STUDIES OF CERTAIN SIERRAN CONCRETE AGGREGATES

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ABSTRACT

The purpose of this investigation has been to understand more fully the behavior of certain Sierran rocks when used as concrete aggregate. The granodioritic aggregate used in the construction of the Florence Lake Dam was selected for detailed examination.

Two lines of attack to this problem have been followed. The aggregate was quantitatively separated into rock types, and these were then studied petrographically to determine the mineralogical composition, with particular emphasis being placed on the alteration products present in the rocks. The other phase of the investigation was the separation of the aggregate into its major mineral constitutents, in order to test the behavior of these isolated constituents as aggregate in mortar bars. Since the length changes of the mortar bars are to be observed over a two year period, only preliminary results can be reported at this time.

On the basis of the known behavior of minerals, the only constituent present in the granodioritic aggregate which might be suspected of causing trouble is a zeolite, a hydrous sodium and/or calcium aluminum silicate. The peculiar property of base exchange whereby the sodium or calcium content of the molecule may be easily exchanged for the other element is worthy of attention in a problem as intimately connected with alkali content as are many concrete failures. The bulk percentage of this hydration product of plagioclase feldspar is

certainly not more than several per cent of the aggregate.

To separate the mineral constitutents of the Florence Lake Dam aggregate, about 500 pounds of fresh appearing rock was milled. Combinations of the separatory processes of sizing, tabling, magnetic concentration, and heavy liquid concentration yielded the following mineral concentrates:

Potash feldspar - 97 per cent purity
Quartz + plagioclase - 53 and 43 per cent respectively,
yielding a combined purity of 96 per cent
Biotite - 96 per cent purity
Hornblende - 98 per cent purity
Magnetite - 98 per cent purity
Sphene, apatite, and zircon - 89, 5, and 4 per cent respectively, yielding a combined purity of 98 per cent

These concentrates, mixed with different amounts of inert quartz, were used as aggregate for mortar test bars. Each aggregate mixture was fabricated with high and low alkali cements, and triplicate bars made for each condition. The mortar test bars are as follows:

Mineral concentrate	Per cent of mineral concentrate in aggregate					
Potash feldspar	2	5	10	25	50	100
Quartz + plagioclase		5	10	25	50	100
Biotite	2	5	10	25	50	100
Hornblende	2	5	10	25	50	
Magnetite	2	5	10	25		
Sphene, etc.	2	5	10			
Fresh "granodiorite"						100
Altered "granodiorite"					50	100
Siliceous magnesian limestone				20		

All bars are curing at a temperature of 100° F. in a sealed chamber containi g moisture. Length measurements to 0.001 mm. were made at weekly intervals for the first month, and then the interval increased to one month. In June 1943 the bars range in age from one to four months.

So far, none of the bars made from granodioritic materials has shown excessive expansion, or even significant expansion. The highest expansion so far with these materials is about 0.04 per cent, as contrasted to an expansion of 0.22 per cent for the high alkali cement and siliceous magnesian limestone aggregate. Graphs have been made recording all expansions of the 200 bars up to June 3, 1943.

RECOMMENDATIONS

1. The length measurement program should be continued as planned for the full two years. The monthly measurement interval might be increased to two months if all the expansion-age curves flatten out in time.

2. If possible, restrict the usage of granodioritic aggregates in the Big Creek area until the results of the current testing program are known. If necessary to use any of these aggregates, select only the freshest rock types, and reject the fines resulting from crushing the aggregate.

3. The behavior of the zeolite found in minor quantities at the Florence Lake Dam aggregate stock pile should be tested by using it as aggregate for mortar test bars. The only way to achieve a concentration of this mineral is by hand-picking some of the remaining aggregate for rock fragments containing veinlets of this light salmon colored mineral. One of these fragments is submitted with this report. Careful chipping of the rock fragments should yield a concentrate with at least 10 per cent of the zeolite. Crush this to - 10 mesh and mix with different amounts of inert quartz to yield three aggregate mixtures with a zeolite content of 1, 5, and 10 per cent. Fabricate each aggregate mixture with a high and a low alkali cement.

   Should the zeolite prove to be the deleterious constituent of the aggregate, a quantitative determination of this mineral in future aggregate would be invaluable. The base exchange property of zeolites is utilized in water softening processes, and it might be possible to at least semi-quantitatively soften water and obtain rapid determinations of the zeolite content of a crushed rock sample.

4. Should any of the bars show excessive expansion, petrographic investigations should be made with a view to determining the mechanism of the reaction involved.

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ILLUSTRATIONS

INTRODUCTION

The purpose of this investigation is to understand more fully the behavior of certain Sierran rocks when used as concrete aggregate. The concrete used in several of the hydroelectric dams of the Southern California Edison Company in the Big Creek-San Joaquin Development area (Plate 1) has shown signs of partial failure. The aggregate which was used in these structures is similar to rock types long employed successfully for concrete aggregate. However, the nature and the distribution of the faulty concrete throws suspicion on the aggregate in the concrete rather than on the physical environment of the structure.

The aggregate which was used in the Florence Lake dam was selected for detailed examination. The concrete in this structure, built in 1926, has notably deteriorated and resurfacing has been necessary. Plate 2 shows two portions of this dam. A close up of some of the concrete which is badly deteriorated and covered with exudations of alkaline salts and calcium carbonate is shown in Plate 3B.

The study of the Florence Lake dam aggregate has been along two principal lines. The aggregate has been separated into rock types and petrographic analyses made of each type. Particular emphasis has been placed on the alteration products present in the rocks. The other line of attack has been to separate the aggregate into its mineral constituents in order to test the behavior of these isolated constituents when used as aggregate for mortar test bars. Length measurements of these bars, approximately 200 in all, are to continue for two years. In this respect, this report is strictly preliminary.

This work has been made possible by a research fellowship sponsored by the Southern California Edison Company at the California Institute of Technology, and has been under the guidance of the Division of Geological Sciences. I wish to express my appreciation to both groups for the very fine cooperation given me throughout this work. Particular thanks are due Mr. R. W. Spencer of the Edison Company and Dr. Ian Campbell of the California Institute of Technology for outlining this research work, and for the many helpful suggestions throughout the course of the investigation. Mr. Rudolf von Huene of the California Institute of Technology deserves no end of credit for the generous contribution of his time and ingenuity in solving many of the mechanical problems encountered. The U. S. Bureau of Reclamation at Denver has kindly made available the results of their extensive aggregate testing program, and has supplied the inert quartz aggregate used in the test bars.

LOCATION

The Big Creek-San Joaquin River hydroelectric development area lies about 50 miles east-northeast of Fresno, California, in the northeastern part of Fresno County. The power development structures of this project range in elevation from 1400 feet on the San Joaquin River at the base of the Sierran slope to over 7300 feet at Florence Lake. The Florence Lake area is of particular interest since it furnishes the aggregate which is being investigated in the testing program. The Florence Lake dam lies across the South Fork of the San Joaquin river at an elevation of 7328 feet in sec. 36, R. 27 E., T. 7 S., Mt. Diablo meridian and base line.

GENERAL SIERRAN GEOLOGY

The Big Creek area lies near the center of the southern half of the great Sierra Nevada block of crystalline rocks which separates the Great Valley of California from the Great Basin for over 400 miles in a north-south direction.

The bulk of this westward tilted mountain mass is composed of genetically related intrusive rocks. The other rocks are composed of steeply dipping lenses and septa of metamorphosed sediments and volcanics, and of relatively flat deposits of younger volcanic rocks.

The known geologic history[1] of the Sierra Nevada

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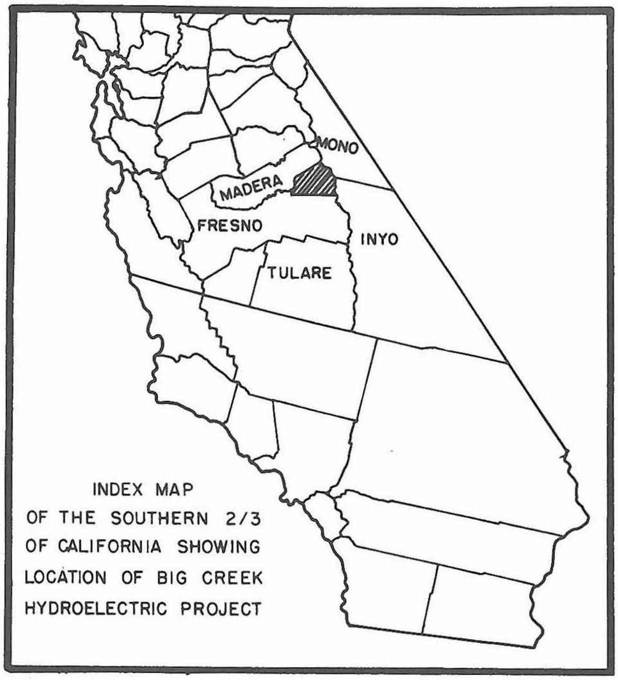
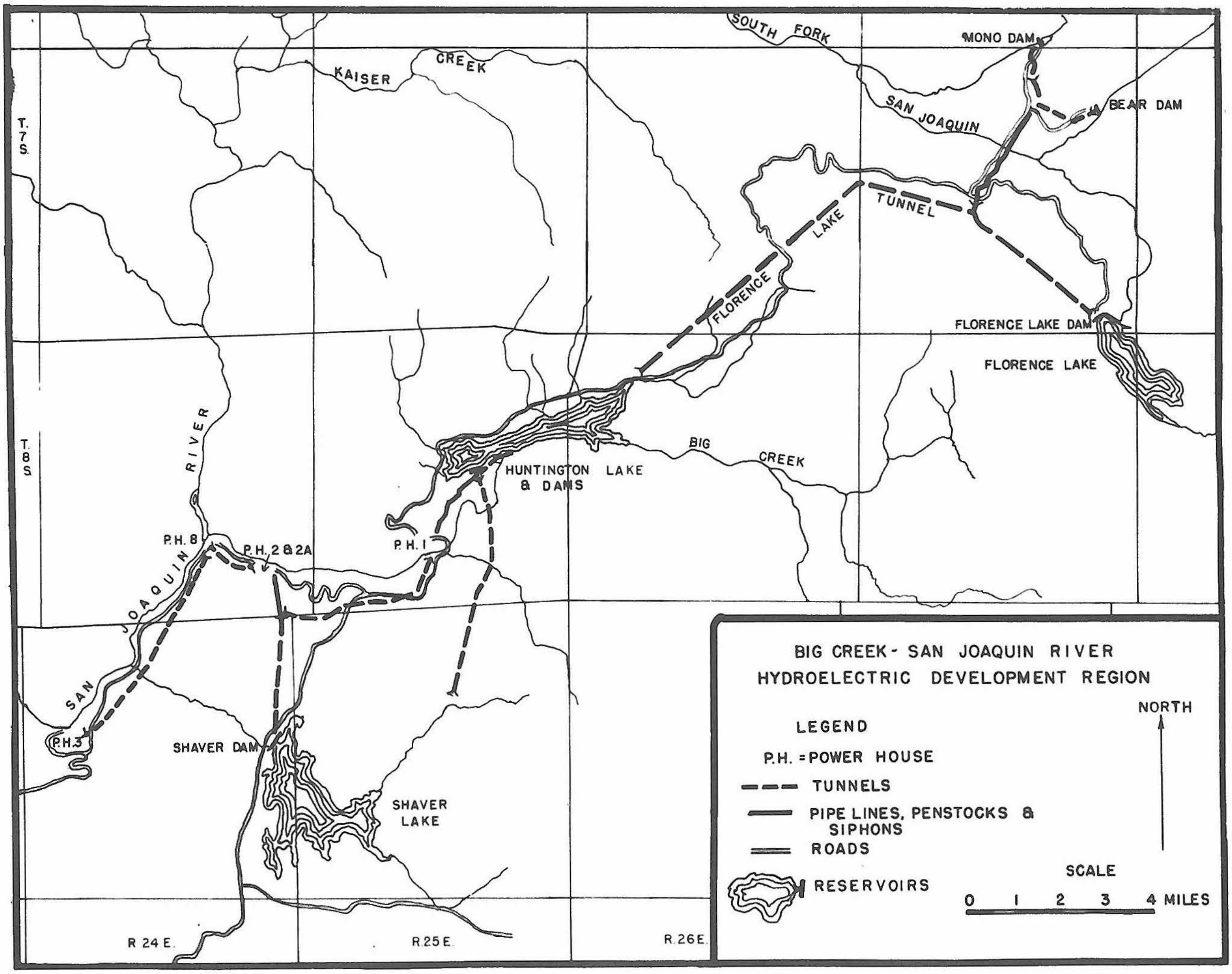
[1] Lindgren, W., The Tertiary Gravels of the Sierra Nevada, U. S. G. S. Prof. Paper 73, pp. 9-10, 1910.

Matthes, Francois, Geologic History of the Yosemite Valley, U. S. G. S. Prof. Paper 160, 1930.

Plate 1


MONO
MADERA
FRESNO
INYO
TULARE
INDEX MAP
OF THE SOUTHERN 2/3
OF CALIFORNIA SHOWING
LOCATION OF BIG CREEK
HYDROELECTRIC PROJECT

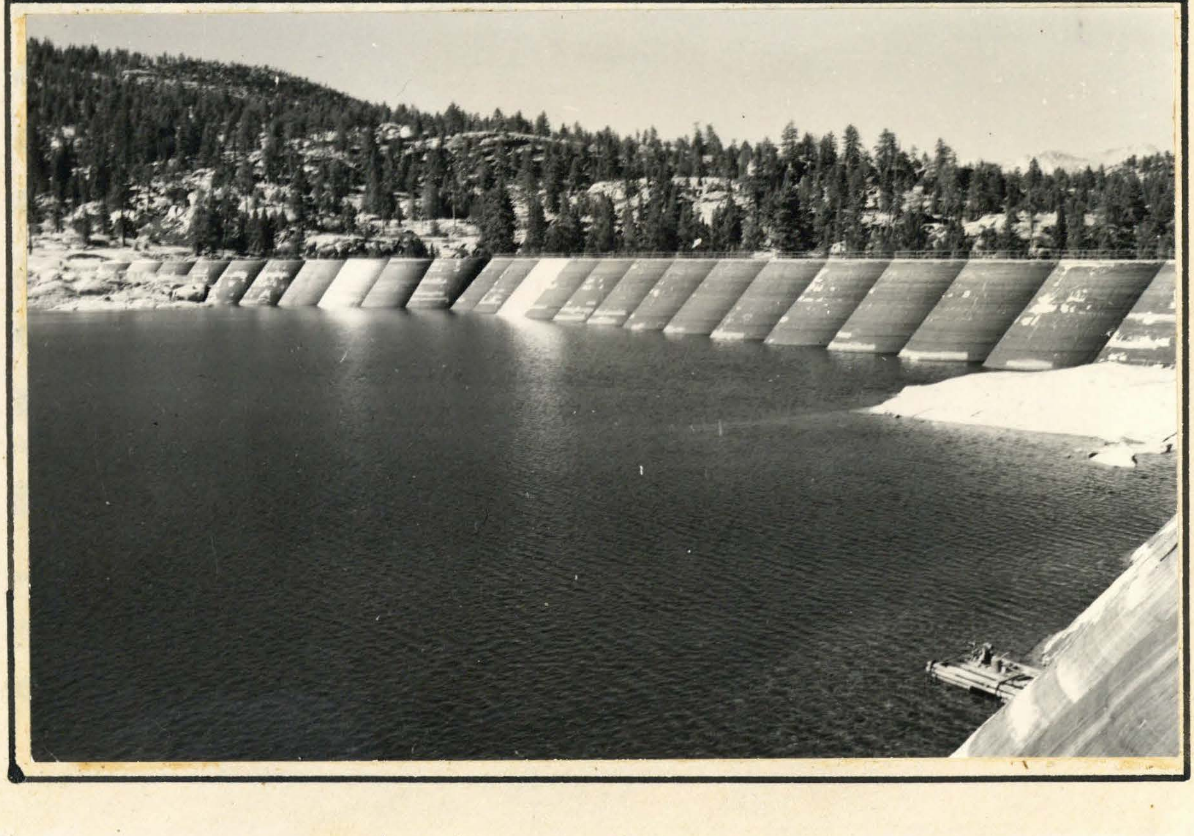

SOUTH FORK
MONO DAM
KAISER CREEK
SAN JOAQUIN
BEAR DAM
T. 7 S.
TUNNEL
LAKE
FLORENCE
FLORENCE LAKE DAM
FLORENCE LAKE
T. 8 S.
RIVER
BIG CREEK
HUNTINGTON LAKE & DAMS
P.H. 8
P.H. 2 & 2A
P.H. 1
SAN JOAQUIN
P.H. 3
SHAVER DAM
SHAVER LAKE
R 24 E.
R.25 E.
R.26 E.
BIG CREEK - SAN JOAQUIN RIVER
HYDROELECTRIC DEVELOPMENT REGION
LEGEND
P.H. = POWER HOUSE
TUNNELS
PIPE LINES, PENSTOCKS & SIPHONS
ROADS
RESERVOIRS
NORTH
SCALE
0 1 2 3 4 MILES

begins in early Paleozoic time with the deposition of marine sediments. The deposits were uplifted and folded into mountain ranges at the close of the Paleozoic period. The mountains were gradually worn down and submerged with the marine deposition of both Triassic and Jurassic sediments. Near the end of the Jurassic period, intense diastrophic activity resulted in parallel northwest-trending crumpled folds. A late feature of the diastrophism was the introduction of enormous volumes of igneous rocks. All variations of igneous rock types from the basic gabbros to the most acidic granites are represented. In general, the successive intrusions became progressively more acidic. Volumetrically, quartz monzonite is the dominant intrusive rock, with granodiorite being the next most important type.

In Cretaceous time, the mountains were stripped off, exposing the intrusive rocks over wide areas. The Tertiary was a time of considerable volcanic activity -- flows blanketing local areas and being at least partially removed by erosion before succeeding flows appeared. Near the close of the Tertiary period, the present crystalline mass was delimited by the vigorous upward faulting on the eastern side, resulting in the present westward tilted mountainous block. The higher portions of the mass were subjected to several stages of mountain glaciation during the Pleistocene. This produced the dazzling expanse of bare rock surfaces so characteristic of the High Sierra. Plate 4A shows this

Plate 2

A. Eastern end of Florence Lake Dam



B. Western end of Florence Lake Dam

carved surface just northeast of Florence Lake.

The formerly extensive glaciers are now but feebly represented in a few isolated areas. Since their retreat, the processes of weathering have gone on to only a superficial degree.

FLORENCE LAKE DAM AGGREGATE

The rock composing the Florence Lake Dam was taken from material excavated in driving the Florence Lake Tunnel, which connects the Florence Lake Reservoir with Huntington Lake. Only the rock excavated from the easternmost two and one-half miles was utilized in the dam. (See Plate 1).

