as schist or phyllite, was probably due to the presence of large amounts of strained quartz.

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PREFACE

The 1973 work was funded by the TVA, and permission was given by that agency in 1974 for publication to make the results available to a wider audience.

The report is being published due to the continued and increasing interest in the recognition and classification of strained quartz as potentially reactive aggregate material. Some of the concrete thin sections originally prepared for this work were used as part of the basis for a paper on classification of strained quartz to be presented at the 7th International Conference on Alkali-Aggregate Reaction to be held in Ottawa, Canada, 18-22 August 1986.

This report was prepared by Mr. Alan D. Buck and Mrs. Katharine Mather, Concrete Technology Division, Structures Laboratory. Mr. Bryant Mather was the Chief, Structures Laboratory, during the publication of this report.

The funds for publication of this report were provided by the Concrete Technology Information Analysis Center (CTIAC); it is CTIAC Report No. 76.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	by	To Obtain
inches	25.4	millimetres
angstroms	0.1	nanometres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass) per cubic yard	0.59327638	kilograms per cubic metre

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvins (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

ALKALI-SILICA REACTION IN CONCRETE FROM FONTANA DAM, NORTH CAROLINA TENNESSEE VALLEY AUTHORITY

Background

1. A petrographic examination of concrete cores from Fontana Dam was requested by the Tennessee Valley Authority (TVA) to determine if an expansive chemical reaction had taken place. It was suspected that an alkali-silica reaction might have occurred and could be responsible, or responsible in part, for past movement of the structure and for a large crack that had developed apparently at a date fairly recent in years but unstated.

Samples

2. Ten ft of 6-in.-diameter concrete core from core holes 1 and 3 was received on 20 September 1973. An additional 3.1 ft of concrete core from core hole 6 was received in December 1973. Identifying data are shown below:

Concrete Laboratory Serial No.	TVA Designation	Approximate Length, ft	Maximum Aggregate Size, in.	Hole
TVA-9 CON-				
1	WES-1(A)*	2.5	3	3, normal to
2	WES-2(A)	1.5		sloping face of dam at elev.
7	WES-3(C)	2.3		1672 ft in Block 31

Pieces 1(A) and 2(A) fit together and come from the top of the hole; piece 3(C) comes from a spot that is about 6.5 ft below the bottom of piece 2(A). This core is solid, not overcored.

3	WES-1(B)	1	3/4 or 1	1, vertical, top
4	WES-2(B)(1-1)**	1		of dam at elev.
5	WES-2(B)(1-2)**	1		1727 ft in Block 31
6	WES-3(B)(1-3)**	3/4		(in roadway)
8	WES-4**	1-1/2	3	
9	WES-5**	1-1/2		

* The letter designations were added at WES to differentiate between identical TVA identifications.

** All of these pieces had had a 1-1/2-in.-diameter core removed from them before receipt at WES.

Pieces 1(B), 2(B)(1-1), 2(B)(1-2), and 3(B) fit together and come from the top of the hole; pieces WES-4 and WES-5 fit together and come from an area that is about 5.5 ft below piece 3(B).

Concrete Laboratory Serial No.	TVA Designation	Approximate Length, ft	Maximum Aggregate Size, in.	Hole
TVA-9 CON-				
10	Specimen 2**	1	1-1/2	6, vertical, in gallery at elev. 1586 ft in Block 31
11	Specimen 3**	1		
12	Specimen 1**	1	>3	

Specimens 2 and 3 (CON-10 and CON-11) fit together; the top of 2 is about 18 ft below the top of the core at the lower gallery floor; specimen 1 is from an elevation about 8 ft below the bottom of specimen 3.

Test procedure

3. The cores were examined and logged. Each piece of core was then sawed down its axis.

4. Drilled, sawed, and broken core surfaces were examined visually and with a stereomicroscope for evidence of alkali-silica reaction and to determine the characteristics of the concrete. Several sawed surfaces were ground to provide surfaces better suited to this examination.

5. Several thin sections were made from pieces of core from holes 1 (TVA-9 CON-4, 6-8) and 3 (TVA-9 CON-1, 2); these sections were examined with a polarizing microscope.

6. Samples of white porcelaneous material, that was believed to be alkali-silica gel, were carefully removed from voids in the concrete with a dissectin needle; samples of the gel from each core were placed in oils of different refractive indices to make powder immersion mounts, and these mounts were examined with a polarizing microscope.

7. A small composite sample of the white gel was obtained as described above. The sample was ground in a small amount of water and the resulting slurry was placed on a 1/4-in.-wide glass slide to dry; the air-dried film was X-rayed.

8. Rather extensive X-ray diffraction (XRD) examinations were made of selected coarse aggregate particles and of cement paste concentrates from core from TVA-9 CON-1, CON-2, CON-7; the aggregate and paste appeared closely similar to those in the other two cores. Specific details are given below:

a. Portions of eight coarse aggregate particles from piece 3(C) and of one particle from piece 1(A) were ground to pass a No. 325 sieve; these powders were backpacked to minimize preferred orientation and were then X-rayed.

b. Some of the clay-sized material (<2 μm) was separated from portions of the powdered coarse aggregate particles by sedimentation in water. The clay-sized particles were allowed to settle from suspension onto glass slides and to dry there. The resulting oriented clay slides were X-rayed air dry. A second slide of each sample was X-rayed after saturation with glycerol, and a third slide of each sample was X-rayed after saturation with ethylene glycol. One slide was X-rayed while the clay film was still damp from added water.

c. A concentration of cement paste from the top and from the bottom portion of core piece 3(C) was prepared as follows:

(1) Small portions of the core were broken.

(2) The concrete fragments were sieved over a No. 100 sieve to concentrate the cement paste in the sizes finer than the sieve.

(3) The samples of concentrated cement paste were ground to pass the No. 325 sieve and X-rayed as tightly-packed powders.