A geologic investigation of the tunnel walls of the critical section is impossible, and only general geological data was gathered at the time the tunnel was driven. Only 9 per cent of the tunnel required lining, which testifies to the physical stability of the wall rock. Although the bulk of the rock is igneous, some metamorphic rock was encountered. The following metamorphic rocks have been reported present at the upper dump at Florence Lake[2]: quartzite, hornblende-biotite schist, biotite schist, diopside gneiss and magnetite gabbro. None of these types

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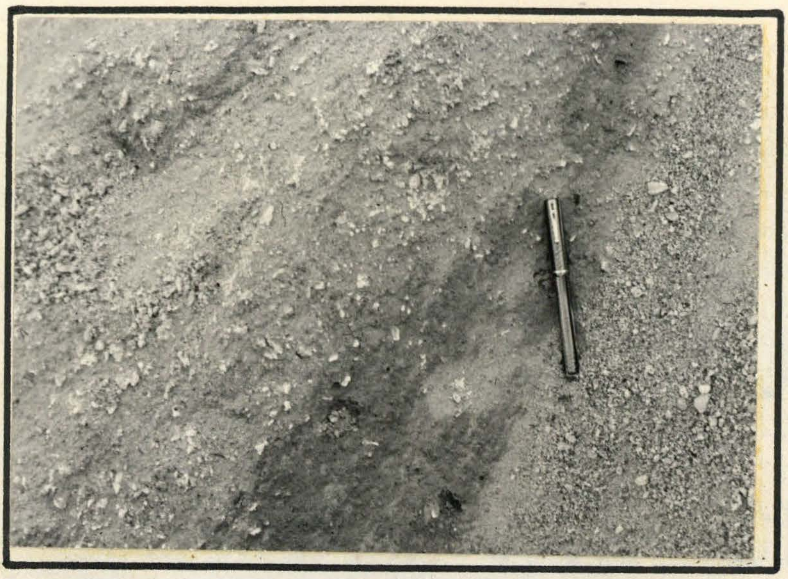
[2] Campbell, Ian, Unpublished report for R. W. Linton, September 22, 1936.



A. Efflorescence on Florence Lake Dam aggregate pile

B. Exudations on concrete buttress No. 27 of Florence Lake Dam

C. Efflorescence on "granodiorite" from Stevenson Creek adit wall

A. Glacially carved rock apron near Florence Lake Dam

B. Pegmatite dike at the base of the Florence Lake Dam are represented in the present day stockpile at Florence Lake.

The bedrock in the vicinity of Florence Lake Dam is massive medium grained intrusive igneous rock, varying in composition from a granodiorite to a quartz monzonite, depending on the ratio of potash to soda lime feldspar[3/]. Small infrequent dikes of aplite and pegmatite cut this massive rock in an unusually straight and persistent manner. Commonly, these dikes are less than one foot in width. Plate 4b shows one of the pegmatite dikes just below Florence Lake Dam. Scattered throughout the massive rock in the manner of raisins in a pudding are inclusions of darker, more basic rock. These inclusions do not amount to more than several per cent at this locality, but locally in the Sierran intrusive rocks they are much more prominent. They are more resistant to weathering than the "granodiorite".

Rock excavated from the tunnel was sorted into three sizes of aggregate by dry screening at the time of the construction of the dam. The sizes were approximately 3" to 1½", 1½" to ½", and less than ½". The rock of the two larger sizes seemed very fresh, and little affected by the

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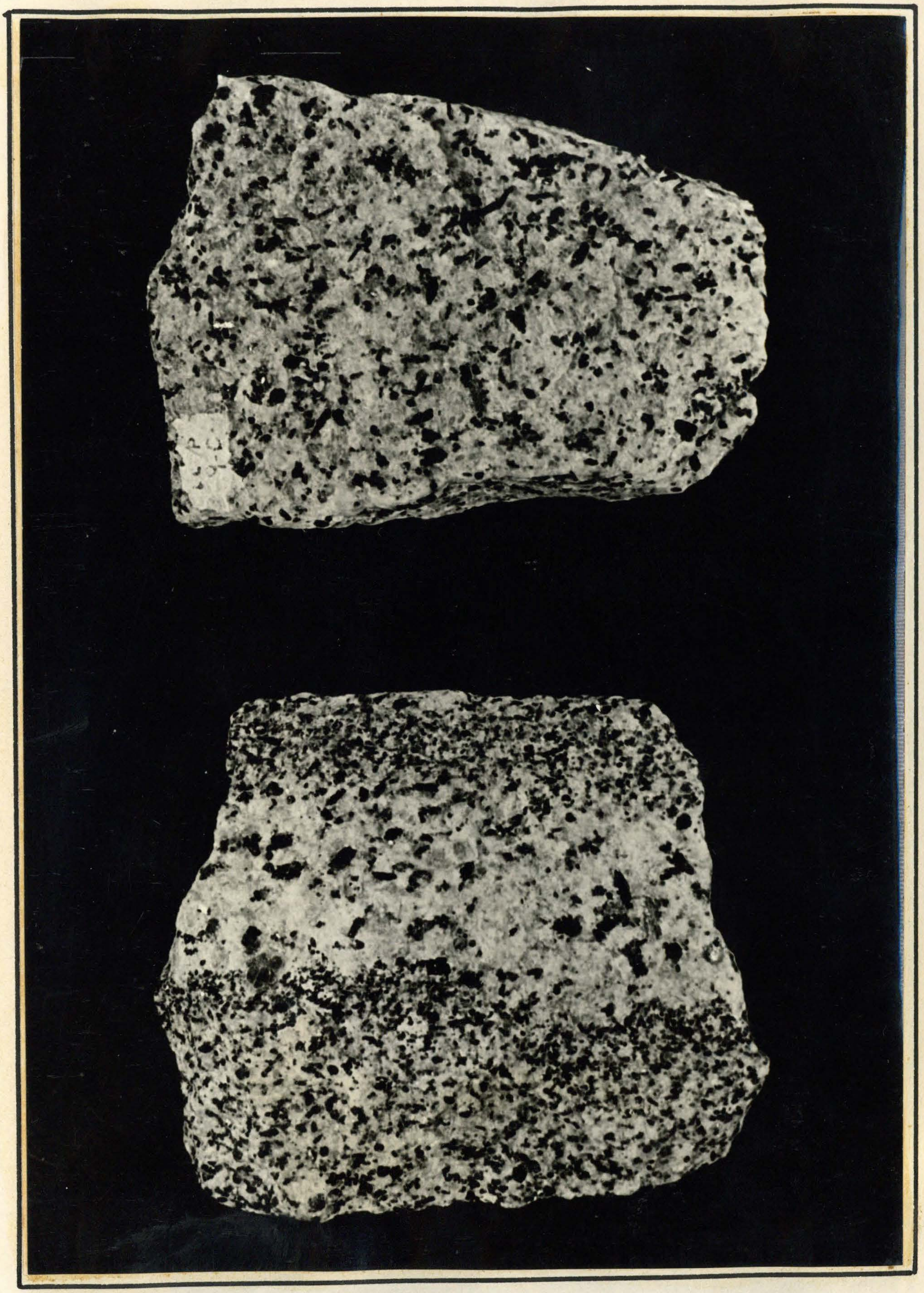
[3/] For convenience, the term "granodiorite" will be used throughout this report to denote the massive intrusive igneous rocks in the Big Creek area of the Sierra Nevada. It is recognized that these rocks are not homogeneous, but consist of a mixture of rocks belonging to the intermediate to acidic clan of intrusive rocks, including granodiorites and quartz monzonites. Whenever petrographic data is available, the precise rock name will be applied.

weathering since its excavation. However, fine weathered fragments tend to be removed from the outside of the cone. The finest aggregate cone was locally speckled with a whitish efflorescence which apparently is an alkali carbonate. (Plate 3A). This efflorescence must form continually, as each rain would tend to wash the cone clean. It was not noted anywhere on the coarser aggregate piles. Examined in detail, the powdery efflorescence seems to be heaviest on the larger pieces of aggregate in the finest pile. The Bureau of Reclamation is conducting tests on this material.

In order to quantitatively analyze the rock types occurring in the aggregate, approximately 475 pounds of rock from the 1/2" to 1 1/2" aggregate pile was hand sorted in the laboratory. All rock fragments which varied in any way from the fresh-appearing "granodiorite" were sorted out. The results are as follows;

	Pounds	Per cent
Fresh-appearing "granodiorite"	449.0	94.6
Altered "granodiorite"	16.8	3.5
Basic inclusions	3.0	0.6
Leucocratic constituents:		
Aplitic granite	2.2	0.5
Pegmatite	3.3	0.7
Miscellaneous (rounded gravel, etc.)	0.5	0.1
	474.8	100.0

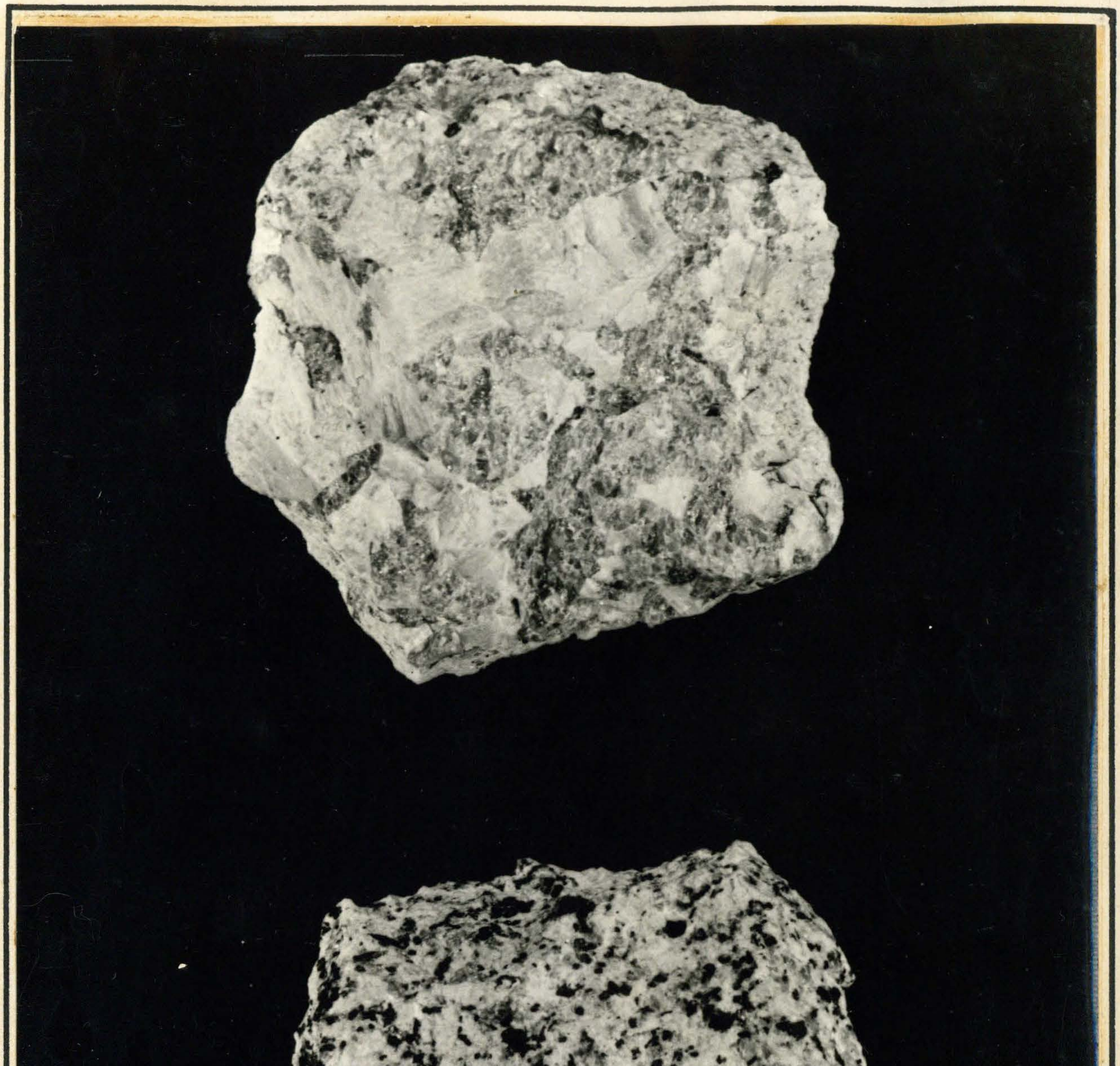
Plate 5



A. Typical Florence Lake "granodiorite" natural scale

B. Banded Florence Lake "granodiorite" natural scale

Plate 6



A. Pegmatite rock natural scale

B. Granodiorite and basic inclusion contact natural scale the sampling procedure and the inaccuracies inherent in hand sorting render these values very approximate. However, it is safe to state that the dark inclusions of the aggregate constitute close to one per cent of the aggregate, and the same is true of the leucocratic constituents. The percentage figure for altered rock is particularly subject to errors. Moderate alteration can not be recognized without microscopic methods. Frequently, one fragment contains both fresh and altered rock. In these cases the entire fragment was considered to be altered. Fortunately these two sources of error are in opposition. The chief purpose of this sorting was to obtain sufficient fresh and altered rock for use as aggregates in mortar test bars.

Fresh "granodiorite"

Over 94 per cent of the aggregate consists of closely allied members of the intermediate to acidic clan of intrusive igneous rocks. While the dangers of an extrapolation to the bulk composition of the aggregate from a few thin sections are recognized, this is the most accurate practical method available. In order to get accurate data on the mineralogic composition, a series of Rosiwal analyses were made on rocks selected at random from the fresh "granodiorite" resulting from the hand sorting. The particular value of these mechanical analyses is to determine the abundance of the minor constituents more accurately than can be done by estimation. The results, with percentages calculated by weight are as follows:

Section	A	B	D	F	G	H	I
Plagioclase	25.1	40.3	34.3	35.8	32.5	42.3	43.0
Quartz	32.6	17.6	34.7	25.1	33.3	24.4	21.9
K-Feldspar	30.7	19.0	12.0	18.2	12.0	12.8	15.0
Biotite	7.6	13.8	10.4	4.9	12.1	9.1	6.0
Hornblende	3.0	8.3	6.8	14.4	6.9	9.1	9.0
Sphene[4]	x	x	0.8	0.6	1.2	0.9	0.4
Magnetite	0.5	1.4	x	1.0	0.8	1.0	0.9
Zircon	x	0.3	x	x	x	x	x
Apatite	x	x	x	x	x	x	x
Epidote	x	x	x	x	x	x	
Sericite	x	x	x	x	x	0.4	3.1
Kaolin	x	x	x	x	x	x	
Calcite	-	-	-	-	-	x	

x = Trace

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[4] The name sphene has been officially adopted in place of titanite for the mineral whose composition is $CaTiSiO_5$.

Following a common rock classification scheme, specimen A is a quartz monzonite, and B, D, F, G, H, and I are granodiorites. The determining factor is the ratio of potash feldspar to total feldspars, with ratio varying from 0.05 to 0.33 for granodiorites, and from 0.35 to 0.66 for quartz monzonites.

The quantitative mineral composition of a number of other thin-sections has been estimated, and it is apparent that the above range of values for quartz, plagioclase and potash feldspar is wide enough to include nearly all variations present. The percentages of the accessory minerals, magnetite and sphene, are subject to more local variation. Combining the data from all thin sections, the average mineralogic composition for the fresh granodiorite is:

	<u>Per cent</u>
Plagioclase (Andesine)	38
Quartz	24
Potash feldspar (chiefly microcline)	18
Biotite	10
Hornblende	8
Magnetite	1
Sphene	0.8
Zircon	Trace
Apatite	Trace

This composition corresponds to a granodiorite.

The average composition of the plagioclase is that of andesine which is composed of 60 per cent of the molecule $NaAlSi_3O_8$ and 40 percent of the molecule $CaAl_2Si_2O_8$. Frequently the plagioclase crystals are zoned, the concentric layers of feldspar being progressively higher in the $NaAlSi_3O_8$ molecule toward the edge of the crystal. There is evidence of a replacement of portions of the initial plagioclase crystals by a more sodic feldspar in some thin sections.

Plate 9A illustrates both the zoning and the replacement. Due to its early crystallization, the plagioclase is generally in well-defined crystals.

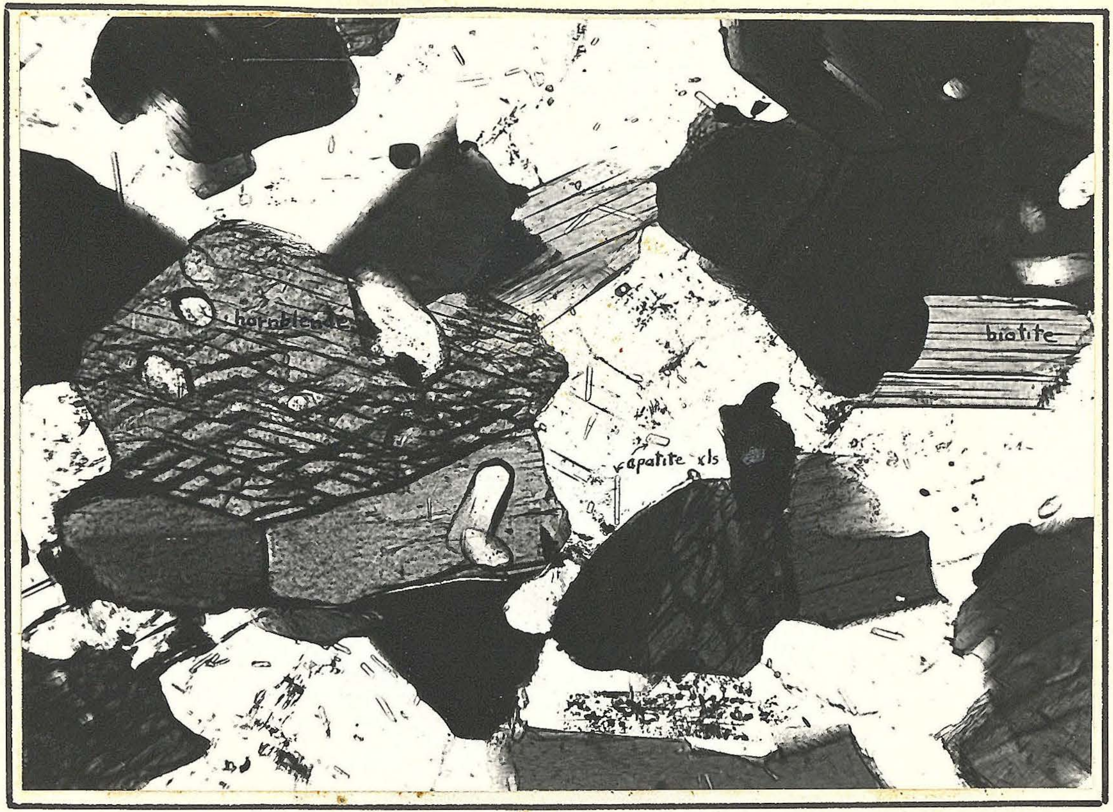
Quartz is clear with very fine hairlike inclusions scattered throughout the crystal. Frequent undulatory extinction is evidence for straining of the crystal and rock mass.

The potash-feldspar consists of both orthoclase and microcline, with the latter predominating. These feldspars have been the last constituents of the rock to crystallize, and thus form a matrix for the earlier crystals. The quartz exhibits this same relationship but to a lesser degree. Plate 9B shows the typical form of the main minerals of the "granodiorite".