9. All X-ray patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.

Results

10. Figure 1 is a copy of the TVA sketch which shows core locations in block 31. Figures 2 and 3 are the TVA and WES logs of hole 1 (CON-3-6, 8, 9); figures 4 and 5 are the TVA and WES logs of hole 3 (CON-1, 2, 7); figure 6 is the WES log of hole 6 (CON-10-12). One break in the core from hole 3 appears to antedate drilling. The break at elevation 1567.8 (hole 6) appears to be old; the break at the bottom of specimen 2 from hole 6 (elevation 1557.7 may antedate drilling; the break at the bottom of specimen 3 appears to be fresh.

11. Examination of concrete surfaces revealed the presence of white, porcelaneous material and a clear, solid material in the voids that looked like alkali-silica gel. While it was not rare, and while it was found on sawed surfaces and on transverse breaks made in the laboratory, filled voids were not over 3/16 in. (4.8 mm) in maximum dimension. Some lined but not filled voids were considerably larger. Reaction rims usually quite narrow (~ 1-2 mm) to somewhat wider in the more coarsely clastic rocks were common. The aggregate appears to be composed of two extreme types with an intermediate type which is present in minor amounts. The aggregate was

described in TVA Technical Report No. 12 as "quartzites" and "schists." In TVA Technical Monograph No. 69,[1] June 1953, the schists are referred to as phyllites, while the U. S. Bureau of Reclamation petrographers described the "quartzites" as feldspathic muscovite schist;[1] in the present state of rock names, metamorphic subgraywacke is the name one tends to confer on the basis of composition of the more coarsely clastic rocks with predominant quartz and feldspar and some muscovite and another brown somewhat pleiochroic mica as it appears in concrete. The Bureau of Reclamation petrographers called the dark fine grained rock phyllite. In this report we refer to "quartzite" and "phyllite" for continuity and simplicity. Examination of concrete surfaces showed cracks in a few aggregate particles which required 30X magnification to be detected; some propagated short distances into the paste. Without the presence of the cracks that propagate from rock to paste one would be reluctant to assume that the cracking was related to alkali-silica reaction but the combination, with the presence of rims and clear and porcelaneous gel makes the assumption that the rare thin cracks in the aggregate and paste are related to alkali-silica gel more convincing.

12. The examination of thin sections with a polarizing microscope did not detect the thin reaction rims just inside the outer boundary of aggregate particles which are seen in reflected light. By knowing which aggregate particles had reaction rims, it was possible to examine the rimmed particles. In one case the reaction rim included a large feldspar grain located at the edge of the particle. Since continuous rims were common, probably most of the different minerals in the aggregate occur within some rim.

13. If the amount and distribution of relicts of cement are considered while the sections are examined in plane light, such relicts are moderately abundant and about equally so in all 10 sections. This observation, and the elevations in cores 1 and 3 from which the sections were taken, all suggest that the sections represent similar mixtures of interior concrete. TVA Technical Report No. 12, 1953, says that the cement content of the interior mass concrete ranged from 0.80 bbl (300.8 lb) per cubic yard and W/C = 0.75, but more frequently contained 0.85 (319.6 lb) and sometimes 0.90 bbl (338.4 lb) per cubic yard. This information supports the idea derived from examination of the sections that the cement contents were similar. Table 1 shows that the similarity of the cement content indicated by relicts was not accompanied by the relatively abundant large and relatively evenly distributed $Ca(OH)_2$ crystals characteristic of mature concrete with a fairly high water-cement ratio and a moderate cement content. Instead, there was a deficiency in $Ca(OH)_2$; most of the crystals were unusually small for concrete of the age and water-cement ratio. In unaltered well cured mature mass concrete such as one expects in a dam of this age, rather large calcium hydroxide crystals border aggregate particles and appear as islands between them. In the Fontana sections, with uncommon exceptions (table 1, 3-C), hydroxide bordering aggregate was small, rare, uncommon, skeletal, and in some cases in all sections there were aggregate particles of all types surrounded by paste that did not contain $Ca(OH)_2$. This condition is one evidence of alkali-silica reaction perceptible in thin sections; it confirms the evidence of the widely distributed rims and gel that alkali-silica reaction has taken place.

14. The white gel that was found in some voids in all three cores was more tightly packed into the voids than is usual for alkali-silica reaction gel. However, examination of it in powder immersion mounts indicated that it is alkali-silica reaction gel. It was found to occur in several forms which were similar to gel found associated with an aggregate composed of quartzite and veinquartz in an alkali-silica reaction that occurred in concrete in a dry dock.[2] The following tabulation describes the gel types found in the Fontana cores and their refractive indices.

Gel Type	Refractive Index
Semicrystalline; first order gray birefringence in crossed polarized light.	$n < 1.480$
Salt and pepper type in crossed polarized light.	$1.482 > n < 1.502$
Alternating growth layers of clear and of tan translucent gel; some of the clear material is amorphous.	$1.480 > n < 1.520$

15. In addition to peaks due to small amounts of contamination by calcite and quartz, the X-ray pattern of the composite gel sample showed peaks at the following positions:

d, Angstroms	
11.3	2.90
8.6	2.74
6.6	1.84
5.0	1.82
3.57	1.78
3.29	1.56
3.14	1.55
	1.54

The identity of the crystalline material or materials responsible for these peaks was not determined, but they were essentially the same as found for some of the dry dock gel.[2]

16. The similarity of this gel in appearance, refractive indices, and X-ray pattern to that found in the dry dock concrete[2] is considered to be conclusive proof that it is gel formed by an alkali-silica reaction. The partial chemical analysis in Table 2 supports this concept.

17. Four of the nine aggregate particles that were X-rayed were quartzite and the other five were phyllite. The composition of all nine particles was similar. All of the particles consisted of substantial amounts of quartz, plagioclase feldspar, and muscovite and biotite mica; potassium feldspar and calcite or potassium feldspar or calcite were sometimes present, and there was usually a small amount of kaolin clay; a small amount of 14.5-angstrom chlorite or vermiculite was present in one piece of aggregate; a small amount of amphibole was tentatively identified in several pieces. Small amounts of iron sulfide were detected with the microscopes. Although the two major rock types differed in color and grain size, they were very similar in composition. The similar composition of the major rock types, as well as the rims and the $Ca(OH)_2$ deficiencies around both suggest that the reactivity comes from one or more of the same constituents in both types.

18. One question that has been raised in discussion with TVA engineers, particularly Mr. Bullock, is was reaction present in all of the cores examined here? The answer given was yes, based on the presence of rims and gel in cores from all three of the holes. In the hope of quantifying the differences, if any, in the observed extent of reaction in the several lithologic types, each rock type was counted on nine finely ground surfaces prepared from cores from holes 1 and 3 (Table 3). Table 3 showed that in pieces from hole No. 1 more than half of the quartzite was rimmed but only one piece of the phyllite; in hole 3 slightly less than half the quartzite was rimmed but no phyllite. It then came to mind that this phyllite is a dark rock and the rims perceived had been on broken surfaces and had appeared as color difference and difference in the inclination of the fracture. Kammer and Carlson[3] show a figure from Buck Dam closely resembling the rimmed phyllite in the Fontana cores.

19. Therefore, counts of each rock type, without and with rims, and with rims and associated gel, were made on fresh broken surfaces of all three cores (Table 4). While Table 4 indicates a higher percentage of rimmed phyllite than Table 3, little phyllite is accompanied by gel. The composition of the aggregate in Tables 3 and 4 is compared below:

	Total Aggregate Percent		Percent of Type Reacted
Ground Surfaces			
Quartzite not rimmed	36	72	
Quartzite rimmed	36		50
Intermediate not rimmed	4	4	
Intermediate rimmed	tr		tr
Phyllite not rimmed	23	24	
Phyllite rimmed	1		4
Total	100		
Number of particles counted	199		
Broken Surfaces			
Quartzite not rimmed	20		
Quartzite rimmed	53	79	84
Quartzite rimmed, with gel	6		
Intermediate not rimmed	2		
Intermediate rimmed	2	5	50
Intermediate rimmed, with gel	1		
Phyllite not rimmed	10		
Phyllite rimmed	6	16	38
Phyllite rimmed, with gel	tr		
Total	100		
Number of particles counted	338		

What Tables 3 and 4 and the summary above make clear is:

a. The composition of the aggregate is fairly consistent in these cores.

b. Each lithologic variety is reactive but reactivity as judged by the proportion of each variety showing evidence of reaction is most extensive in the quartzite and least in the phyllite.

20. Figure 1 shows that core hole 1 is at the highest elevation and nearest the upstream face. Core hole 6 is at the lowest elevation and not much farther from the upstream face than core hole 1. Core hole 3 starts at elevation 1675 and dips into the dam normal to downstream surface. TVA Technical Monograph No. 69 shows on figure 27 that normal reservoir levels range from 1590 ft in late December to 1708 ft in May through August. On this basis hole 6 is usually below reservoir level; the same is true of hole 3 on the downstream face; hole 1 starting from the roadway has half or more of its length above normal maximum reservoir level.

21. Gel was not abundant in this concrete but a comparison of gel observed associated with rimmed aggregates, rimmed aggregates without gel, and the sum of the two, all expressed as percentages of total aggregate is of some interest:

Core Hole	With Associated Gel, %	Rimmed, %	Sum, %
1	9	72	81
3	3	68	71
6	13	38	51

While it is assumed that moisture is a necessary participant in the reaction between alkali hydroxyl, and some aggregates, the results above suggest that the concrete from holes 1 and 6 was provided not only with moisture to form rims and presumably expand the coarse aggregate, but had more water available to make visible gel than the concrete in core 3. We cannot advance any reasonable suggestion why the visibly reacted aggregate is so much lower a percentage of the total in core 6, which is also the core in which gel is most abundant.

22. A question worth consideration in terms of future aggregate selection and future treatment of the dam is: Did the alkali-silica reaction, which is present in all the cores from block 31 examined here, contribute to the stress developed, to growth in height, and development of the crack near the curve in the left abutment? Reference (1) pages 230-235 notes that a daily thermal cycle of 40 F produced by solar radiation may cause a maximum stress of 600-800 psi which is relaxed as the temperature decreases; the stress rise is 450 to 500 psi in summer and 300 psi in winter; these are average rather than extreme stresses but probably apply near the surface. Reference (1) also points out that there is a thermal gradient from the warmer downstream to the cooler upstream face. If this represents a situation that continued for several years or to the present, the warmer concrete toward the downstream face would expand and the cooler upstream face contract; if the downstream face ratchets as it lengthens, some of the increase in height and tendency to tilt upstream may be regarded as the result of thermal effects on concrete with a moderate thermal coefficient. While it seems reasonable to believe that thermal influences were active participants in the behavior of the structure, alkali-silica reaction has gone on in block 31 to a greater degree than can be considered innocuous or negligible. To the extent to which expansion caused by alkali-silica reaction was not restrained by the abutments, and by the compressive strength and elastic modulus of the surrounding and overlying concrete, alkali-silica reaction provided an additional expansive force. The magnitude of the expansive force may be judged by the length-change measurements in process at the TVA laboratories. These measurements are most important as predictors of whether additional growth caused by alkali-silica reaction may be expected. It will also be interesting and significant to observe whether or not the length-change specimens develop significant cracking. One of the odd aspects of the concrete examined here is that cracks

not produced in pulling core are few and narrow; only one example was found of cracks in the interior of an aggregate particle and dying out at the rim, which is one characteristic of alkali-silica reaction in relatively unrestrained concrete. The average modulus of the concrete is said to be 5×10^6 psi which suggests that the compressive strength should be at least 5000 psi. It is believed that the restraint of the abutments, foundation, and overlying concrete of essentially structural quality prevented the development of frequent cracks characteristic of less restrained concrete of lower modulus undergoing alkali-silica reaction.