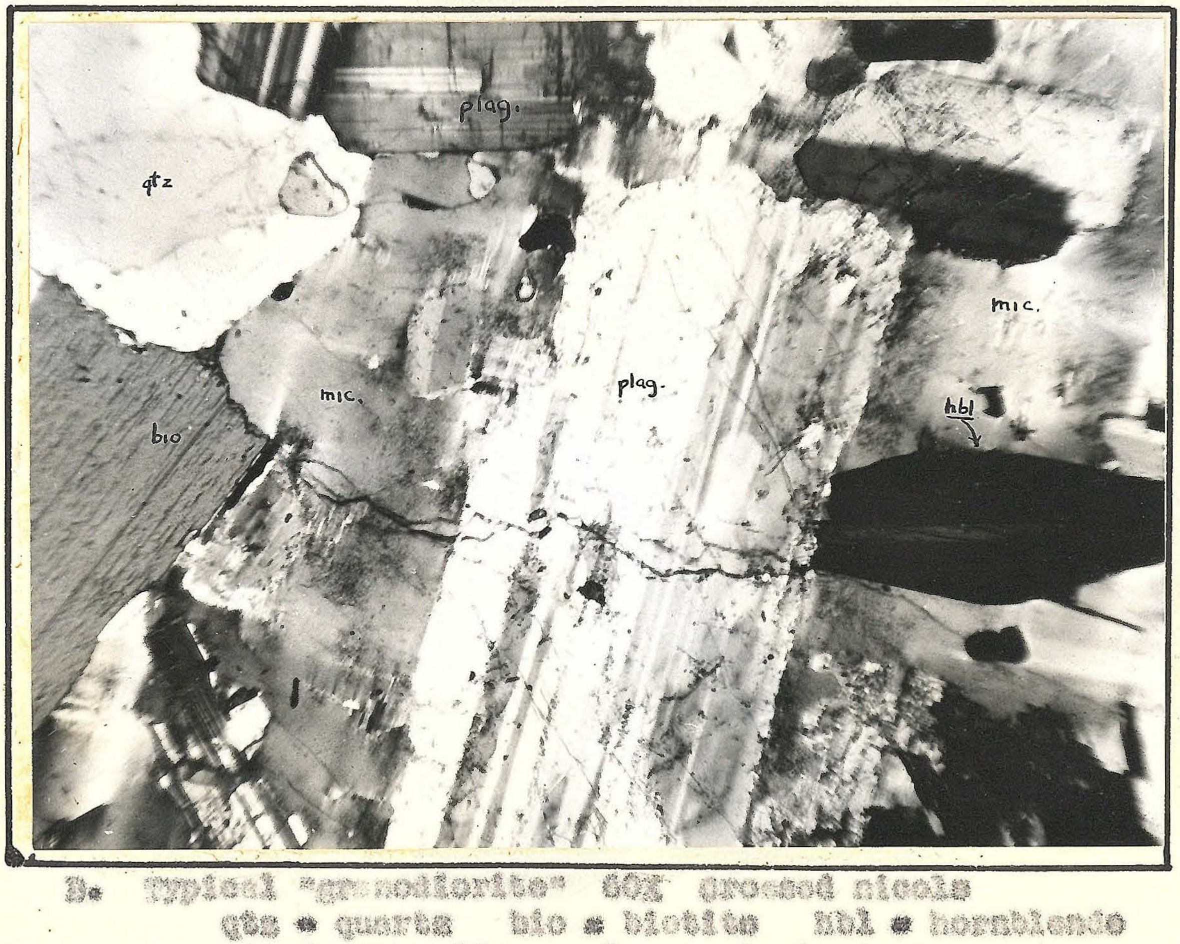
The accessory minerals, magnetite and sphene, have a tendency to be concentrated with the biotite and hornblende, either as inclusions or as components of a clot made up of basic minerals. The sphene typically has rhombic crystal outlines. Plate 10A illustrates this development.

Alteration of the "granodiorite"

The plagioclase feldspar is most susceptible to alteration. Sericite, a finely crystalline potash mica, is the most common alteration product. Kaolin is usually present, distributed dustlike over most of the feldspar, although at



A. Basic inclusion 100X Parallel nicols



B. Typical "granodiorite" 60X crossed nicols
qtz = quartz bio = biotite hbl = hornblende
mic = microcline plag = plagioclase

Plate 7

A. Basic inclusion 100X Parallel nicols

B. Typical "granodiorite" 60X Crossed nicols
qtz = quartz bio = biotite hbl = hornblende
mic = microcline plag = plagioclase

Plate 8

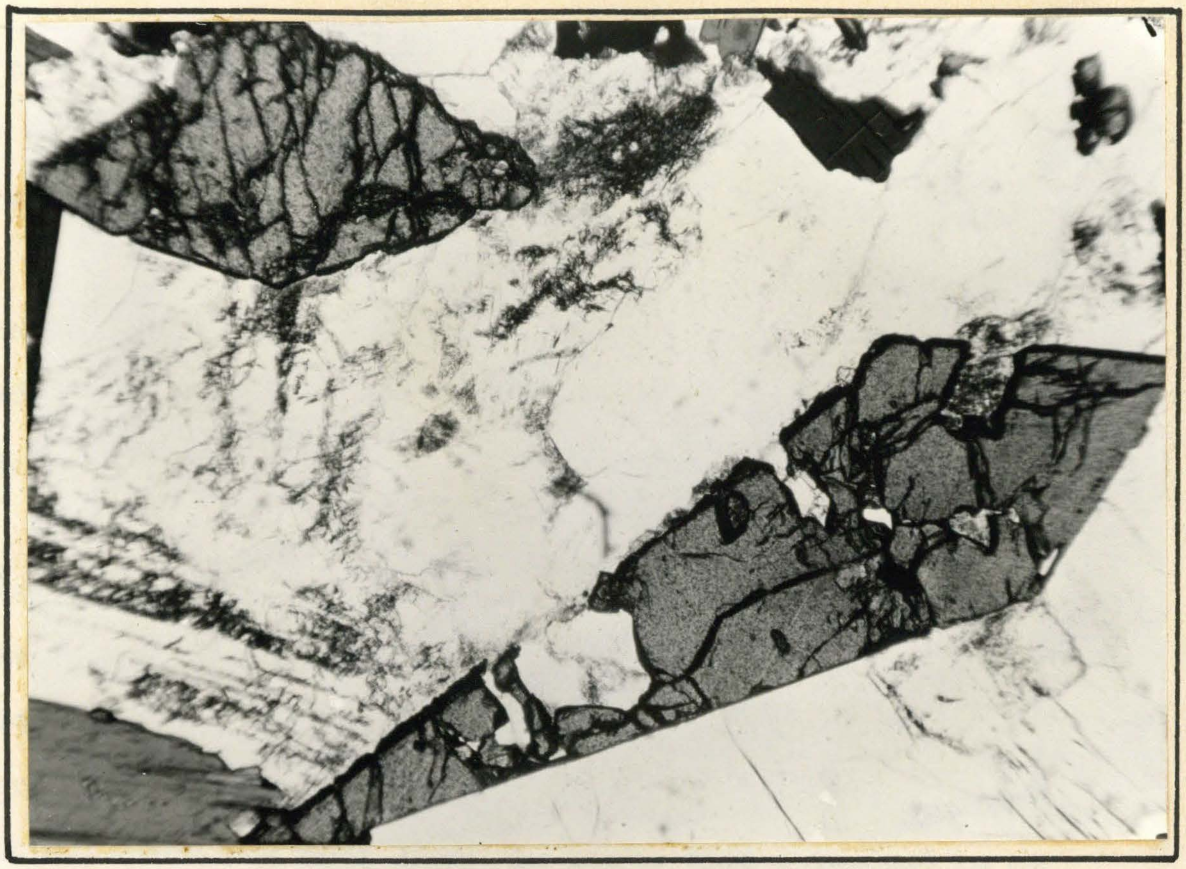
A. Pegmatite - large microcline crystal with inclusions of quartz. 60X Crossed nicols

B. Aplite - compare crystal size with that of the pegmatite above. 60X Crossed nicols

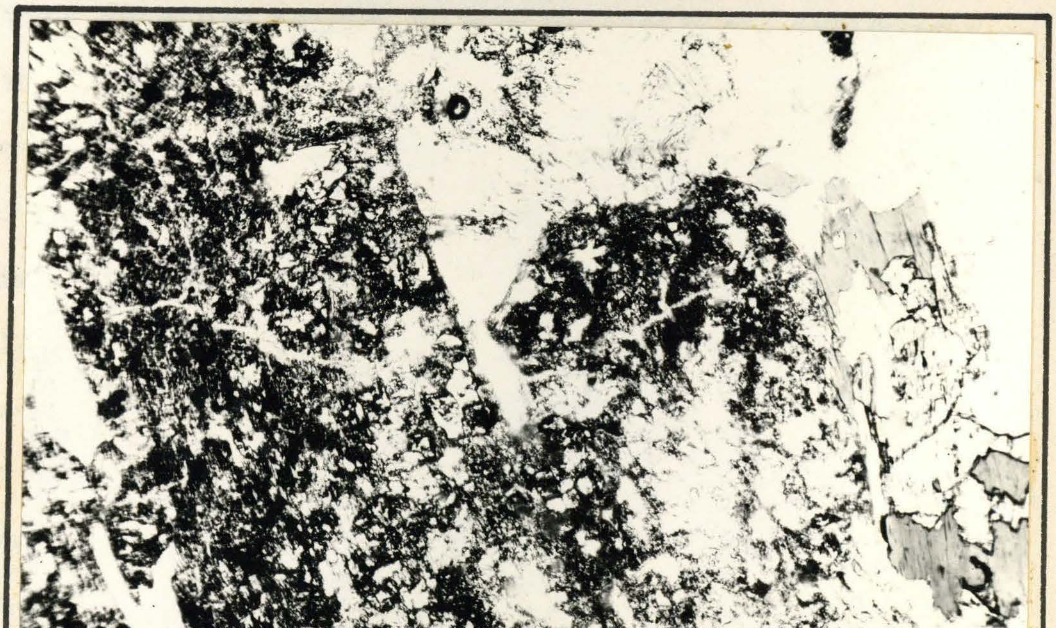
Plate 9

A. Zoned plagioclase crystal, partially replaced by oligoclase 60X Crossed nicols

B. Graphic texture of pegmatite. Quartz crystals in feldspar 60X Crossed nicols



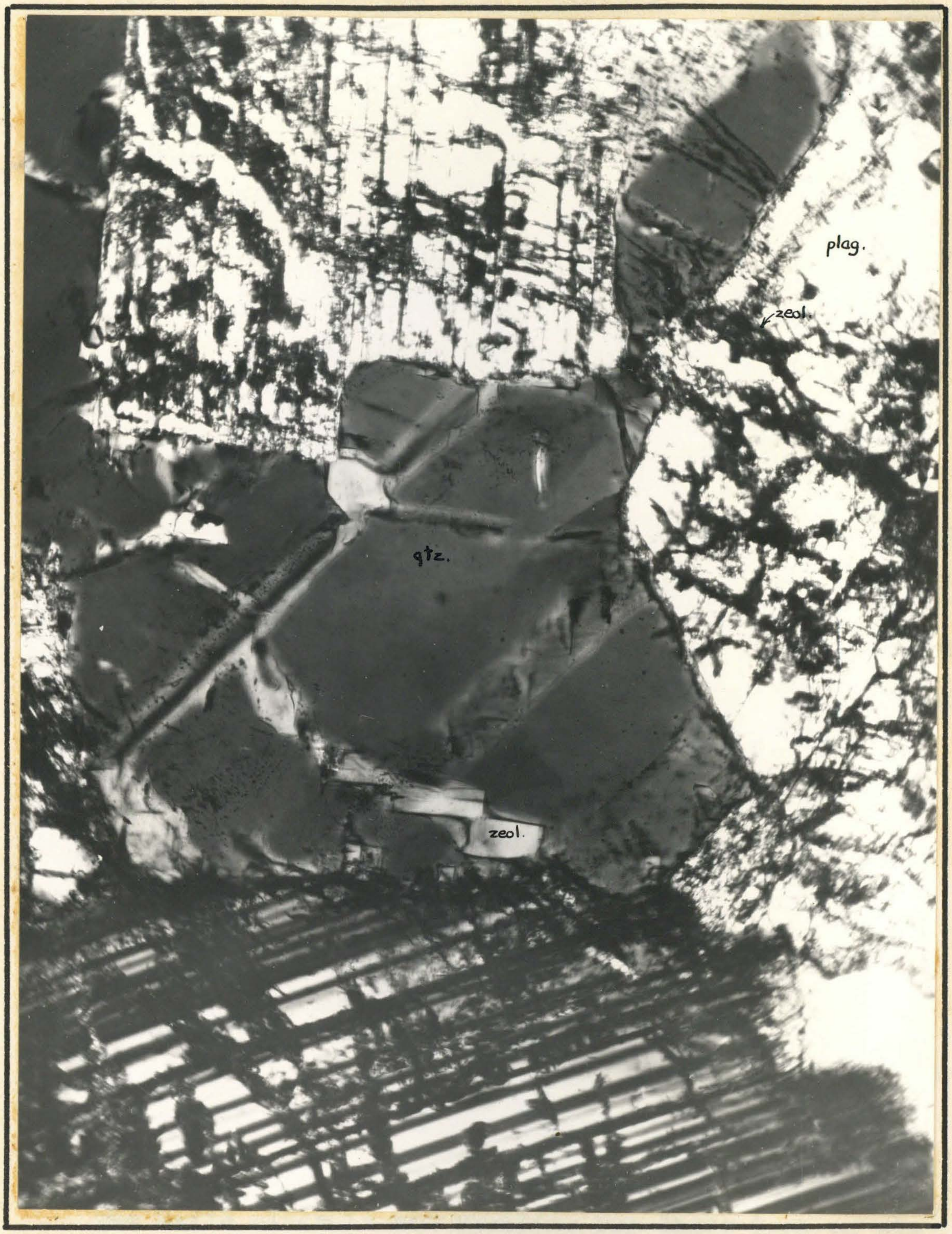
A. Sphene crystals in "granodiorite" 60X Parallel nicols



B. Extreme alteration of plagioclase crystals to sericite. kaolin and minor zeolite 60X Parallel nicols times it is localized along tiny fracture cracks. Epidote is present in the more calcic centers of zoned plagioclase crystals. At times minute patches of calcite are present. In the most altered rocks the sum of all these alteration products of plagioclase would not exceed 25 per cent of the rock. The minor amount of extensively altered rock makes the total volume of these alteration products very low.

A zeolitic alteration of some of the plagioclase feldspar is worthy of more attention. Some zeolite has been noted in nearly all of the badly altered rocks of the Florence Lake Dam aggregate. Perhaps of more volumetric significance is the considerable amount of this alteration product which has been found in rocks that appeared to be fresh to the naked eye. The most typical development is along tiny fracture cracks in the plagioclase, intimately mixed with kaolin. It is impossible to establish whether the cracks have localized the alteration products, or whether these products have caused the fracturing.

Where the alteration has been more extensive, the zeolite lined fractures give way to wider veinlets of the material. One specimen was found where the zeolite had formed a layer about 1/8" thick in a fracture plane of the rock. A thin section transverse to this fracture showed the plagioclase to be extensively altered to zeolite, and many small veinlets of the zeolite cut across the other minerals in the rock. (Plate 11).



Zeolitic alteration of plagioclase crystals, with zeolite veinlet cutting the gray quartz crystal in the center. Other small veinlets cut quartz in upper right. Crossed nicols 200x

This zeolite has not been identified to match any zeolites described in the literature. The mineral is slightly salmon colored, has at least one good cleavage, and hardness is around four. Optically, its properties are as follows:

Indices of refraction = 1.490 B = ? = 1.500
The probable error is 0.001 for each determination.

Biaxial, and probably negative.

Twinning is present occasionally.

With respect to the good cleavage, the mineral is lengthfast and exhibits parallel extinction. There is a poorly developed cleavage perpendicular to the good cleavage.

The zeolites are hydrous aluminum silicates of calcium and/or sodium. The water content is variable, and easily lost. This causes a variation in the optical properties, which probably accounts for the lack of correspondence between this mineral and published descriptions of the zeolites. Its behavior when heated and its optical properties correspond most closely to stilbite, $H_4(Ca,Na_2)Al_2(SiO_3)_6 \cdot 4H_2O$.

This zeolitic alteration of the "granodiorite" may amount to several per cent of the total rock mass, but its accurate estimation is extremely difficult.

The potash feldspar has altered chiefly to kaolin, but frequently sericite is also present. The potash-feldspar is less affected by alteration than the plagioclase.

The mafic minerals are striking for their lack of alteration. Commonly these minerals remain unaffected when adjacent plagioclase has suffered intense alteration.

Epidote and chlorite are the chief alteration products of the biotite and hornblende when these minerals are altered. The biotite seems to be more sensitive to chloritization and epidotization than the hornblende.

Most of the alteration of the "granodiorite" has taken place along fractures which have localized the hydrothermal activity. These veinlets grade from pure epidote at the center outward through a zone of less intense epidotization but of very intense sericitization, kaolinization, and chloritization into fresh appearing rock. The intensely altered zone is rarely more than a few inches in width.

A few rock fragments show signs of surface weathering. In these cases the disintegration cracks are stained by iron compounds.

Basic Inclusions

The basic inclusions constitute about one per cent of the aggregate. This rock is fine grained and much darker than the enclosing "granodiorite". The principal dark minerals, biotite and hornblende, are present in about equal proportions and may total from 30 to 50 per cent of the rock. The predominant light mineral is plagioclase, usually andesine. Potash feldspar, if present at all, constitutes less than five per cent of the total feldspars. Quartz varies from less than five per cent to about 20 per cent of the rock. Thus these inclusions vary from diorite to tonalite in rock type. Little alteration was noticed in the thin sections examined. The minerals can be expected to behave the same as in the "granodiorite". Plate 7_A is typical of these inclusions.

Magnetite and sphene are more common in these inclusions than in the "granodiorite", but probably never comprise over five per cent of the rock. Apatite is present in small quantities. The origin and composition of these inclusions in the Sierran intrusive igneous rocks has been extensively studied by Pabst[5/].

[5/] Pabst, A., Observations on the Granitic Rocks of the Sierra Nevada, U. of Calif. Publication in Geo. Sci., Vol. 17, 1928.

Leucocratic Constituents

Rock containing negligible amounts of dark minerals constitutes somewhat over one per cent of the Florence Lake Dam aggregate. The rock varies from the aplitic constituents with a uniform grain size of about one millimeter to pegmatitic material with crystals several centimeters across. Plate 8 shows typical fields of aplitic and pegmatitic rock, both with the same magnification to facilitate comparison.

Petrographic examination of the aplitic material reveals an average composition of about 45 per cent quartz, 45 per cent potash feldspar, eight per cent plagioclase feldspar (oligoclase) and the remaining two per cent consisting of biotite and magnetite. Kaolin is slightly developed in the potash feldspar and traces of sericite are noted in both types of feldspar.

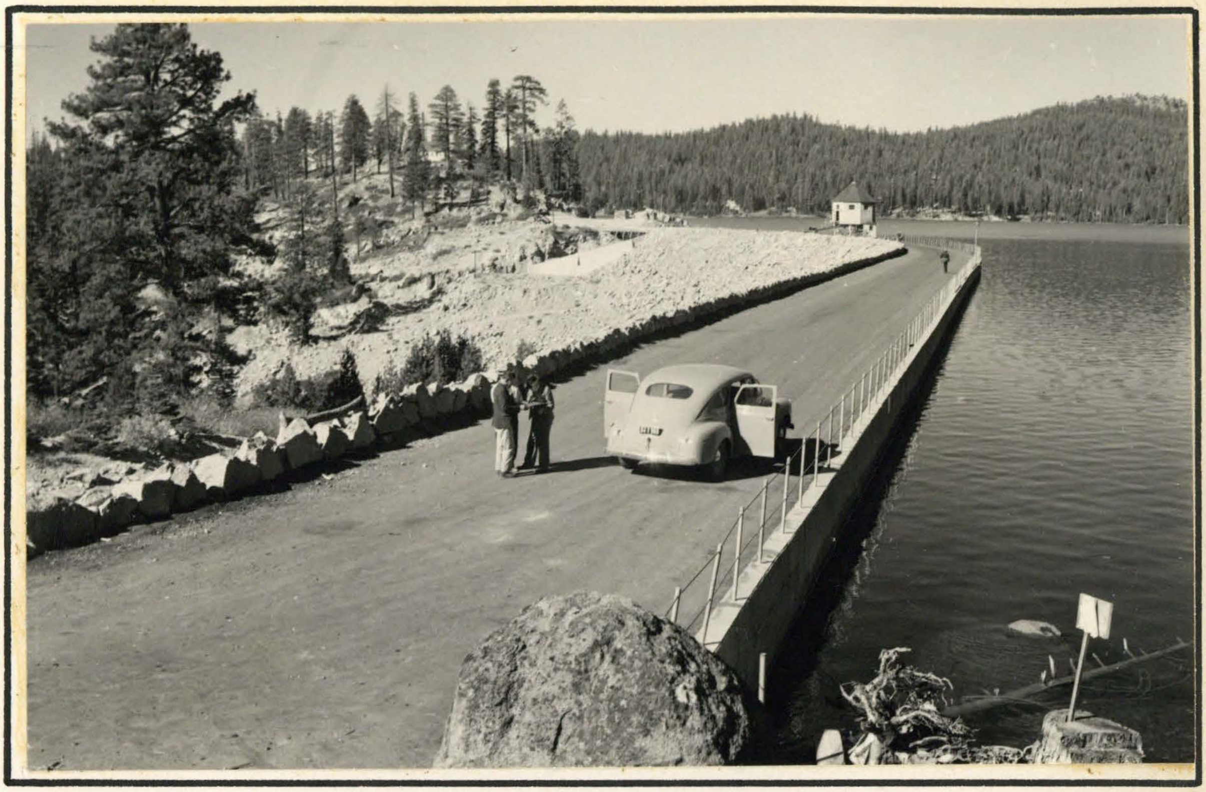
The chief characteristic of the pegmatite veins is the extreme variation in size of the mineral crystals. The composition of the pegmatite dikes is similar to the aplitic dikes, about 90 per cent of the rock consisting of equal quantities of quartz and potash-feldspar (principally microcline) the remaining 10 per cent being plagioclase. A graphic texture of quartz and potash-feldspar is commonly developed. This is shown in Plate 9B.