23. A second question, of more than academic importance as it may affect choices of aggregate in future construction is: Why was this aggregate reactive in this structure? Factors that bear on the answer are outlined in the following:

a. Table 1-D from a TVA internal report of April 1946 shows an average alkali content of 0.64 percent as Na_2O from one source of cement and maximum values of 0.71 and 0.75 percent as Na_2O from two others used in the dam.

b. The major constituents of the aggregate are quartz and feldspars (in approximately equal amounts) and the micas, muscovite, and biotite. Minerals that have generally been accepted as reactive with the alkalies in portland cement were not detected.

c. In 1955 L. S. Brown[4] recorded some observations on alkali-silica reaction that appear relevant to the Fontana concrete. Concerning observations on broken surfaces he writes:

> "Across the bottom of Fig. 14 a piece of quartz aggregate is seen. Another piece of quartz is shown in Fig. 15, this one from the same New York concrete shown in Fig. 5. Both of these pieces of quartz show secondary features similar to those seen in the chert."

and of sawed surfaces:

> "Figure 5 is from a 1920 construction in New York. Aggregate is a natural sand and gravel. A particular feature here is that the aggregate is practically wholly quartz. The narrow dark borders can be seen, though less plainly because of the better optical continuity of quartz. Observable displacement is limited to a single crack that passes from one piece of aggregate into another, terminating in both."

d. Buck and K. Mather[2] observed the phenomena Brown discussed in several cores in which no coarse aggregate other than quartzite and vein quartz was detected.

e. Items c and d above are the only two documented and fully straightforward instances of the reactivity of quartz in concretes, believed to have experienced normal temperature regimes, of which we know. The reactivity of silica flour in autoclave products is well known.

f. However, the picture is complicated by the instances of reaction in phyllite[3] and other micaceous rocks.

g. These include Dolar-Mantuani[5] who found reacted argillites in dams 200 miles north of Toronto and verified the reactivity of the argillite by the expansion of mortar bars, in the quick chemical test and by expansion of cylinders. Sand made from graywacke drill cores showed some expansivity in mortar bars. Dolar-Mantuani described the argillites as follows:

"Many thin sections prepared from pieces of the foundation rock and from coarse aggregate in the concrete revealed that the medium dark gray (N4 in the rock-color chart) argillites from the Lady Evelyn Lake area are usually weakly metamorphosed; they consist of quartz, feldspar, sericite, illite and some chlorite probably interlayered with kaolinite. (The micaceous minerals were determined by the X-ray method on the plus No. 30-size fraction of the crushed varved argillite after the coarser grained, mostly greenish varves were eliminated.) The micaceous minerals do not seem to envelop the minute quartz grains completely."

h. Idorn[6] figured several particles of phyllites showing evidence of alkali-silica reaction in concrete showing evidence of reaction; he appears to ascribe the reaction to "soluble silica."

i. Mather[7] stated:

"In 1944 Parsons and Insley[8] reported results of petrographic examination of phyllite from Buck Dam, Va., as 'fine-grained microcrystalline quartz and chalcedony, mica, calcite, and traces of feldspar, chlorite, and limonite.' Later in 1944, Bean and Tregoning[9] reported studies of reactivity of aggregate constituents in alkali solutions and one of the materials that they studied was phyllite from the Buck Dam. They reported that it exhibited little reactivity in their study. My discussion of this paper[10] reviewed the information on the nature and reactivity of various forms of silica.

"In 1948 Kelly et al[11] reported results of mortar-bar tests of a variety of materials, again including the Buck Dam phyllite. They reported excessive expansion only when KOH was added to the mortar in which this aggregate was used; but only slight expansion when no additions were made."

j. Gillott, Duncan, and Swenson discussed reactions in concrete in Nova Scotia[12]: The main alkali-expansive rock types of Nova Scotia are of sedimentary origin: greywackes, argillites, and phyllites. These rocks contain little or no opal, vitreous silica or volcanic glass. Fine quartz, which is a common constituent, frequently showed signs of strain, inclusions, intergrowth and sutured boundaries. The resulting defect molecular packings on the surface probably constitute a significant proportion of the total quartz volume. Although such material may be a causative agent of expansive alkali-silica reaction this has yet to be demonstrated through experiment. This fine quartz is the only mineral present in significant quantity, however, that can be related to the reactive component of the classical alkali-silica aggregates. Gillott et al noted various differences in test behavior from more customary alkali-silica reactive materials and suspected the mechanism differed. They determined the effect on diffraction patterns of rock wafers of phyllite made before and after immersion in 2M NaOH for various periods to be the expansion of 10-A micas to about 12.6A, and interpreted this effect as removal of interlayer material in the mica of the phyllite, allowing the mica to swell to an unlimited extent as it imbibed water. This hypothesis may be valid for the phyllites these authors studied but it is not completely satisfactory for the Fontana aggregates because the so-called quartzite (metamorphic subgraywacke) is more reacted, and thus presumably more reactive, than the phyllite.

k. Dr. Mehta[13] has examined some of the Fontana cores and noted exfoliation of the phyllites in scanning micrographs, but regards the basis for swelling in phyllite as similar to that of other permeable solids having high internal surface and poor intercrystalline bonding.

24. Summary.

a. All of the cores from Fontana Dam examined here have undergone alkali-silica reaction, demonstrated by rims formed on crushed stone, the production of gel, and rarely, the development of microfractures in the quartzite (metamorphic graywacke) coarse aggregate projecting into the paste.

b. It is our opinion that the rarity of microfractures, which are common in much concrete affected by alkali-silica reaction, results from the high modulus and strength of the concrete which restrained some of the volume change and formation of cracks in most of the aggregate and mortar.

c. Since the TVA has the results of other tests on concrete from Fontana, TVA engineers are better able than we, since we have less information, to judge the importance of alkali-silica reaction in the development of the large crack near the curve in the dam. We believe that alkali-silica reaction contributed to the expansion of the structure to the extent that the reaction overcame the restraint but are not in possession of information that would establish whether it played a significant role.

d. Probably the most important predictive tests on the future behavior of the dam are length-change tests of cores or sawed prisms stored at 100% RH and temperatures similar to thosethat can exist in the dam. Acceleration of the test by raising the storage temperature to 100 F will increase speed with which the results become available without serious danger of changing the mechanism and producing a misleading result.

e. No positive statements are made on the reactive constituents of the aggregates. While some quartz, usually strained, is reactive in some circumstances[2,14] the features of the quartz or the environment that make this so are not established. The mica in the Fontana aggregates appeared to be normal and the question of the reactivity of mica is not yet entirely clear.

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8. W. H. Parsons and Herbert Insley, Jour. American Concrete Institute, 40, p 229, 1944.