Alteration is slight and, when present, kaolin is the principal product.

"1939" AGGREGATE

This aggregate is from a short tunnel near Huntington Lake Dam No. 1. In 1939 it was used in concrete for repair work on this dam, and has already shown considerable disintegration. (see Plate 12).

The aggregate was not analysed quantitatively for rock types, but several representative specimens were collected as well as a number which appeared to be variants.



A. Huntington Lake Dam No. 1 Dam facing put on in 1939

B. Deteriorated concrete of Huntington Lake Dam No. 1 "1917" aggregate was used. Typical of 1939 con crete failures also.

The bulk of this rock is medium grained, and intermediate in rock type between "granodiorite" and quartz monzonite since the potash feldspars are about 1/3 the volume of the plagioclase, andesine. The dark minerals constitute about 20 per cent of the rock, and biotite is dominant over hornblende. The usual accessories are present. Myrmekite is present in the customary small amount. Microscopic study reveals extensive fracturing which was not apparent to the naked eye. The presence of some fracture filling is evidence that this is not due simply to stresses incurred by grinding. The quartz is particularly susceptible to this shattering and exhibits undulatory extinction.

A variety of alteration products are present; however, they collectively constitute but a small percentage of the rock. The plagioclase has chiefly altered to epidote and sericite. Small patches of calcite are occasionally present in the plagioclase. In a few places, zeolitic alteration of the plagioclase has taken place. This would amount to less than one per cent of the rock specimen.

The ubiquitous kaolin is "dusted" over all of the feldspars in minor amounts. Generally, the mafic minerals are extremely fresh in appearance, although in some places the biotite has altered to chlorite.

The chief variant in the granodiorite-quartz monzonite is a fine grained granite. Petrographic analysis reveals a composition of about 35 per cent quartz, 10 per cent plagioclase, and 30 per cent potash feldspar. The dark constituents of the rock amount to about five per cent and are largely biotite. Sericite and kaolin are the chief alteration products of the feldspars, with no zoolite being positively identified. The rock is relatively free from fractures, and the quartz is unstrained.

An intensely altered quartz monzonite was petrographically analyzed from this aggregate. This rock consisted of approximately equal quantities of quartz, plagioclase, and potash feldspars. Any former mafic minerals have now been altered to a nearly colorless, highly birefringent mica, probably representing a stage in the formation of chlorite. Sericite is the chief alteration product in all feldspars, often obliterating 80 per cent of the original crystal. Plate 10A shows the extreme alteration. Kaolin is prominent, especially on the potash feldspars where it may opacify about 50 per cent of the crystal. Small amounts of calcite, less than one per cent, have formed from the plagioclase.

"1917 QUARRY" AGGREGATE

Several specimens were collected from the "1917 Quarry" near the Huntington Lake Dam No. 2. The rocks at this locality are peculiarly subject to crumbling and little fresh rock could be found at the quarry location (Plate 13). This contrasts strikingly with most of the rock in the

Plate 13

"1917 quarry" near Huntington Lake Dam No. 2
The extreme disintegration which has taken place
with this rock in the quarry is rare with most
"granodiorites" of the region

vicinity of Florence Lake, where the glacially polished surface is still preserved intact in many exposed places.

Petrographic study reveals that the rocks collected are quartz monzonite, with approximately equal quantities of quartz, plagioclase, and potash feldspars. The dark minerals constitute about 20 per cent of the rock and consist of biotite and hornblende in about a 3:2 ratio. These minerals have the tendency to occur in small clots. The usual accessory minerals of magnetite, sphene, apatite, and zircon are present.

The minerals of the thin section made from the freshest rock which could be found in the quarry are but slightly altered. A little kaolin "dust" is present on the potash-feldspars. Although the plagioclase feldspar is remarkably clear, a few small areas of probable zeolitic alteration are present. There is no obvious control for the little fracturing that is present in the section.

A rock which was crumbly and iron-stained was also studied microscopically. This also was revealed to be a quartz monzonite. A trace of sericite is present in the plagioclase feldspar and slight amounts of kaolin "dust" occur in the potash-feldspars. The iron-staining present in the section is along minute fractures, following grain boundaries in the main. This rock has a high content of myrmekite.

Another peculiarity of this rock is the occurrence of some quartz as series of rounded blebs, in a line, cutting across other crystals. A few thin border zones of quartz around some of the biotite suggests a partial replacement by quartz. It appears as if there had been an introduction of silica near the close of the crystallization cycle.

Why, or whether, these minor peculiarities of this rock cause the rapid disintegration that has proceeded at the quarry site is not known. Rock from this quarry should probably be condemned as aggregate although such condemnation is mainly due to its known rapid disintegration on exposure rather than to its mineralogic composition.

SUMMARY OF GEOLOGICAL STUDIES OF THE VARIOUS AGGREGATES

On the basis of the known behavior of minerals when used as aggregate for concrete it is not possible to condemn the unaltered intrusive igneous rock of the Big Creek region. It is hoped that the mortar testing program using the separate minerals components of the Florence Lake Dam aggregate will supply more details on this problem of mineral behavior.

The alteration products of these aggregates may be viewed with some suspicion, but again, there is no irrefutable evidence along this line. The minor amounts of zeolite[5A], formed by the hydration of feldspar, may be the source of trouble. The use of a badly altered plagioclase feldspar aggregate led to disastrous results in southern California in 1923[6]. The investigators concluded that the presence of a zeolite, laumontite, was the main source of the trouble. This had formed from the alteration of plagioclase feldspar similar to that of the Florence Lake aggregate. (The Bureau of Reclamation is currently experimenting with the aggregate described in the above paper, as well as with mortar bars of pure zeolite minerals.) The percentage of alteration products present in the Florence Lake aggregate is undoubtedly much lower than in the case cited, but the differences are of degree, and not of kind.

Further mention of zeolites in reactive aggregate is

[5A] It should also be kept in mind that the positive identification of zeolitic alteration products is nearly impossible using readily available magnifications with the bulk of the rocks. The one positive identification of it was in a thin section sliced perpendicular to an 1/8" thick veinlet of the zeolite. It is a necessary extrapolation from this instance to similar but much smaller concentrations of an alteration product in the rest of the rocks.

[6] Pearson, J. C. and Loughlin, G. F., An Interesting Case of Dangerous Aggregate: Am. Cement Inst. Proc., Vol. XIX, pp. 142-155, 1923.

made by Meissner[7], in describing the concrete deterioration at Parker dam. In this case, there are also local concentrations of opaline silica, a known reactive aggregate[8], which perhaps justly deserves full credit for the pernicious reactions. However, the occurrence of the zeolite in this aggregate may also have significance. The peculiar property of base exchange exhibited by members of the zeolite group of minerals, whereby the Na or Ca content of the molecule may be easily exchanged for the other element, is worthy of attention in a problem as intimately connected with alkali content as is this one.

It should be kept in mind that perhaps the bulk percentages of alteration products are not the crucial factor, but more their distribution. The zeolitic alteration tends to be along fracture and cleavage cracks in the plagioclase. If a rock altered in this manner were broken the surface concentration of these alteration products would be much higher proportionally than their actual volume, as is estimated from thin section analysis. This surface concen-

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[7] Meissner, H. S., Cracking in Concrete Due to Expansive Reaction between Aggregate and High-Alkali Cement as Evidenced in Parker Dam., Jour. Am. Concrete Inst., Proc. Vol. 37, p. 657, April, 1941.

[8] Stanton, T. E., Expansion of Concrete Through Reaction Between Cement and Aggregate; Proc. A. S. C. E. Dec. 1940, Vol. 66, pl. p. 1781.

tration would be ideal for an aggregate-cement reaction. If this alteration product should be revealed as deleterious in aggregate, its volume might be reduced to a safe point in aggregate by removal of the finer crushed particles which carry higher percentages of alteration products.

SEPARATION OF THE MINERALS OF THE FLORENCE LAKE "GRANODIORITE"

The investigation into the behavior of the mineral components of the Florence Lake Dam aggregate required a separation of about four pounds of each of the major constituents of the rock, and a lesser amount of the accessory minerals, magnetite and sphene. The extremely low percentage of these minerals in the rock necessitated milling about 500 pounds to obtain the requisite amounts of these minerals.

Milling equipment which had been used for a gravity separation pilot plant was available for this work. The equipment consisted of the following:

Small jaw crusher
Crushing rolls
Pulverizer
Vibrating screen (-30 mesh)
Cone classifier
Two 3' by 8' Wilfley tables
one 18" by 39" Wilfley table
Electromagnet

The same results could have been obtained with the minimum equipment of one crushing device, one Wilfley table and an electromagnet, but not as conveniently. Quantitative studies of recovery were of no significance for this work.

Plate 14 is a flow diagram of the separation processes used to obtain the different mineral concentrates. This only shows the succession of processes used, and does not mean that the separations were carried out continuously.

Crushing

It was first necessary to determine the size at which the different mineral constituents of the rock would be liberated as free particles. The theoretical aspects of this problem of comminution are well analyzed by Gaudin[9]. However, for this work an entirely empirical approach was employed. The rock was crushed in a jaw crusher and then by crushing rolls to yield a -10 mesh product. The ground material was then graded using screen sizes 20, 40, 60, 80, 100, 120, 140, and 160. Grain thin sections of the different fractions were prepared and studied microscopically. For the purposes of the testing program, the larger the mineral particles which would be separated, the better, yet the percentage of locked particles increases with size. Consideration of these opposed requirements resulted in choosing 30 mesh as the largest size which would yield a

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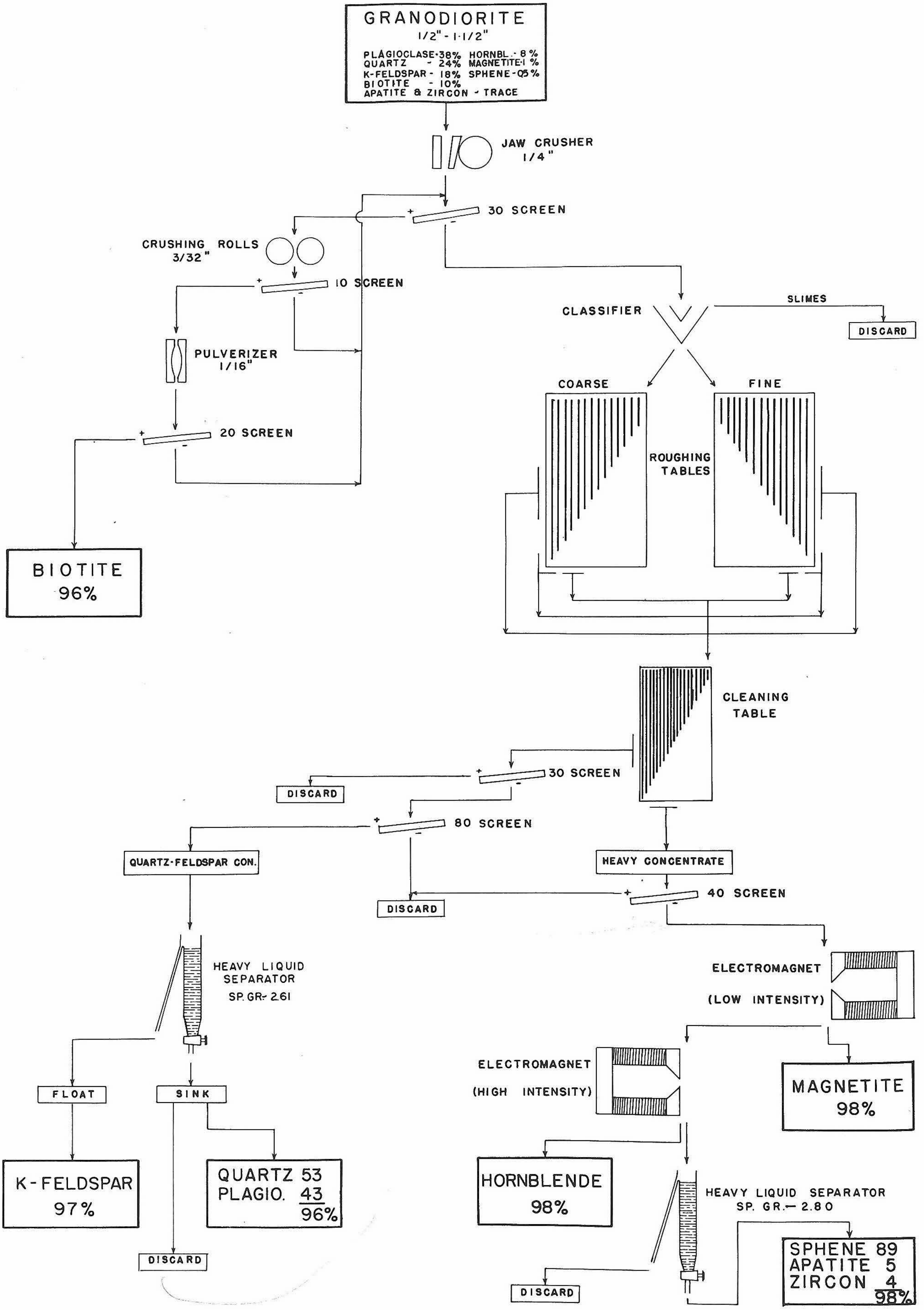
[9] Gaudin, A. M., Principles of Mineral Dressing, McGraw-Hill Book Company, Inc., 1939, pp. 70-89.


GRANODIORITE
1/2" - 1·1/2"
PLAGIOCLASE - 38%
QUARTZ - 24%
K-FELDSPAR - 18%
BIOTITE - 10%
APATITE & ZIRCON - TRACE
HORNBL. - 8%
MAGNETITE - 1%
SPHENE - 0.5%
JAW CRUSHER
1/4"
30 SCREEN
CRUSHING ROLLS
3/32"
10 SCREEN
PULVERIZER
1/16"
20 SCREEN
BIOTITE
96%
CLASSIFIER
SLIMES
DISCARD
COARSE
FINE
ROUGHING
TABLES
CLEANING
TABLE
30 SCREEN
DISCARD
80 SCREEN
QUARTZ-FELDSPAR CON.
DISCARD
HEAVY CONCENTRATE
40 SCREEN
HEAVY LIQUID
SEPARATOR
SP. GR.- 2.61
FLOAT
SINK
K-FELDSPAR
97%
QUARTZ 53
PLAGIO. 43
96%
DISCARD
ELECTROMAGNET
(LOW INTENSITY)
ELECTROMAGNET
(HIGH INTENSITY)
MAGNETITE
98%
HORNBLENDE
98%
HEAVY LIQUID SEPARATOR
SP. GR.— 2.80
SPHENE 89
APATITE 5
ZIRCON 4
98%
DISCARD
+
-

sufficiently pure mineral product.

The mineralogic composition of the different sizes revealed certain tendencies for mineral distribution. Among the mafics, the biotite is dominant in the coarser sizes and hornblende tends to be concentrated in the finer sizes. This behavior is a direct reflection of the cleavages of these minerals. The two cleavages in hornblende yield prismatic slivers of the mineral which readily pass through a screen, whereas the single cleavage of biotite yields plates which can not pass through a screen whose openings are much larger than the thickness of the biotite flakes. The accessory minerals are more abundant in the finer sizes studied, due to their original grain size. No appreciable change in the proportions of quartz, plagioclase, and potash feldspar was noticed. Quantitative studies of this behavior of the common igneous rock minerals when crushed and screened has been made by Johannsen and Merritt[10].

This selective concentration of crushed minerals in the different sizes formed the basis for the separation of biotite. The process is shown diagrammatically on the flow sheet, Plate 14. Material from the crushing rolls was

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[10] Johannsen, Albert & Merritt, C. A., Comparative Losses in Crushing and Sifting Rock Minerals, Jour. of Geology, Vol. 34, No. 3, pp. 278-80, April-May, 1926.

screened by No. 10 sieve[11]. The plus 10 mesh material contained about twice as much biotite as was present in the original rock. This preliminary concentrate was then put through the pulverizer, whose grinding plates had been set at a distance about equal to the opening in a No. 20 screen. The biotite cleaved into thinner plates and passed through the pulverizer edgewise, but the other minerals of the rock were broken down in more than one dimension, yielding a fine powder. The elasticity of the mica also contributed to the preservation of the biotite flakes. A simple screening with a No. 20 screen caught the plates of biotite and allowed the ground powder of the other minerals to pass through. This process furnished biotite which was 96 per cent pure. The biotite flakes were cleaned of dust by placing the concentrate between two nestling screens of a much finer size than the biotite flakes and passing an air blast through the screens.

Classification

The material crushed to -30 mesh was roughly classified before being tabled. The cone classifier which was used floated off the slimes (about 250 mesh in the case of quartz) and made one sorting of the remaining material with

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[11] All screen sizes are U. S. standard.

the dividing size in the case of quartz being around 60 mesh.

The classification process, one of water elutriation, separates particles in accordance with their settling velocity. Settling velocity is a function of the size, shape, and specific gravity of the particle[12]. Thus most magnetite of the rock was so heavy in relation to its fine size that it was sorted into the same fraction as the much coarser quartz and feldspar.

If the specific gravity of the desired constituent differs appreciably from the gravity of the gangue, the process of classification can be applied to effect a separation by simply sizing the material closely prior to classifying[13].

Tabling

The main split of the minerals in the course of the separations was accomplished by the standard Wilfley concentrating tables. Two 3' by 6' Wilfley tables served for the rough concentration of the fractions from the classifier. This size of table permitted a very rapid preliminary

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[12] Gaudin, A. M., op. cit., pp. 202-4.

[13] Richards, Robert H., Development of Hindered Settling Apparatus, Trans. Am. Inst. Mining Engrs., 41, pp. 396-453, 1910.

separation of the material. All of the heavy concentrates and middlings, as well as portions of the light concentrates, were re-worked on a 16" by 38" Wilfley table to yield the purest concentrates possible by tabling methods. This tabling process would have permitted a rough separation of magnetite from the other heavy minerals, namely; zircon, sphene, hornblende, biotite, and apatite but the process used did not necessitate a separation of magnetite in this manner. Since recovery had little significance in this separation program only the light and heavy concentrates were retained, the middlings being rejected after several re-workings.