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14. K. Mather, "Examination of Cores from Four Highway Bridges in Georgia," Sponsored by The Georgia Department of Transportation, Miscellaneous Paper C-73-11, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1973.

Table 1

Fontana Thin Sections

Hole	Section	Description
3	1-A-1	Probably interior concrete. Residual cement abundant but like the others. Deficient in $Ca(OH)_2$ by comparison with residual cement and especially so around some aggregate particles, both quartzite and phyllite.
3	1-A-2	Like 1-A-1; both from elevation about 1 ft in from and normal to face of core started at elevation 1672.
3	2-A-1 2-A-2	Depth 2.40 - 2.50. Both show too few small and skeletal $Ca(OH)_2$ remains to agree with the relative abundance of residual cement.
3	3-C	Elevation 10.4 - 10.85 in hole. Unhydrated relicts as in previous.
	3-C-2	$Ca(OH)_2$ reworked and recrystallized to smaller crystals; some deficiencies in hydroxide but also some long typical crystals along borders of aggregate.
1	2-B	Depth 1.0 - 1.2 ft. Partly recrystallized fine-grained $Ca(OH)_2$ and some deficiencies in $Ca(OH)_2$.
1	3-B	Depth 3.15 - 3.55. Resembles 2-B; deficient in $Ca(OH)_2$.
1	4-1	Depth 9.1 - 9.5 ft. Similar to two previous.
1	4-2	ditto

Table 2

Chemical Analysis of Gel from Cores from Fontana Dam

	Percent
Loss on ignition at 550 C	24.80
CaO	4.76
K_2O	6.68
Na_2O	6.75
SiO_2	50.70
Sum	93.69

Weight of sample from all three cores = 0.0161 g

Calculated formula: $1.6\ Na_2O \cdot 1.0\ K_2O \cdot 1.2\ CaO \cdot 12\ SiO_2 \cdot 20\ H_2O$

Table 3

Reacted Aggregate on Sawed Surfaces

Hole No.	Depth ft	Piece No.	Quartzite	Quartzite Rim	Ground Sawed Surfaces: Intermed.	Intermed. Rim	Phyllite	Phyllite Rim	Total
1	2.5	2B	10	8	1	-	4	-	23
	3.0	3B	5	9	3	-	2	-	19
	9.2-9.8L	4	7	9	-	-	5	-	21
	9.8H	4	11	9	-	-	3	-	23
	11.1	5	6	8	1	-	3	1	19
TOTAL			39	43	5	-	17	1	105
%			37	41	5	-	16	1	100
3	1	1A	4	9	3	1	9	-	26
	2.3	1A	15	4	-	-	8	-	27
	3	2A	5	7	-	-	5	-	17
	10.4-10.9L	3C	9	8	-	-	7	-	24
TOTAL			33	28	3	1	29	-	94
%			35	30	3	1	31	-	100
			Summary						
1			37	41	5	-	16	1	
3			35	30	3	1	31	-	
TOTAL %			36	36	4	tr	23	1	100

Table 4

Reacted Aggregate and Gel on Broken Surfaces

Hole No.	Piece No.	Quartzite			Intermediate			Phyllite			Total
		—	R*	R&G*	—	R*	R&G*	—	R*	R&G*	
1	1B	3	10	6	1	1	-	1	3	-	25
	2B	2	21	4	1	2	-	1	5	-	36
	3B	2	18	2	-	-	-	-	6	-	28
	4	1	15	-	-	-	-	2	-	-	18
	5	7	13	-	1	-	-	2	-	-	23
TOTAL		15	77	12	3	3	-	6	14	-	130
%		12	59	9	2	2	-	5	11	-	100
3	1A	13	48	-	2	2	-	5	8	1	79
	2A	3	7	1	-	-	-	-	-	-	11
	3C	4	9	-	-	-	-	5	-	-	18
TOTAL		20	64	1	2	2	-	10	8	1	108
%		18	59	2	2	2	-	9	7	1	100
6	2	10	19	2	-	-	2	2	-	-	35
	3	9	9	7	2	-	-	6	-	-	33
	1	13	11	2	-	-	-	9	-	-	35
TOTAL		32	39	11	2	-	2	17	-	-	103
%		31	38	11	2	-	2	16	-	-	100
					Summary						
1		12	59	9	2	2	-	5	11	-	100
3		18	59	2	2	2	-	9	7	1	100
6		31	38	11	2	-	2	16	-	-	100
TOTAL		67	180	22	7	7	2	33	22	1	341
%		20	53	6	2	2	1	10	6	tr	100

*R = rim; R&G = rim with gel.

SUBJECT Location of Conc Holes for USBR PROJECT Fontana Dam

Stress Analysis

COMPUTED BY JWC DATE 7/17/73 CHECKED BY DATE

Notes:

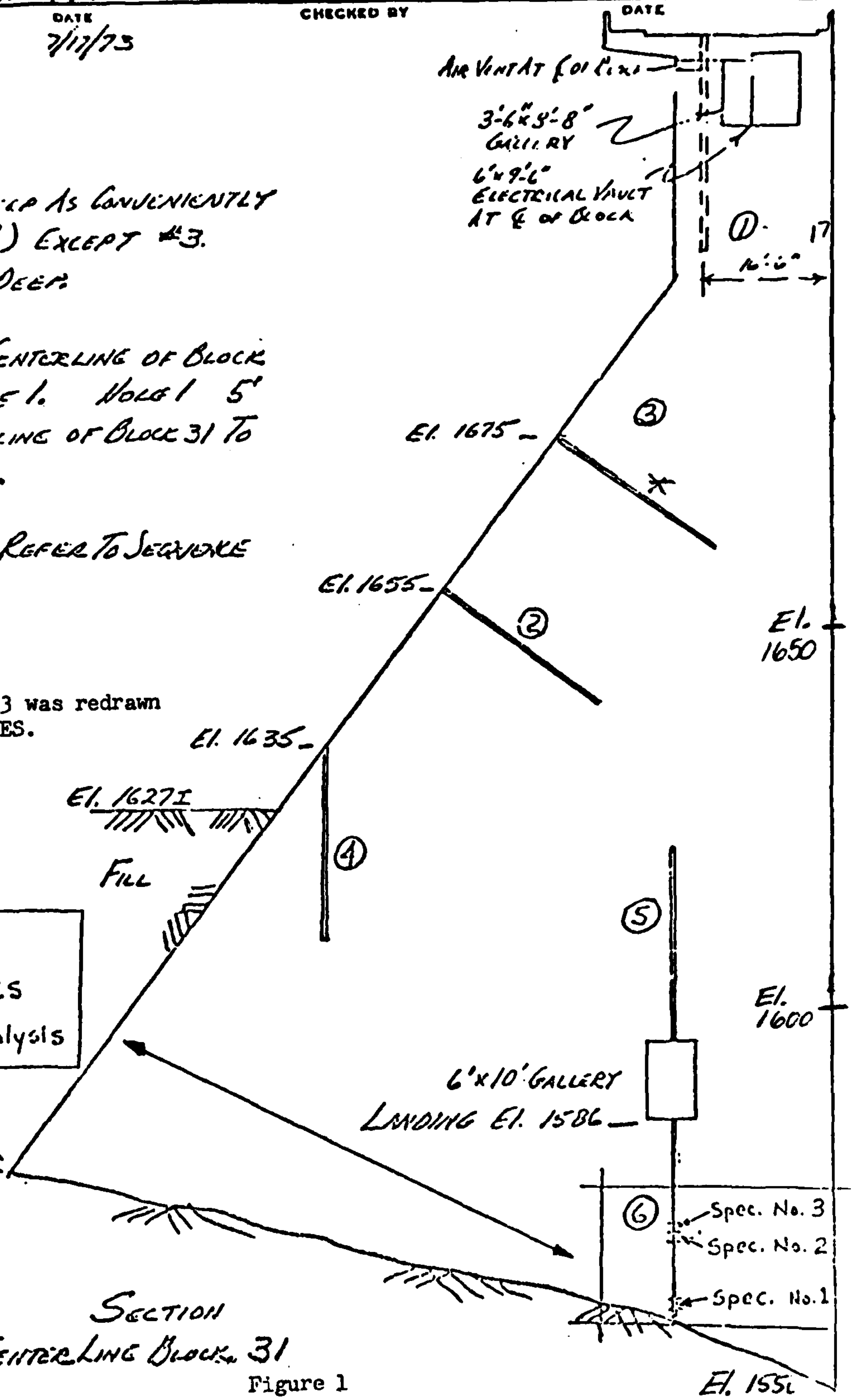
1. All Holes As Deep As Conveniently Possible (30'±?) Except #3. Hole #3 25' Deep.

2. All Holes On Centerline of Block 31 Except Hole 1. Hole 1 5' West of Centerline of Block 31 To Miss Air Vent.

3. Hole Numbers Refer To Sequence of Drilling

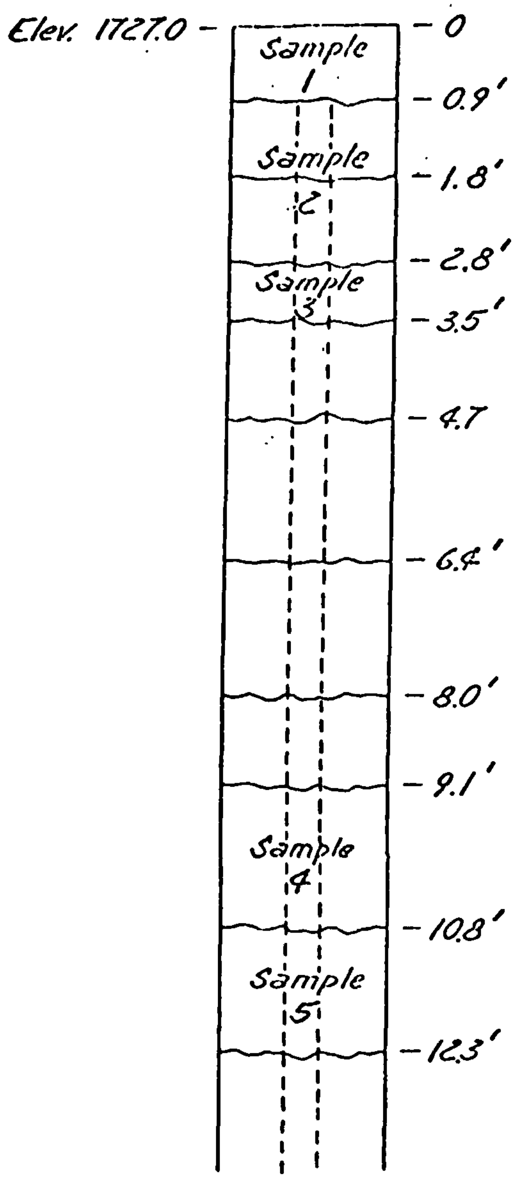
*The slope of core 3 was redrawn to correct it by WES.

12-10-73
Sent 3 cores to WES for petrographic analysis



Section
CenterLine Block 31

Figure 1



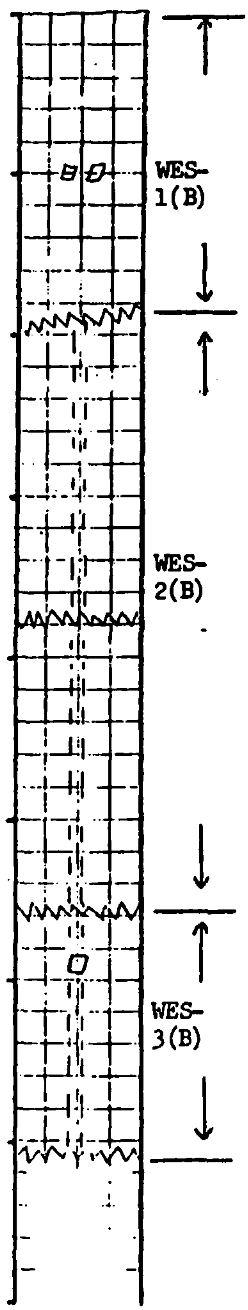
HOLE 1

Figure 2

Note: Boring drilled normal to top surface of dam

FONTANA DAM
BLOCK 31 ℄
6 INCH OVERCORE SAMPLES
TENNESSEE VALLEY AUTHORITY MATERIALS ENGINEERING LABORATORY
SUBMITTED r.l.l. — RECOMMENDED — APPROVED
[illegible]