Richards' paper contains an excellent discussion of the principles involved in tabling processes[14]. With particles of the same shape, the following generalizations may be made concerning the paths of the particles:

1. Beginning from the feed corner of the table, the travel of any particles is a diagonal line.
2. With the same mineral, the lines will be parallel, and the finer the particle, the farther upstream the line will be on the table.
3. The higher the specific gravity of the mineral, the higher upstream the line will be.

The closer the sizing of the table feed, the cleaner the

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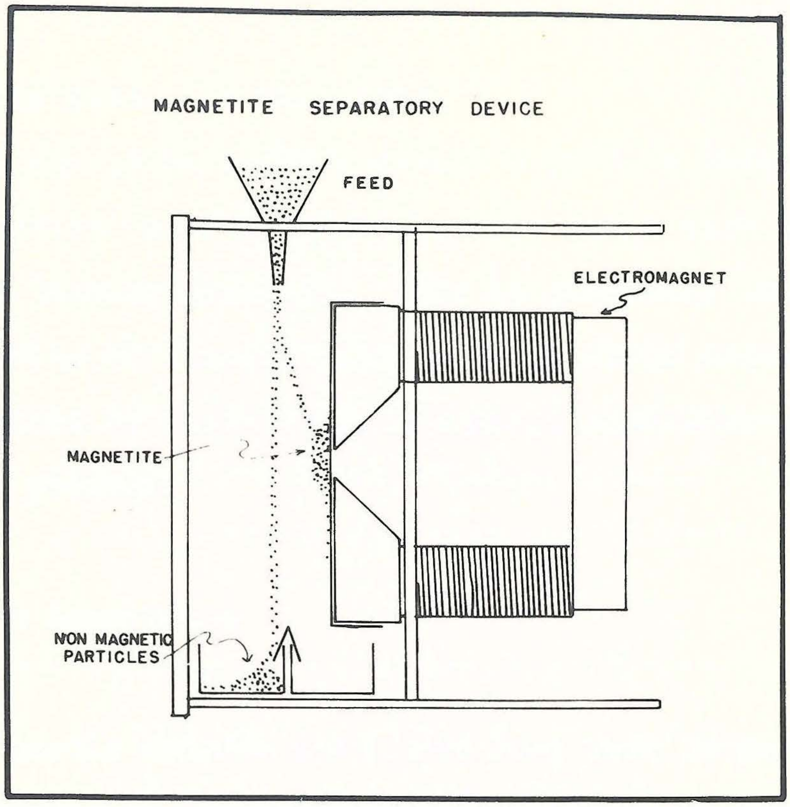
[14] Richards, Robert H., The Wilfley Table, Trans. Am. Inst. Mining Engrs., Part I, 38, pp. 556-580, (1907), Part II, 39, pp. 303-318, (1908).

concentrates will be. The sizing done by the classification process (approximately 30-60 mesh and 60-250 mesh) was sufficient for the separations in this work. In fact, crushed material can be fed directly onto the table without any classification, but this process does not yield clean concentrates. Plate 12B diagrammatically shows the distribution of the different mineral particles on the surface of the concentrating table, and the location of the different cuts.

The diagram shows that the path of mineral particles is not entirely a function of the specific gravity. This is due to the variation of resistance of different shaped particles to a flowing film of water. The biotite behaves as if it were lighter than the quartz and feldspar. This is due to its flaky character. Not all of the biotite was of a shape which would allow the effect of that shape to dominate over the effect of the specific gravity. Thus the quartz-feldspar concentrate was contaminated with biotite throughout its width on the table. Fortunately, practically none of the biotite was present in the heavy concentrate, as cut.

After the removal of magnetite from the heavy concentrate it was re-tabled, and a definite line of zircon noticed. Very careful cutting yielded a high concentration of zircon, but the total amount of it was so slight that the hope of obtaining a separation of zircon for the

Plate 15


MAGNETITE SEPARATORY DEVICE
FEED
ELECTROMAGNET
MAGNETITE
NON MAGNETIC PARTICLES

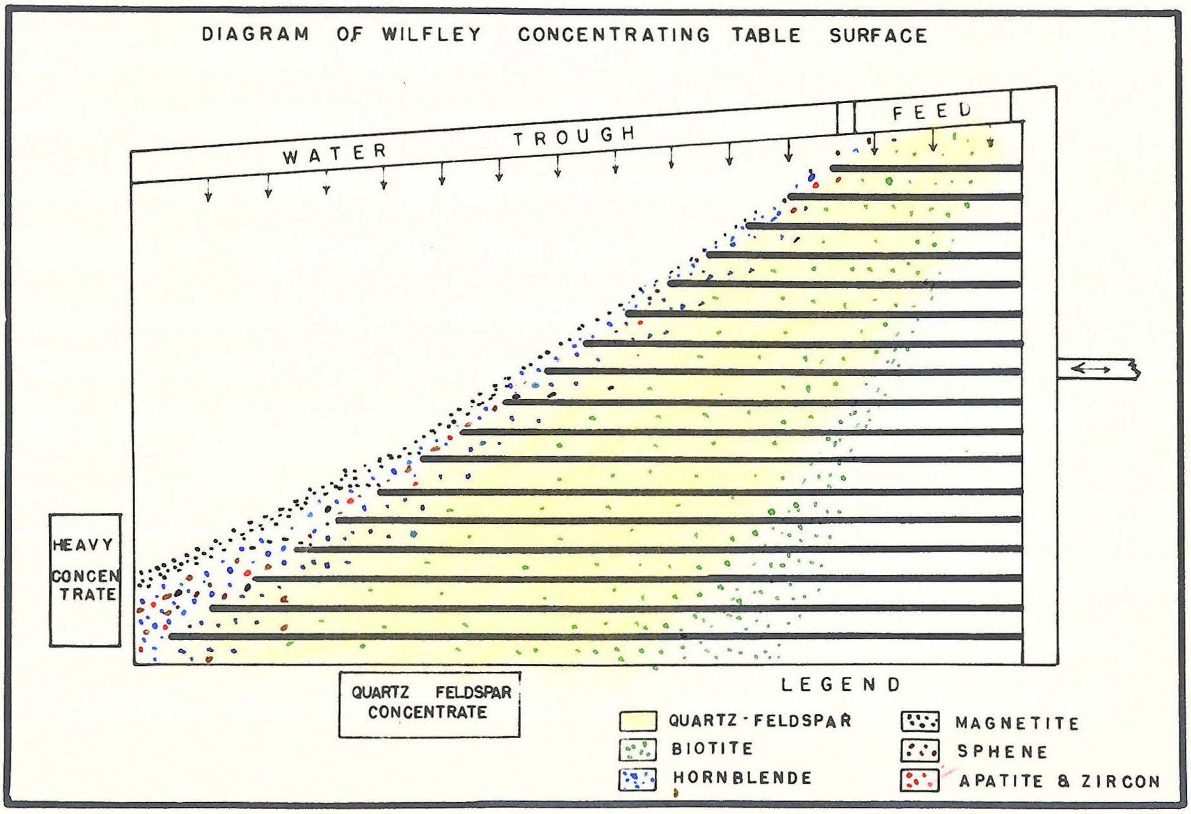


DIAGRAM OF WILFLEY CONCENTRATING TABLE SURFACE
WATER TROUGH
FEED
HEAVY CONCENTRATE
QUARTZ FELDSPAR CONCENTRATE
LEGEND
QUARTZ-FELDSPAR
BIOTITE
HORNBLENDE
MAGNETITE
SPHENE
APATITE & ZIRCON

aggregate tests was abandoned.

At any point tabling yields a product which will have large particles of heavier minerals mixed with small particles of lighter minerals. This is precisely the reverse of the results of classification. Very clean concentrates may be obtained by classifying the rough concentrates after the tabling process.

Magnetic separation

Magnetic methods have long been used successfully for both commercial and laboratory separation of minerals. The science has now reached the stage at which minerals previously considered as non-magnetic can be affected in a magnetic field and the limitation is placed more on the cost of the necessary equipment than on the possibility of magnetic concentration. The Bureau of Mines has recently completed an extensive program of investigation of magnetic methods of separation. The results of this, with a complete review of the literature have been published[15].

About ten pounds of heavy concentrate from the tabling process had to be sorted into the highly magnetic mineral, magnetite, the weak to moderately magnetic hornblende and

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[15] Dean, R. S., and Davis, C. W., Magnetic Separation of Ores, U. S. Bureau of Mines Bulletin 425, 1941.

biotite, and the practically non-magnetic mineral group including quartz, feldspars, sphene, zircon, apatite and pyrite. The electromagnet used was capable of producing an intense field. The magnet was composed of two 7" solenoids with 2800 turns of copper wire each about an iron core, and operated with a direct current of 100 volts and 2 amperes. Magnetic flux between the two poles passed across an adjustable air gap between two metal shoes on the base of each coil.

The customary laboratory separation procedure with such equipment is to place the minerals to be separated on a card and move it under the gap between the poles until the magnetic mineral has been pulled up to the poles. By varying the length of the air gap between poles, and the distance between the card and the air gap minerals of different magnetic attractions may be separated. This process is impractical for handling ten pounds of material.

A method permitting rapid and clean separations was devised. The electromagnet was tipped on end, so that the poles were vertically aligned. A short-stemmed glass funnel in which the inside of the funnel stem was slightly conical (upper end of 1½" stem was 0.2" and the outlet diameter was 0.1") was mounted as shown in Plate 15A. As long as the funnel stem was full, the particles fell in a fine smooth stream with no spraying. A sheet of paper covered the metal pole shoes and the air gap between them.

The magnetite in the stream of falling particles was deflected over to the poles where it was held against the paper as long as the magnet was turned on. The high speed of the falling particles and the low field intensity prevented all minerals but magnetite from being deflected. Middlings caught in a box under the poles consisted largely of locked particles of magnetite and other minerals. Over 98 per cent of the magnetite was removed from the feed in the first operation, and the remainder was extracted with one re-working. The magnetite concentrate required several re-cleanings to achieve a purity of 98 per cent.

To remove the hornblende from the practically nonmagnetic minerals of the heavy concentrate a higher field intensity separation was necessary than was practical with the above arrangement of the magnet. The air gap was decreased to about 1/8" and the entire electromagnet turned on its side to make the air gap vertical. A funnel with the stem opening pulled out to about 0.07" was used to feed the particles in a fine stream into the gap between the poles. As soon as the gap had filled to capacity with magnetic particles, the flow of the stream was cut off by placing the funnel stem opening on the top of the pole block. When the electromagnet was turned off with a foot switch, the particles fell cleanly away from the uncovered poles into the container below the gap. It was convenient to fasten the collecting boxes for the magnetic and non-magnetic fractions together so that these two boxes could be easily moved in and out from under the gap in one motion.

The magnetic concentrate by this second method only required one cleaning to achieve a high degree of purity. The non-magnetic fraction had to be re-worked twice to remove all the black minerals, but this operation was fast due to the small amount of dark minerals after the initial separation.

Heavy liquid separation

Heavy liquid separation was used to obtain three of the final mineral concentrates. The potash feldspars were floated off from the quartz-plagioclase mixture, and the quartz and feldspar of the non-magnetic concentrate was floated off from the heavy concentrate of sphene, apatite, and zircon.

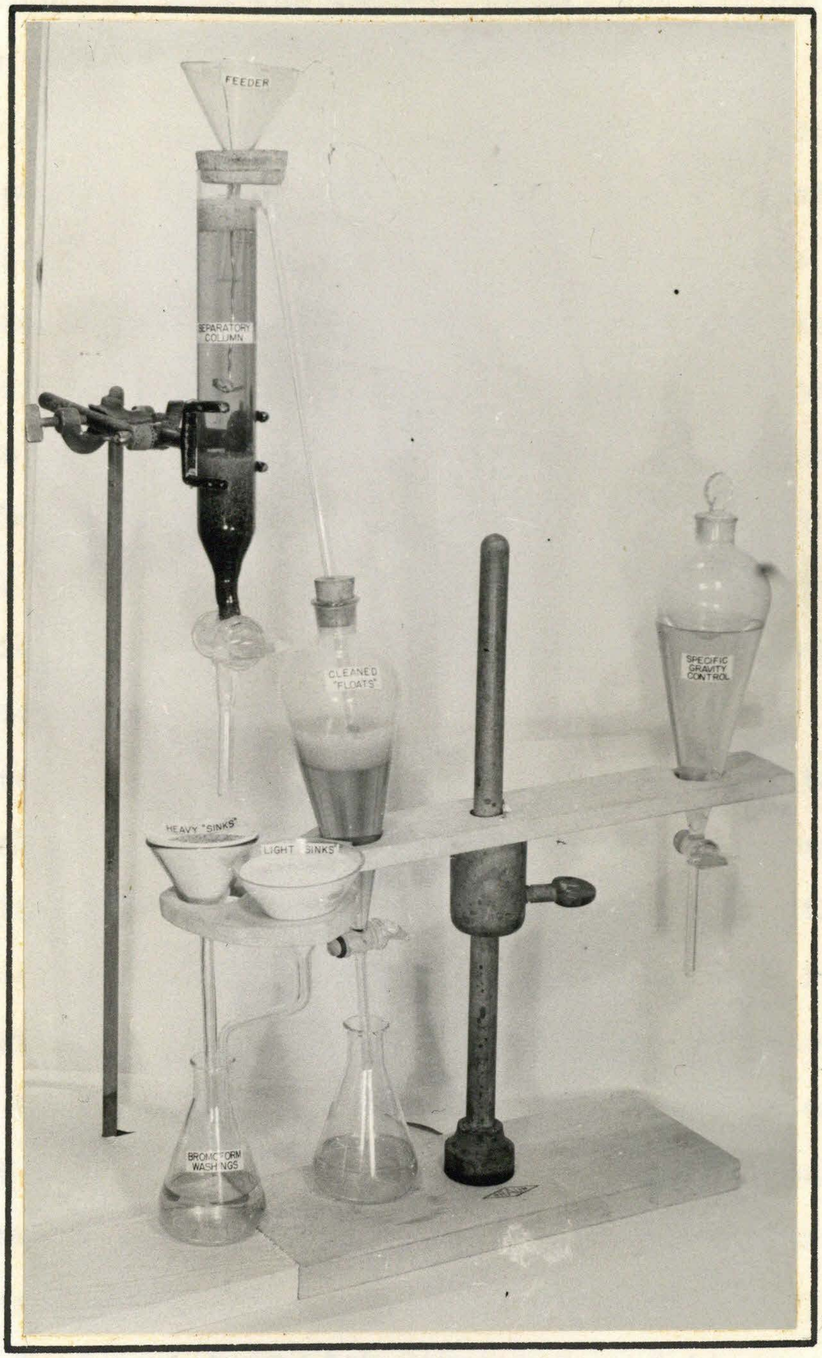
The specific gravities of the minerals occurring in the Florence Lake Dam aggregate are as follows:

Potash feldspars	2.57
Quartz	2.65
Plagioclase (andesine)	2.66
Biotite	3.0
Hornblende	3.2
Epidote	3.3
Apatite	3.2
Sphene	3.5
Zircon	4.7
Pyrite	5.0
Magnetite	5.1

The separation of three and one-half pounds of potash feldspar involved the treatment of about 25 pounds of the light concentrate from the tabling operation. The numerous heavy mineral separation devices used by sedimentary petrographers are not designed to handle large quantities of material. To adapt them to treat 25 pounds of material was out of the question. On other other hand, the commercial methods of the "sink and float" separatory process are not readily adaptable to small scale laboratory models.

A simple and efficient separatory device was designed to fit the needs of the job. This is shown in Plate 16, and is largely self explanatory. The main separatory column was made from 1 1/4" pyrex tubing, with a large bore stop cock joined to the base. Tubing, 1/8" in diameter, was joined to the top of the column in a manner to prevent mineral grains from plugging up the opening when the liquid level is raised to allow the floating grains to overflow into this side tube. The side tube leads into either a standard separatory funnel or to a filter funnel, depending on the nature of the separation. The stop cock drains into funnels equipped with filter papers. The stand holding the funnels is designed so that either one of these funnels may be swung under the drain of the separatory column to permit the rapid separation of different parts of the "sink" grains. To reduce evaporation loss, both funnels drain into the same flask. The separatory column may be stirred by use of the disc attached to a copper wire which leads out through the top of the column.

Plate 16



Heavy Liquid Separatory Apparatus

In operation, about 50 milliliters of mineral particles are dumped into the feeder funnel, and either washed into the column with the heavy liquid, or allowed to flow in dry. Heavy liquid is added until the level rises to just below the side outlet, and the pulp is stirred briefly, and then allowed to stand undisturbed till the separation is complete. Rarely is more than five minutes necessary to effect the separation. When complete, more heavy liquid is added through the feeder funnel and as the level rises, the floating particles are washed into the side tube and down. Then the lower stop cock is opened and the "sinks" drained into one or both of the funnels. The process is then repeated.

After the stirring of the separatory column, the particles which are heavier than the liquid settle at rates dependent largely on their specific gravity and are thus stratified. This process is aided by very gentle raising and lowering of the stirring disc. The gradual smooth taper of the base of the column and the wide bore of the stop cock preserve the "strata" as the mineral slush is drained out. In this manner, relatively clean quartz-plagioclase concentrates were obtained (as "sinks") even when the feed contained high percentages of biotite.

The particular advantage of having the "floats" drain into another separatory funnel is that this permits a recleaning of the concentrate. All that is necessary is to keep considerable quantities of the heavy liquid in this funnel and to slosh the funnel around occasionally to prevent grains from trapping others of different specific gravity. In the case of the feldspar separation, about 5 per cent of the floats from the primary separatory column would sink in the secondary funnel. This enabled the purity of the concentrate to rise to 97 per cent, which is high considering the closeness of the specific gravities of the "floats" and the "sinks".

The heavy liquid used in the process was bromoform. Its chief advantage lay in its availability, and fortunately the apparatus minimized evaporation loss, which normally is especially serious with bromoform. Pure bromoform has a specific gravity of 2.87. For lower specific gravities, a mixture of bromoform and acetone is used. In this work, the true specific gravity of the heavy liquid was never determined. For the feldspar separation, single fragments of quartz, potash feldspar, oligoclase and labradorite were placed in a separatory funnel with bromoform, and the liquid gradually diluted with acetone until only the potash feldspar chip floated. The use of two plagioclase minerals with specific gravities slightly greater and less than quartz afforded delicate control in the dilution of the bromoform. All of the heavy liquid added to the separatory column was added from this specific gravity control funnel, thus making a constant checking of the gravity a routine matter.

The non-magnetic heavy concentrate was cleaned of quartz and feldspar impurites by the use of bromoform used at its full strength.

This method of separation proved very satisfactory. It is particularly applicable where the volume of the "sinks" is greater than the "floats", and to cases where a rough split is desirable among the "sinks". Only two pounds of bromoform are necessary to keep the cycle in operation, but larger quantities speed up the separations. If the concentrates are thoroughly washed with acetone the bromoform loss is greatly reduced, since the bromoform dissolved by the acetone from the particles can be recovered in pure form by diluting the washings with large quantities of water. The acetone dissolves in the water, and liberates the bromoform. About four pounds of bromoform were lost in treating 25 pounds of quartz-feldspar concentrate. This seems very reasonable.

By the use of Clerici's solution, heavy liquid separations can be made for all gravities up to about 4.5[16]. With this solution very satisfactory mineral concentrates of most of the minerals occurring in igneous rocks should be possible.

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[16] Krumbein, W. C., and Pettijohn, F. J., Manual of Sedimentary Petrography, 1938, Appleton-Century Company.

Flotation and electrostatic separation

With the exception of quartz and plagioclase, the chief minerals of the Florence Lake Dam aggregate were separated from each other. The combination of quartz and plagioclase is not too undesirable. The non-reactive nature of crystalline quartz is a fundamental assumption of the testing program, and one substantiated by the tests of the U. S. Bureau of Reclamation. Thus any irregularities in the growth curves of the bars of plagioclase and quartz would throw suspicion on the plagioclase. The specific gravities of the two minerals are nearly coincident, and they may both be classed as non-magnetic as far as could be determined by existing equipment. Actually, there is a slight difference in the magnetic constants of these two minerals[17/].

The separation of quartz and any kind of feldspar by flotation is a common procedure[18/]. However, almost all cases of successful separation of these two constituents require the use of an activator, such as hydrofluoric acid,

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[17/] Gaudin, A. M., op. cit., p. 456.

[18/] Ralston, O. C., Flotation and Agglomerate Concentration of Non-Metallic Minerals, U. S. Bur. Mines, Rept. Investigations 3397, 1938 (many references).

to chemically alter the surfaces of one or both of the constituents before the flotation process is effective. The nature of the aggregate investigation prohibited any such surface attack of the minerals to be separated.

The process of electrostatic separation has developed recently. Theoretically, quartz and any kind of feldspar may be separated, but only with very expensive and specialized equipment[19/].

The following is the analysis of each of the mineral concentrates obtained by the separation processes; The percentages are by weight and were obtained by mechanical grain counting.

Biotite

98 per cent biotite. The remainder is chiefly composed of extraneous fibrous material and of small mineral fragments clinging to the edge of the biotite flakes. The fibrous material is presumed to have come from the burlap bags used for shipping the aggregate. Flakes are dominantly of the size range from 14 to 20 mesh.

Hornblende

98 per cent hornblende. Most of the remainder consists of epidote and biotite. Grains range from 60 to 150 mesh.

Sphene, zircon, apatite

89 per cent sphene, 5 per cent apatite, and 4 per cent zircon. The remaining 2 per cent consists chiefly of pyrite, with traces of epidote, hornblende, quartz and feldspar. Particle size varies from 40 to 200 mesh, with the sphene concentrated in the coarser sizes and the apatite and zircon present largely from 150 to 200 mesh.

[19/] Johnson, H. B., Selective Electrostatic Separation, Am. Inst. Mining Met. Engrs., Tech. Pub. 877, 1938.

Magnetite
98 per cent magnetite. The remainder consists of small grains of epidote, sphene and hornblende. Particle size ranges from 40 to 200 mesh, with the bulk occurring from 80 to 150 mesh.

Potash feldspar
97 per cent potash feldspar, with a ratio of orthoclase to microcline of about 1:4. 93 per cent of the particles are free potash feldspar, 5 per cent are locked particles in which the potash feldspar is the chief constituent, and the remaining 2 per cent consists of quartz, plagioclase and biotite. The particle size ranges from 30 to 80 mesh.

Quartz-plagioclase
96 per cent quartz and plagioclase, of which quartz makes up 54 per cent and plagioclase 42 per cent. The average composition of the plagioclase is that of andesine. Impurities are largely potash feldspar with lesser amounts of biotite and hornblende present. The particle size varies from 30 to 80 mesh.

AGGREGATE TESTING PROGRAM

Recent emphasis has been given to the study of deleterious reactions involving the aggregate and the cement paste in concretes with the discovery of the marked effect of the alkali content of the cement. It is not known if the deterioration present in the Florence Lake Dam concrete is due to an alkali reaction. It is simply a possibility. In consideration of this possibility, the mineral concentrates obtained from the Florence Lake Dam aggregate were fabricated with both high and low alkali cements.

Due to the nature of the alteration products which are present in the Florence Lake Dam aggregate, it was not possible to isolate any of them for use in the testing program. However, the most altered rock was crushed up and used in two different percentages as aggregate for mortar test bars. It is probable that the mineral concentrates obtained in the separation process represent the freshest mineral grains of that type in the Florence Lake Dam aggregate, since there is a "survival of the fittest" which in this case could more aptly be termed the "survival of the freshest".

The mineral concentrates were used as aggregate in different percentages ranging from 2 per cent of the aggregate to 100 per cent. The remaining percentage of the aggregate consisted of inert quartz supplied by the Bureau of Reclamation. The percentages were selected in consideration of their natural proportion in the rock, and also the amount of mineral concentrate which was readily available.

The following is a table of the aggregate mixes used in the fabrication of the mortar test bars which comprise the testing part of this investigation. The percentage figure after the mineral name indicate the amount of that mineral concentrate used in the aggregate, the remaining percentage consisting of inert quartz.

Mineral	Per cent of mineral concentrate in aggregate					
Quartz-plagioclase		5	10	25	50	100
Potash feldspar	2	5	10	25	50	100
Biotite	2	5	10	25	50	100
Hornblende	2	5	10	25	50	
Magnetite	2	5	10	25		
Sphene	2	5	10			
Fresh "granodiorite"						100
Altered "granodiorite"					50	100
Siliceous magnesian limestone				20		

Each aggregate mix listed above has been fabricated with a high and low alkali cement, with triplicate bars being made for each condition. The cements used are as follows:

1. Low alkali cement. This is the special United States Bureau of Reclamation cement No. 13, which is supplied by the Penn-Dixie Co. of Clinchfield, Georgia. The total alkali content of this cement is 0.18%.

2. High alkali cement. This is cement produced by the Riverside Cement Co. of Riverside, California. The analysis for alkali content is 0.47% and 0.87% Na_2O, thus giving 1.34% for the total alkali content.

Mixing

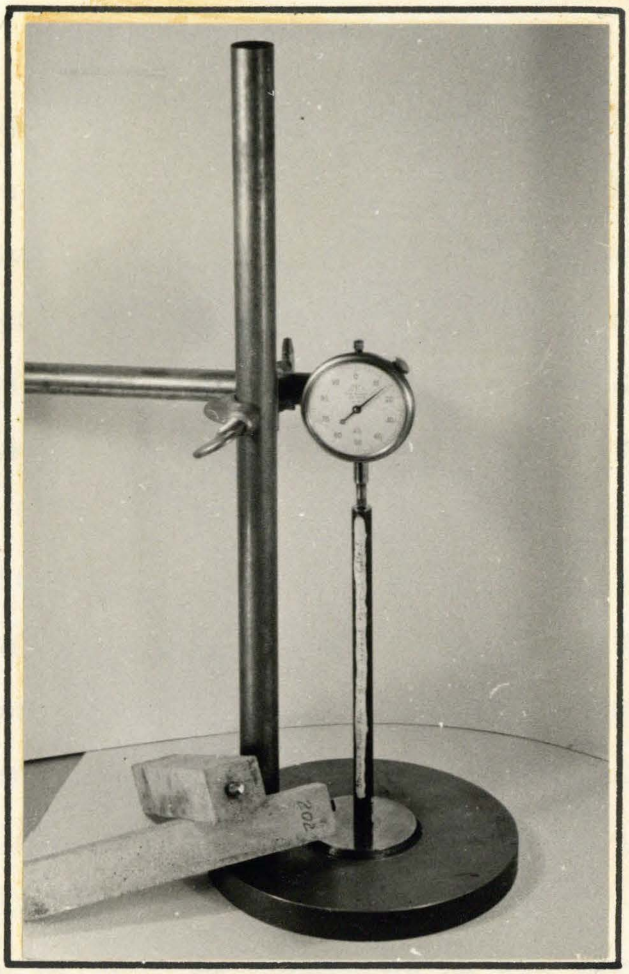
All mortars consist of one part of cement to two of aggregate, by weight. The standard quartz grading used in the aggregate is 24 per cent each of sieve sizes Nos. 8-16, 16-30, 30-50, 50-100, and four per cent of 100-150. The grading of the various mineral concentrates was controlled by the sizes which could be effectively separated. The water-cement ratio was held as close to 0.45 as possible, but in many instances, it was necessary to increase this ratio to achieve the optimum consistency of the mortar. Distilled water was used exclusively for mixing.

Molding

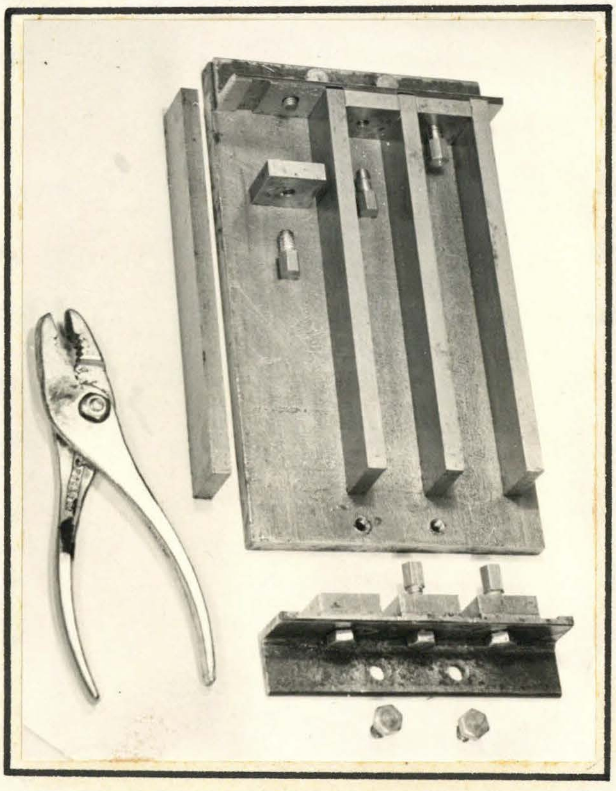
Four molds, each with a capacity of three 1" by 1" by 6" bars, were used in the program. These molds are designed so that the reference points in both ends of the mortar bar are separated by five inches of the mortar. Plate 17B shows one of these molds. In placing, the mortar was first puddled around the reference points, and then the molds were filled. The mold with its contained mineral was vibrated by hand in both horizontal and vertical directions for about a minute after which the mortar was struck off even with the top of the mold. Bars were fabricated in groups of 12.

Curing

The mortar filled molds were kept at a temperature of 70° F. in an atmosphere 100 per cent humidity for 24 hours. The bars were then removed from the molds, numbered, wrapped in moist paper towels, and allowed to cure for seven days at 70° F. The towels were re-moistened when necessary to insure 100 per cent humidity around the bars.



A. Length measurement apparatus with Invar standard and several mortar test bars.



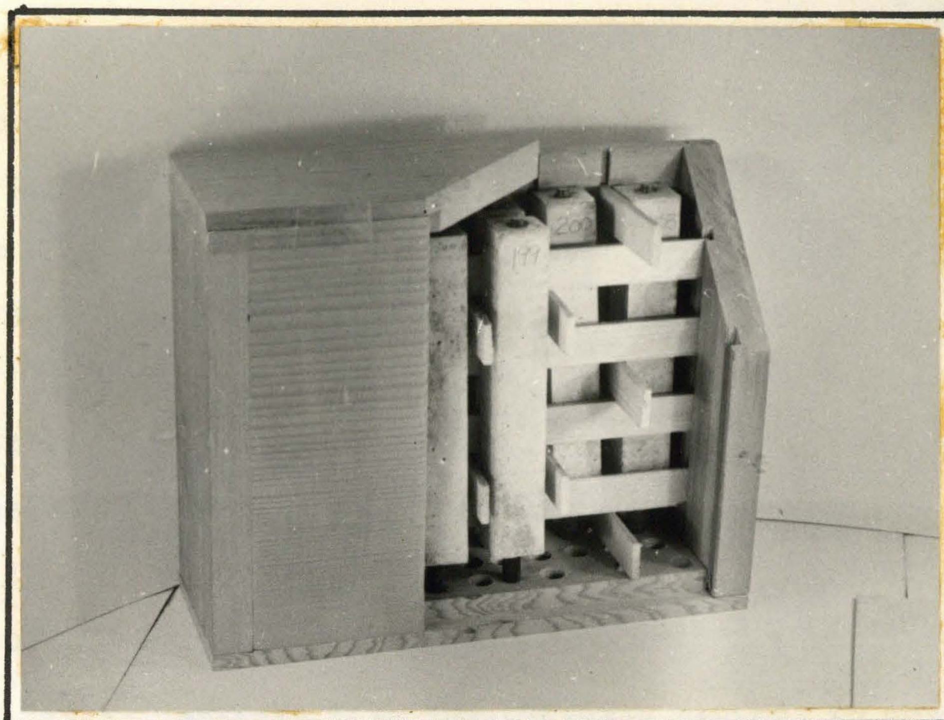
B. Detail of a mold used to make 1"x1"x6" mortar bars

After the initial measurements the bars were put into redwood boxes, each of which holds 12 bars in a vertical position. One-half inch lengths of 3/16" diameter rubber tubbing slipped over the basal reference point of the mortar bar holds the bar out of contact with a 1/4" of water in the bottom of the box. Plate 18A is a cut-a-way view of one of these boxes. The inside of the lid of the box is lined with blotter paper which is saturated before sealing the box. The boxes were boiled in paraffin to make the wood as air and water tight as possible. Scotch cellulose tape sealed off the crack between the lid and the box.

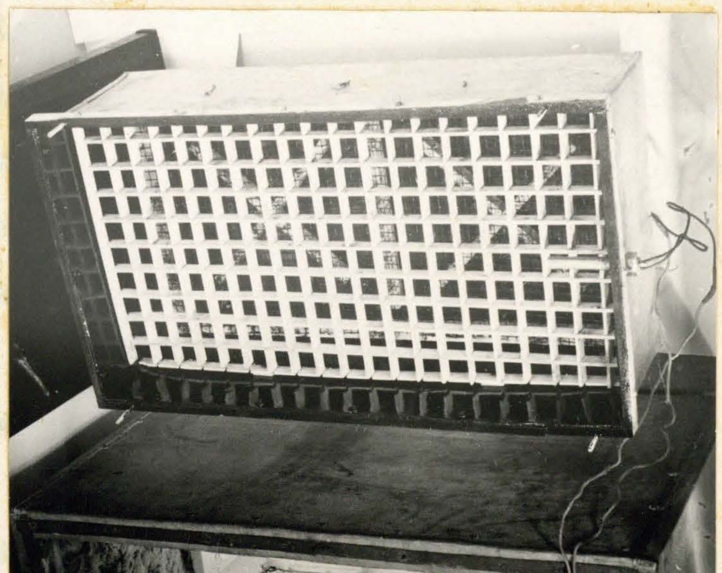
The filled boxes were stored in the curing cabinet, a re-vamped ice box with thermostatic control to maintain a temperature of 100° F. Humidity in the curing cabinet was kept as high as possible to prevent the bars from any appreciable drying. This curing system was not entirely satisfactory. Weight losses of several per cent did occur with many of the bars in spite of all remedial measures tried. The chief troubles with the wooden box-curing cabinet combination were the necessity of almost daily attention to maintain the proper humidity, and the lack of uniformity of curing conditions for all bars. This latter objection even held true for bars within a single box.

The system of having all the bars made at one time in a separate "sealed" container within the curing cabinet was advantageous during the early stages of the curing since

Plate 18



A. Redwood curing box for 12-1"x1"x6" mortar bars



B. Curing chamber for 200 mortar bars. Temperature thermostatically maintained at 100° Fahrenheit measurements of some set of bars were necessary every day and the box containing one set of bars could be removed from the curing cabinet without disturbing the temperature and humidity of the other bars in the cabinet.

To eliminate these troubles a second curing chamber was built. (Plate 18B). This consists of two concentric boxes separated by several inches of rock wool insulation. The inner box has a rack to accomodate 200 bars. With the lid on, the inner box is essentially hermetically sealed. This box is equipped with thermostatic control to maintain the temperature at 100° F. The heat is supplied by a battery of light bulbs in an asbestos lined box just under the inside box. About half an inch of water in the bottom of the inner box supplies the humidity to prevent moisture loss from the bars. This curing chamber allows all bars to cure under uniform conditions and will not require attention more frequently than monthly intervals.

Measurements

Initial length measurements were made at the end of a seven day curing period during which the temperature was maintained at 70° F. Successive measurements were made at approximately weekly intervals for the first month, and then the interval was increased to one month. The absolute length of the bar is not determined, but only the difference between the length of the mortar bar and the length of a standard Invar metal bar.

The reference points in the ends of the bars were ground down at the end of the initial seven day curing to a foursided pyramid with apical angle of 76°. The measurement apparatus available necessitated making these points. Plate 17A shows the measuring apparatus, standard bar, and several mortar bars. The raised central portion of the basal plate is flat and highly polished.

In making the measurements, the maximum reading of the dial gage is recorded. The gage reads directly to hundredths of a millimeter, and may be estimated to thousanths with a probable error not in excess of 0.003 mm. As a check on the curing conditions, the weight is determined to 0.1 gram each time the length measurement is made.

Initial data for the mortar test bars

The abbreviations used in Table following are:

High	high alkali cement
Low	low alkali cement
Hbl	hornblende
Qtz-Plag.	quartz-plagioclase concentrate
K-feld	potash feldspar
Sphene	sphene, apatite, zircon concentrate
Fresh Gr	fresh "granodiorite"
Alt. Gr	altered "granodiorite"
Si Mg ls	siliceous magnesian limestone

Bar	Cement	Mineral	%	Water cement	Length* mm.	Weight grams	Date measured
1	High	Biotite	2	0.52	-0.302	232.2	2-12-43
2					0.742	231.3	
3					0.226	229.7	
4	Low	Biotite	2	0.52	0.851	234.7	"
5					0.534	236.9	
6					0.692	236.1	
7	Low	Biotite	5	0.52	-0.718	236.4	"
8					-0.866	238.8	
9					-0.610	238.6	
10	High	Biotite	5	0.52	-1.314	237.7	"
11					-0.515	227.9	
12					-0.404	237.0	
13	High	Biotite	10	0.45	-1.076	231.4	2-15-43
14					-0.609	231.2	
15					-0.624	229.6	
16	Low	Biotite	10	0.45	0.840	236.6	"
17					0.747	239.4	
18					0.363	242.6	
19	High	Biotite	25	0.54	-0.454	236.3	"
20					0.547	233.7	
21					0.142	232.3	
22	Low	Biotite	25	0.54	-1.595	235.5	"
23					-1.604	236.0	
24					-2.644	235.3	
25	High	Biotite	50	0.59	-2.117	227.9	2-18-43
26					-0.241	224.2	
27					-1.759	227.9	
28	Low	Biotite	50	0.59	-1.166	228.3	"
29					-0.940	221.0	
30					-1.656	222.4	
34	Low	Biotite	100	0.60	-0.948	207.2	"
35					-0.308	202.0	
36					0.103	201.0	
37	High	Biotite	100	0.60	-1.828	203.1	
38					-1.179	208.5	
39					0.215	195.9	
40	Low	Magnetite	2	0.45	-0.269	246.3	2-21-43
41					-0.329	247.6	
42					-2.554	252.6	
43	High	Magnetite	2	0.45	-1.708	244.3	"
44					-1.455	242.3	
45					-2.633	244.3	
46	Low	Magnetite	5	0.45	-1.531	247.3	"
47					-0.443	242.7	
48					-1.056	245.4	

*As compared to a standard Invar metal bar.