LOG OF 6-IN. DIAMETER TVA CONCRETE CORE NO. 1
FROM BLOCK 31, FONTANA DAM



Depth, ft	Field No.	CL Serial No.	
0	WES-1(B)	TVA-9 CON-3	Top is formed surface, elev. 1727 ft. All breaks in this core are fresh. The top 4 pieces of core contain 3/4 or 1-in. maximum-size aggregate. Two rebars at ~ 1/2 ft.
1	WES-2(B)	4	A 1-1/2-in. diameter core hole starts with piece 2(B) and continues to the bottom of this core.
2		5	Some void fillings of white gel and rimmed aggregate particles were visible when core was sawed along its axis.
3	WES-3(B)	6	Rebar at ~ 3 ft.

Vertical Scale: 1 square = 0.1 ft

Figure 3

TVA CORE 1 (CONTINUED)

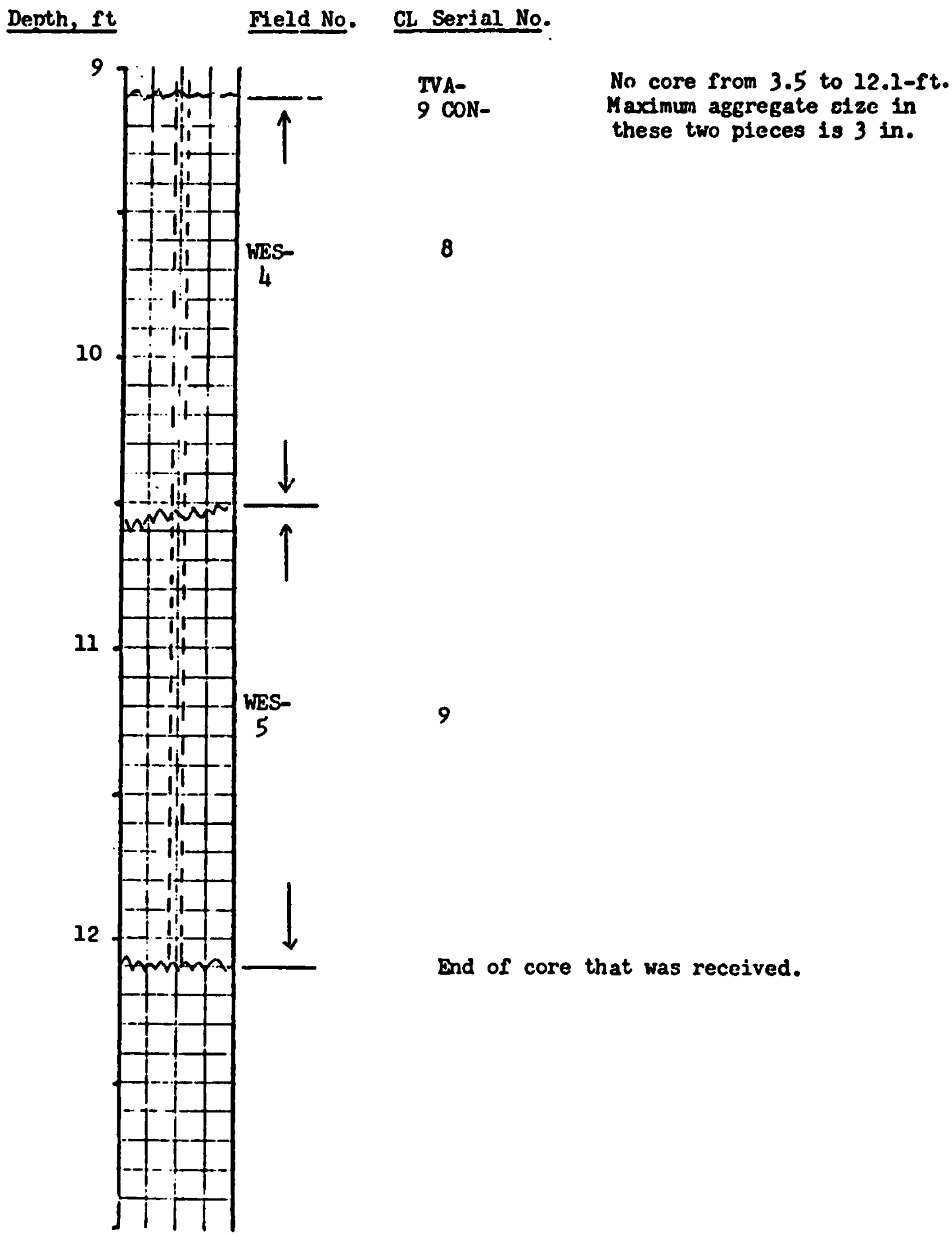
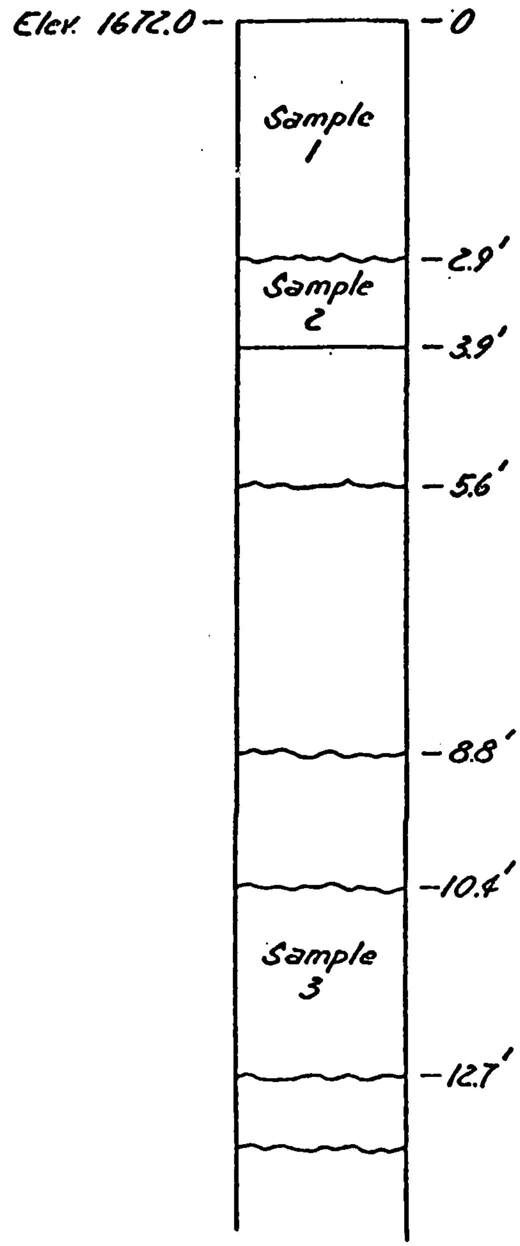