Bar	Cement	Mineral	%	Water cement	Length mm.	Weight grams	Date measured
49	High	Magnetite	5	0.47	-0.906	245.1	2-21-43
50					-1.404	245.1	
51					-0.508	244.2	
52	Low	Magnetite	10	0.45	-0.945	242.7	2-23-43
53					-0.645	247.4	
54					-0.390	244.6	
55	High	Magnetite	10	0.45	-0.424	244.2	"
56					-0.814	242.4	
57					-1.397	247.0	
58	High	Magnetite	25	0.45	0.349	254.5	"
59					-1.384	251.9	
60					-1.068	253.4	
61	Low	Magnetite	25	0.46	-2.687	250.8	"
62					-2.663	248.8	
63					-1.507	248.3	
64	Low	K-feld.	2	0.45	0.106	244.4	2-25-43
65					0.578	242.1	
66					-0.157	247.6	
67	High	K-feld.	2	0.42	-0.855	241.5	"
68					-0.809	241.6	
69					-0.536	242.7	
70	High	K-feld.	5	0.45	0.698	238.4	"
71					-1.955	242.4	
72					-0.452	240.0	
73	Low	K-feld.	5	0.46	-0.845	237.3	"
74					-0.817	233.8	
75					-0.593	236.8	
76	High	K-feld.	10	0.50	-1.270	232.3	2-28-43
77					-1.236	234.0	
78					-1.232	234.3	
79	Low	K-feld.	10	0.45	-1.456	241.7	"
80					-0.365	242.5	
81					-1.924	241.3	
82	Low	Hbl.	2	0.45	-1.291	243.4	"
83					-0.441	243.9	
84					-0.105	242.4	
85	High	Hbl.	5	0.45	-0.137	245.9	"
86					-0.802	246.9	
87					-0.568	243.6	
88	High	Hbl.	2	0.45	0.176	241.8	3-3-43
89					-0.567	239.5	
90					-1.803	240.9	
91	Low	Hbl.	5	0.45	-0.618	239.6	"
92					-1.195	239.1	
93					-2.193	240.3	
94	High	Qtz-plag.	100	0.57	0.492	223.2	"
95					-0.870	225.1	
96					0.130	226.4	
97	Low	Qtz-plag.	100	0.57	0.172	221.5	"
98					-2.363	221.0	
99					-0.824	220.4	

Bar	Cement	Mineral	%	Water cement	Length mm.	Weight grams	Date measured
100	Low	Hbl.	10	0.45	-0.701	241.3	3-6-43
101					-1.174	240.5	
102					0.018	243.5	
103	High	Hbl.	10	0.45	0.139	240.6	"
104					-0.084	242.1	
105					0.742	243.5	
106	High	Hbl.	25	0.45	0.499	242.3	"
107					-0.304	245.4	
108					-0.601	243.8	
109	Low	Hbl.	25	0.45	-0.353	246.3	"
110					-0.219	250.4	
111					-0.063	249.9	
112	Low	Sphene	2	0.45	-0.345	238.6	3-9-43
113					-0.215	241.9	
114					0.262	241.0	
115	High	Sphene	2	0.45	-0.084	244.0	"
116					0.556	243.9	
117					-1.965	245.9	
118	High	Sphene	5	0.45	0.259	246.1	"
119					0.059	248.4	
120					-0.854	249.1	
121	Low	Sphene	5	0.45	-0.480	246.4	"
122					-0.288	245.6	
123					-0.208	242.7	
124	High	K-feld.	25	0.45	-1.895	251.9	3-15-43
125					-1.687	233.6	
126					-2.316	234.7	
127	High	Sphene	10	0.45	-0.677	248.2	"
128					-1.273	244.8	
129					-1.070	245.1	
130	Low	Sphene	10	0.45	-1.087	245.0	"
131					-1.520	245.3	
132					-0.159	245.1	
133	High	Magnetite	5	0.45	-0.540	243.4	"
134					-0.256	242.7	
135	No bar made						
136	High	Qtz-plag.	50	0.62	-1.246	225.7	3-20-43
137					-0.998	224.2	
138					-1.961	226.4	
139	Low	Qtz-plag.	50	0.58	-1.224	257.9	"
140					-0.870	232.4	
141					-1.811	231.7	
142	High	Qtz-plag.	25	0.46	-1.429	236.5	"
143					-1.254	233.8	
144					0.389	236.0	

Bar	Cement	Mineral	%	Water Cement	Length cm.	Weight grams	Date measured
145	Low	qtz-plag.	25	0.46	-0.689	233.1	3-20-43
146					-0.302	233.4	
147					-0.295	232.0	
148	High	qtz-plag.	10	0.45	-1.472	235.6	3-28-43
149					-0.641	234.8	
150					-3.035	235.2	
151	Low	qtz-plag.	10	0.45	-1.672	241.4	"
152					-1.087	243.8	
153					0.574	242.7	
154	High	qtz-plag.	5	0.45	-1.227	242.1	"
155					-0.809	243.1	
156					-1.732	243.5	
157	Low	qtz-plag.	5	0.45	-1.557	235.9	"
158					-0.683	235.2	
159					-1.985	234.2	
160	High	si-Mg-ls.	20	0.45	-0.849	235.6	3-30-43
161					-0.679	237.0	
162					-1.138	235.7	
163	Low	si-Mg-ls.	20	0.45	-2.051	240.9	"
164					-1.805	238.4	
165					0.107	236.5	
166	High	K-feld.	25	0.45	-0.902	236.3	"
167					-0.676	235.4	
168					-0.200	238.0	
169	Low	K-feld.	25	0.45	-2.262	232.6	"
170					-1.485	236.1	
171A					-0.520	233.0	
171B	High	Hbl.	50	0.47	-0.674	243.1	4-8-43
172					-0.885	243.9	
173					-0.543	243.2	
174	Low	Hbl.	50	0.47	-1.640	244.9	"
175					-0.584	246.1	
176					0.125	249.6	
177	Low	Fresh gr.	100	0.50	-0.320	240.0	"
178					0.894	242.6	
179					-1.003	242.7	
180	High	Fresh gr.	100	0.50	0.006	231.4	"
181					-1.653	230.7	
182					-1.489	233.5	
183	High	Alt. gr.	100	0.50	-0.661	229.5	4-17-43
184					-1.106	229.3	
185					-0.930	227.5	
186	Low	Alt. gr.	100	0.50	-0.744	237.1	"
187					-0.922	234.2	
188					-1.425	236.6	
189	High	Alt. gr.	50	0.55	-0.998	229.6	"
190					0.329	229.6	
191					0.280	228.9	

Bar	Cement	Mineral	%	Water cement	Length mm.	Weight grams	Date measured
192	Low	Alt. gr.	50	0.55	-1.727	231.4	4-17-43
193					-2.175	233.2	
194					-0.270	232.6	
195	High	K-feld.	50	0.55	-0.728	220.5	5-21-43
196					-1.141	223.6	
197					0.158	222.0	
198	Low	K-feld.	50	0.58	-1.255	224.1	"
199					-0.563	224.2	
200					-0.073	222.6	
201	High	K-feld.	100	0.59	-0.074	206.5	"
202					-0.808	211.6	
203	Low	K-feld.	100	0.58	-0.332	210.2	"
204					-0.674	213.8	

Validity of results of the testing program

The validity of this testing program in revealing any dangerous aggregate rests largely on the following:

1. The curing conditions, while not identical with the environment of concrete within a structure, are such that any deleterious nature of the aggregate will be revealed during the time of the testing period.

2. The sizes and percentages of the minerals used as aggregate are such as to permit any deleterious nature of those minerals to develop and be detected.

3. The inert quartz used as part of the aggregate for most of the mortar bars is essentially inert under the testing conditions.

4. Physical appearance of the mortar test bars and their changes of length may be used as the criteria to detect deleterious aggregate-cement reactions.

It is not practical to simulate the environment of concrete within a major structure to test the possible reactivity a given combination of cement and aggregate may have. Methods of acceleration of any possible reactions must be employed.

Stanton was the first to note the acceleration in the speed of reaction between opaline silica and a high alkali cement which may be obtained by curing test bars in moist sealed containers.[20] The Bureau of Reclamation at Denver has tested the effect of temperature on the speed of reaction, and found that 100° F. has an additional accelerating effect. The full particulars of their comprehensive investigation of alkalies in cement was printed for limited distribution in July 1942.[21] From the success of the testing methods, that is, the use of sealed containers and a temperature of 100° F., experienced by the Bureau of Reclamation and others working along the same lines it is probable that the use of these curing conditions will promote any deleterious reaction possible with the combinations of cement and aggregate used in this testing program.

The size of a mineral particle, and its percentage of the total aggregate may affect its behavior in concrete.[22] In the case of the known reactive mineral, opal, sizes from 50 to 100 mesh yield the greatest expansion with a high alkali cement. Little or no expansion is detectable with particles below 150 mesh. Particles the size of 8 mesh produce about

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[20] Stanton, T. E., op. cit. p. 1786

[21] U. S. Bureau of Reclamation, Progress Report - Alkalies in Cement and their effect on Aggregates and Concretes. Laboratory report No. Ce-40, Denver, Colo. July 1942

[22] U. S. Bureau of Reclamation, op. cit., pp. 176-183

one-third of the expansion produced by 50 mesh reactive mineral. In the process of separating the minerals used in this testing program it was a case of taking what could be had and hoping for the best. All of the separated particles are less than 10 mesh and larger than 200 mesh.

The amount of mineral used in the aggregate is also important. Again, to cite the experience with opal, it is found that about 5 per cent of this mineral in the aggregate yields the maximum expansion. In this investigation, consideration of the percentage is not as serious as that of size, since the percentages could be easily controlled. In general, test bars were fabricated with amounts of mineral both higher and lower than the natural percentage of that mineral in the Florence Lake Dam aggregate.

The Bureau of Reclamation has established the essentially inert character of the quartz used for aggregate mixes. The assumption that deleterious aggregate may be detected by the physical appearance and the length changes of the mortar test bar is necessary, and undoubtedly justified.

Little may be said in regard to the time necessary for reactions to develop. Opal shows excessive expansion in the first month. However, this does not mean that all reactive minerals will have the same rate of response. It is perfectly possible to have a test bar expand very slowly, but continually until it reaches an excessive high. Stanton reported a case where there was no expansion at 12 months, and very appreciable expansion in the period from 12 to 18 months.[23]

The best indication that the curing conditions obtained to date in this investigation are those which promote reaction between aggregate and cement is the large expansion of the bars made from siliceous magnesian limestone and high alkali cement. These bars lost 2 to 3 grams in the early curing, and yet the reaction was not checked. Thus it is reasonable to infer that similar weight losses with many of the other bars will cause no lasting damage to possible reactions. Another insight to the nature of these reactions is seen in the experience of the Southern California Edison Company at their Alhambra laboratory.[24] After fabrication, the bars, which included a set made from siliceous magnesian limestone and high alkali cement, were cured in a system which dried out the moisture from the bars to such an extent that those made from the known reactive combination actually shrunk. However, when the proper curing conditions were restored and the moisture content regained by the bars, the reaction proceeded immediately.

Preliminary results of the testing program

Although it is too early in the testing program to formulate definite conclusions from the tests, some generalizations

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[23] Stanton, T. E., Expansion of Concrete through Reaction between Cement and Aggregate, Unpublished discussion p. 10, August, 1941

[24] R. W. Spencer., oral communication, January, 1943

may be made;

1. During the initial two months of curing, the low alkali bars average about one third less expansion than the high alkali bars, regardless of the aggregate.

2. None of the minerals from the Florence Lake "granodiorite" approach the reactivity, at least the early reactivity, of the bars made from siliceous magnesian limestone and a high alkali cement. At two months, the average expansion of the latter bars is 0.22 per cent, as contrasted with a figure of 0.04 per cent for the greatest average expansion of bars made from Florence Lake "granodiorite" minerals.

3. There is a close connection between the length changes of the bars and the moisture contnet of the bars, with shrinkage taking place when the bar dries.

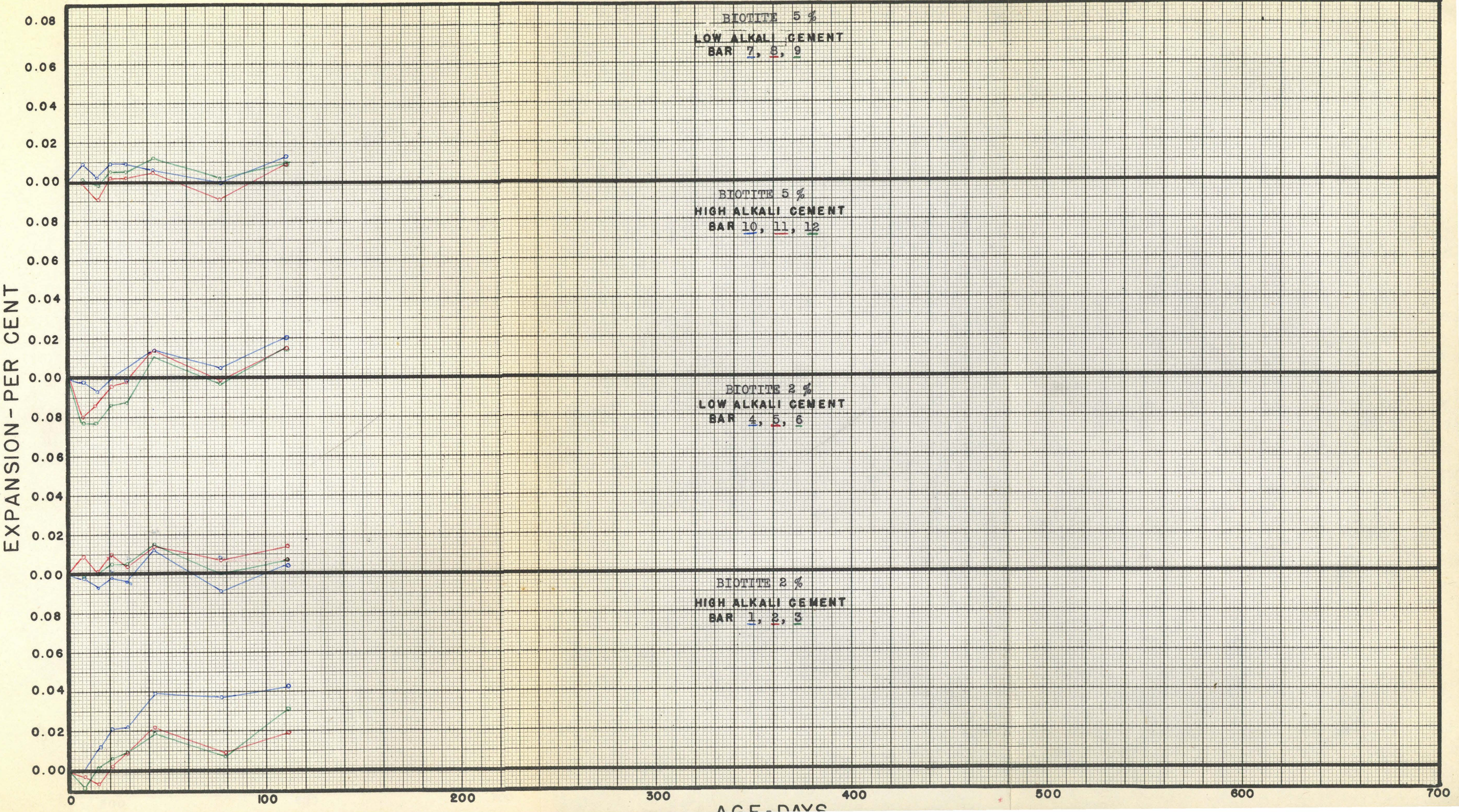
4. The results found to date with different sets of bars made from identical aggregate and cement show a good correspondence.

The curves obtained so far in the testing program for the expansion-time relations of the bars are difficult to analyse, to to the very appreciable variance of curing conditions between separate boxes used initially in the curing chamber. It was found that bars in one redwood box would gain in weight during the same time that another set would lose weight. All of the bars were transferred to the single large curing chamber in the middle of May. Conditions are uniform for all bars within this chamber. The last complete set of measurements was made two weeks after the transfer, and the graphs show that many of the differences of expansion between bars of the same set have been eliminated. All of the weight which was lost in the first curing chamber was regained in this last two weeks.

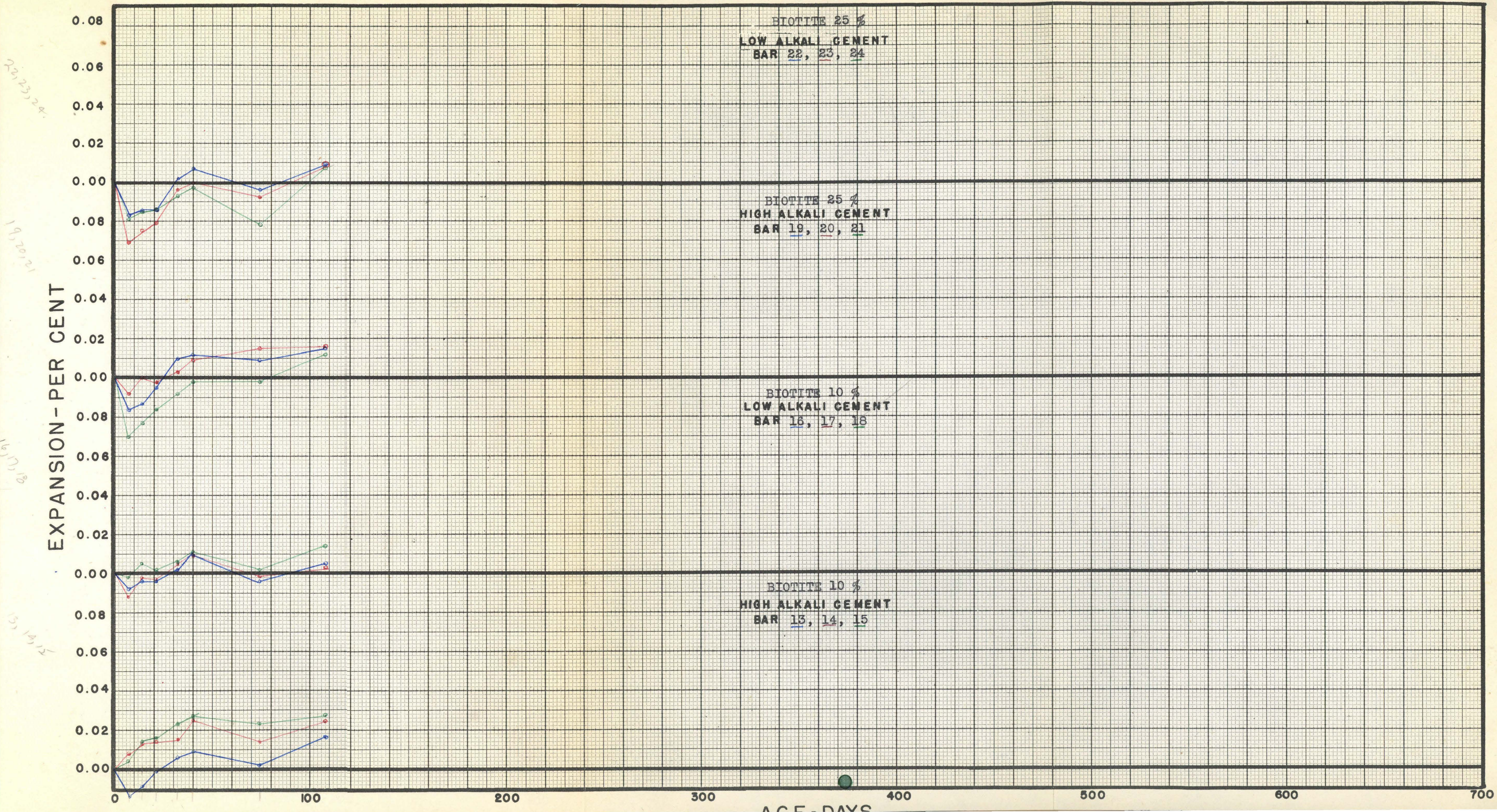
At the time of the last measurements, all bars were closely examined for cracks, exudations, or any other peculiar surface condition. Only bar 160 was cracked, and this only half an inch in length. This bar was one made from known reactive aggregate and high alkali cement. The other bars of this set have white spots peppered on the surface, but no cracks.