Figure 3 (continued)



Hole 3

Figure 4

Note: Boring drilled normal to downstream face of dam

FONTANA DAM

BLOCK 31

6 INCH SOLID CONCRETE CORES

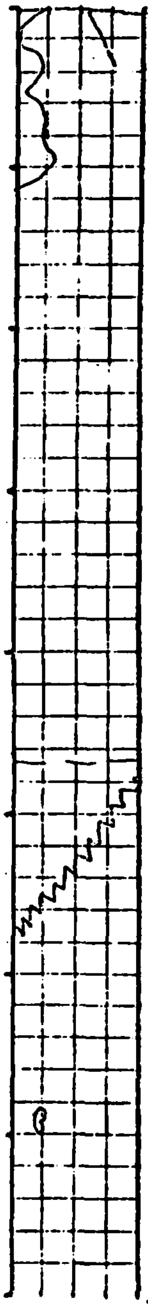
TENNESSEE VALLEY AUTHORITY
MATERIALS ENGINEERING LABORATORY

SUBMITTED rlk	RECOMMENDED	APPROVED
KNOXVILLE		

LOG OF 6-IN. DIAMETER TVA CONCRETE CORE NO. 3
FROM BLOCK 31, FONTANA DAM

Depth, ft | Field No. | CL Serial No.

0



TVA-
9 CON-

Top of core is formed surface; elev. 1672 ft. Entire core contains 3-in. maximum size aggregate.

Old vertical crack for ~first half ft.

1

WES-
1(A)

1

Some void fillings of white gel and rimmed aggregate particles were visible when core was sawed along its axis.

2

Old diagonal break.

3

WES-
2(A)

2

4

Sawed surface

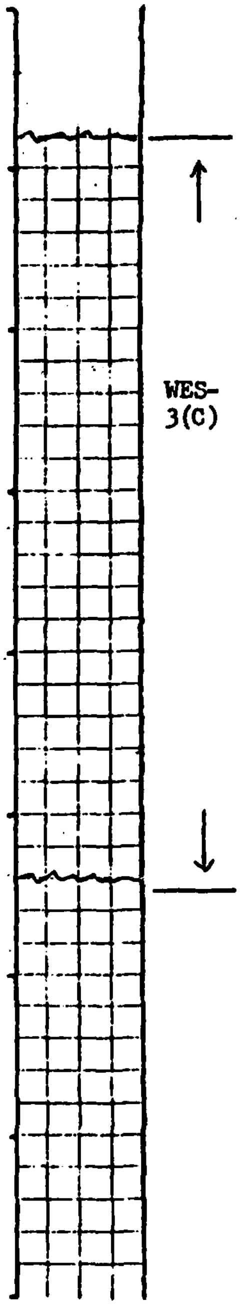
Vertical Scale: 1 square = 0.1 ft

Figure 5

TVA CORE 3 (CONTINUED)

Depth, ft | Field No. | CL Serial No.

10



No core from 4.0 to 10.4 ft.
Break is fresh.

11

WES-
3(C)

TVA-
9 CON-
7

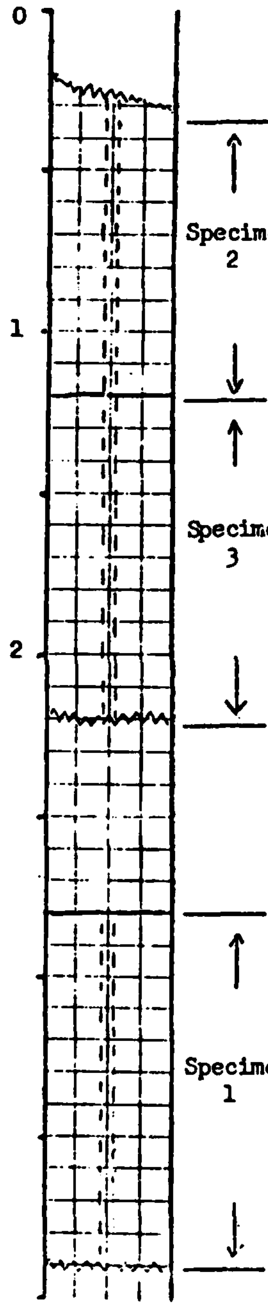
12

Fresh break. End of core that was received

Figure 5 (Continued)

LOG OF 6-IN. DIAMETER TVA CONCRETE CORE NO. 6,
BLOCK 31, FONTANA DAM

Depth, ft | Field No. | CL Serial No.



TVA 9 CON-

Upper break at elev. 1567.8 (18.2 ft below gallery floor) appears to be old.

Specimen 2 — 10

Sawed

The maximum aggregate size in pieces 2 and 3 is 1-1/2 in.; it is 3 in. in piece 1. A 1-1/2-in. diameter core hole extends through all 3 pieces.

Specimen 3 — 11

Break at 1565.8 may antedate drilling. No core from the interval 1565.8 ft to 1557.7 ft was furnished.

Sawed

Some void fillings of white gel and rimmed aggregate particle were visible when the core was sawed along its axis.

As marked by TVA this was wrong end up. Break at bottom is fresh.

Specimen 1 — 12

End of core that was received

Figure 6 Vertical Scale: 1 square = 0.1 ft

END
10-86
DTIC