In the following graphs, the length changes for each cement-aggregate combination are plotted on separate coordinate axes, and so arranged that four combinations of three bars each can be put onto one sheet. The twelve bars whose length changes are recorded on any one graph were fabricated together, and stored in the same redwood curing box before transfer to the single curing chamber now in operation. The length changes of the lowest numbered bar of the set of three is plotted with blue ink, those of the intermediate bar with red ink, and those of the highest numbered bar with green ink.

FLORENCE LAKE AGGREGATE INVESTIGATION

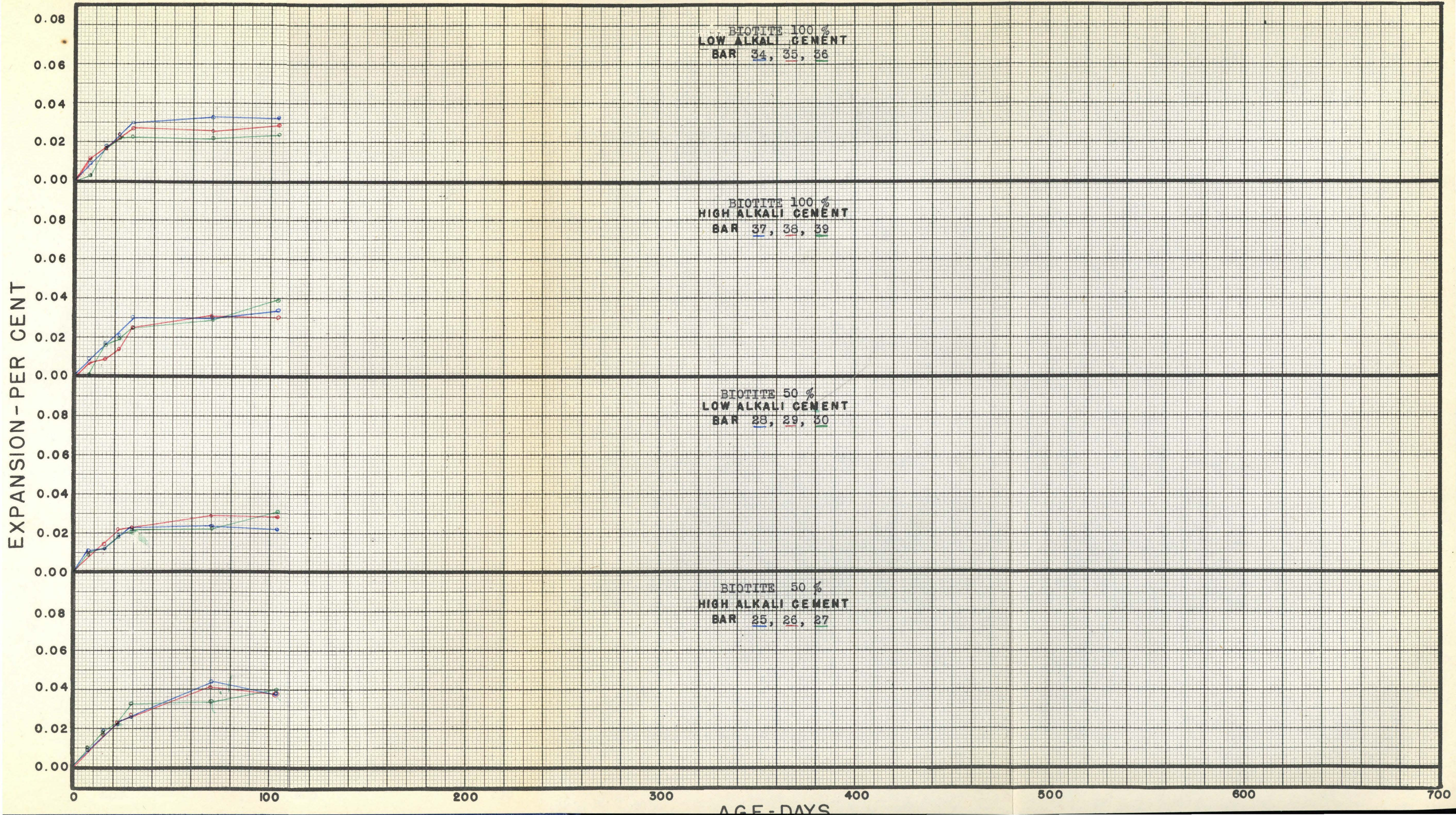


FLORENCE LAKE AGGREGATE INVESTIGATION



FLORENCE LAKE AGGREGATE INVESTIGATION

25-39



40-51

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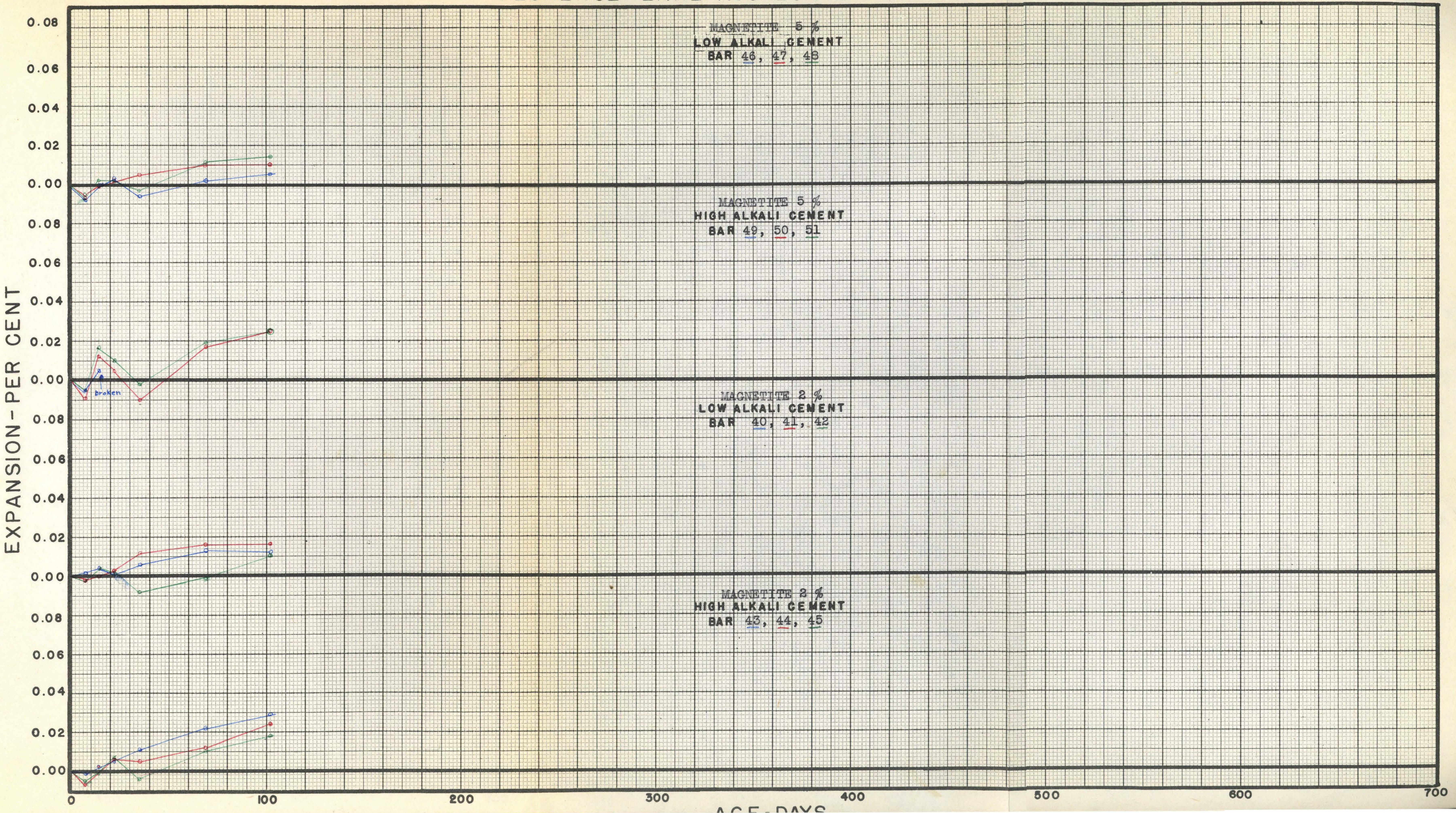
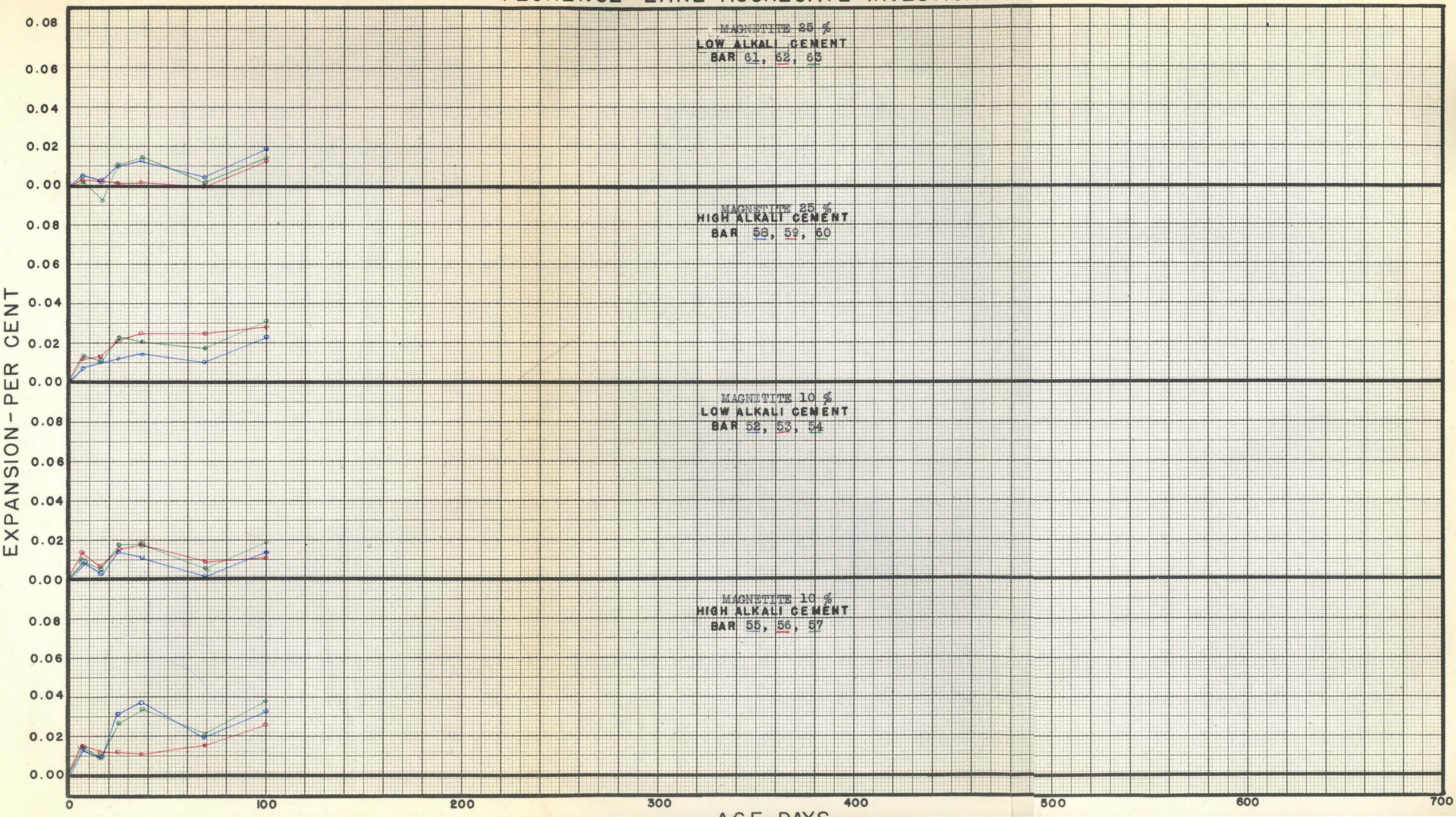


FLORENCE LAKE AGGREGATE INVESTIGATION

52-63



64-75

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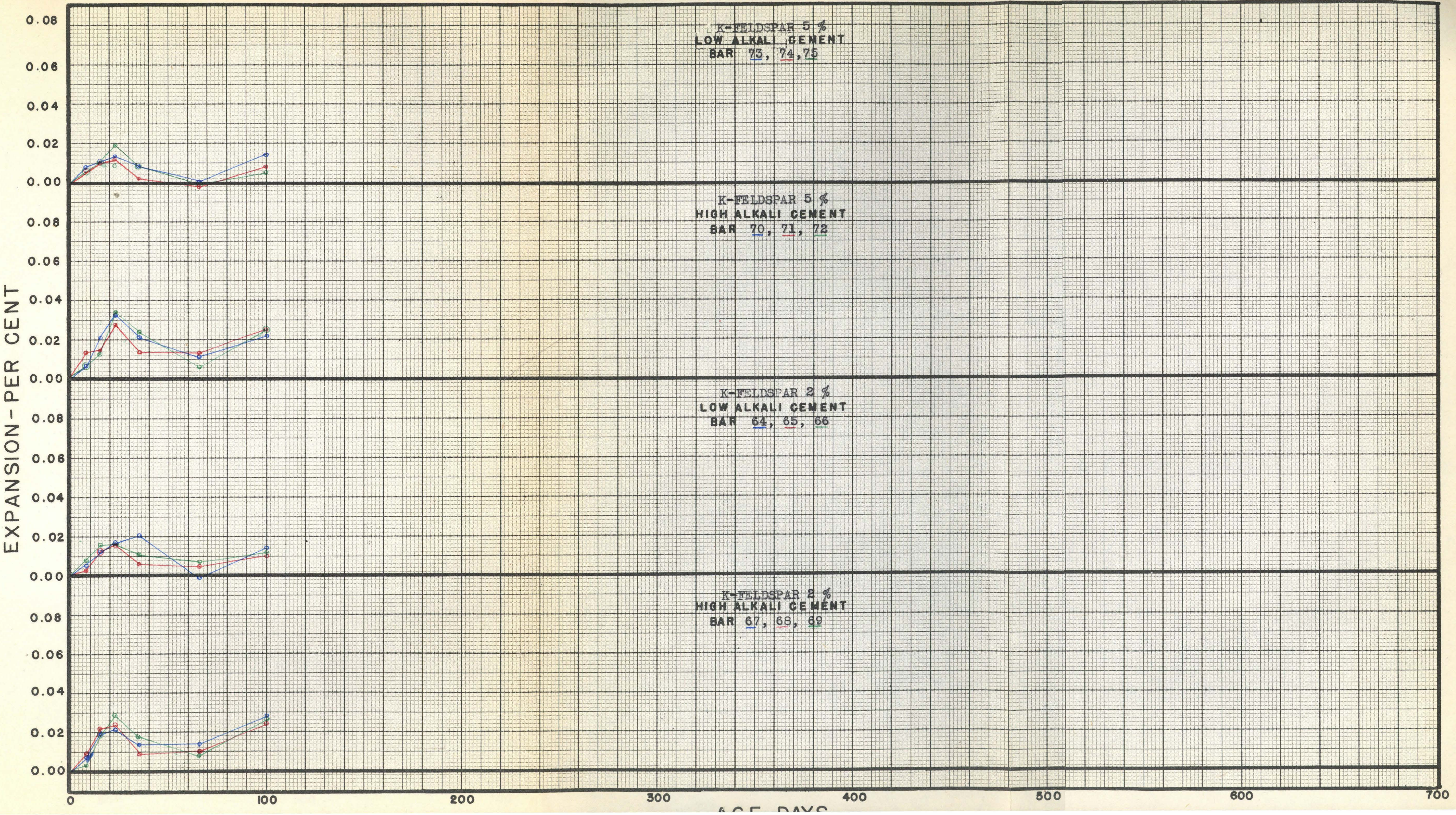
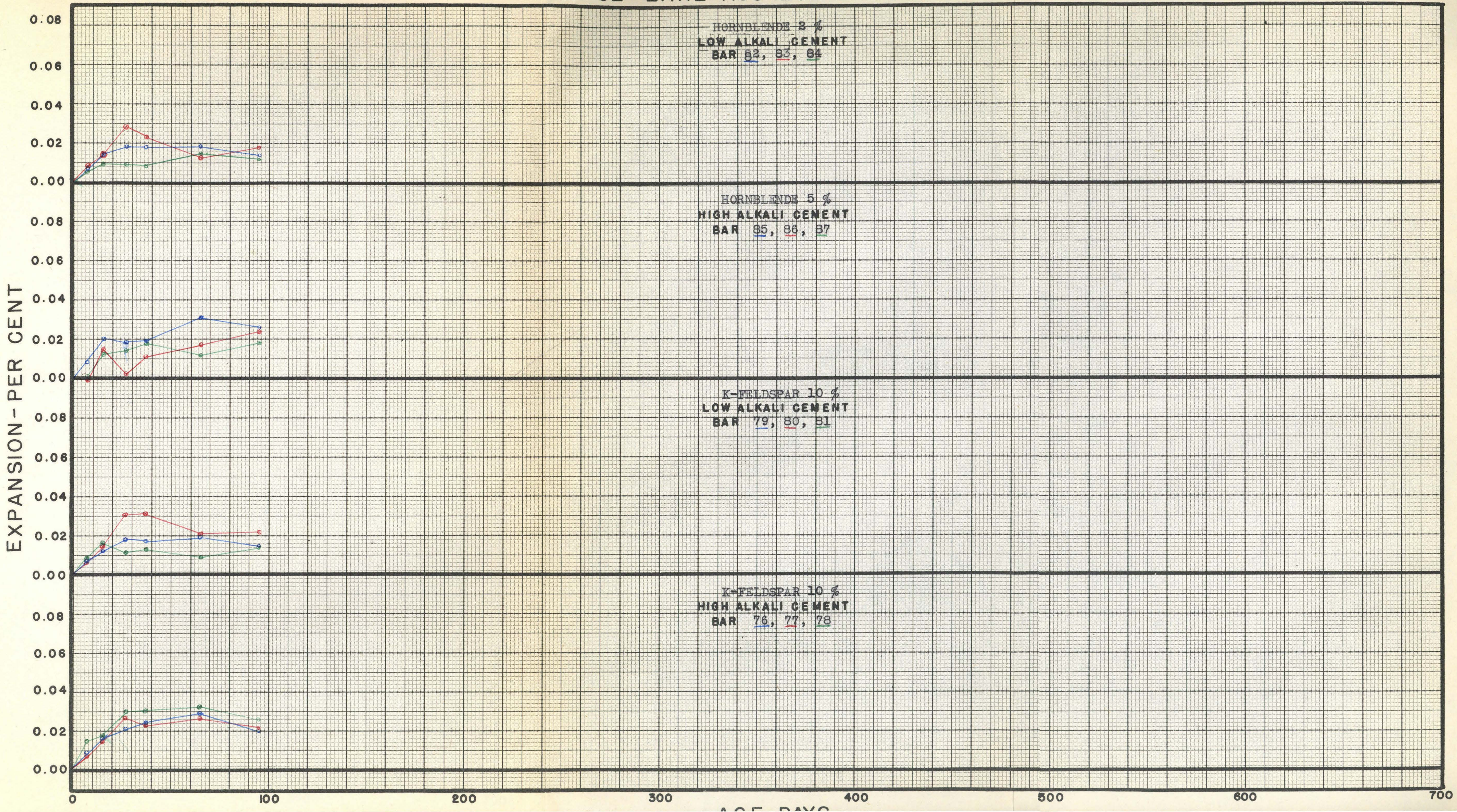


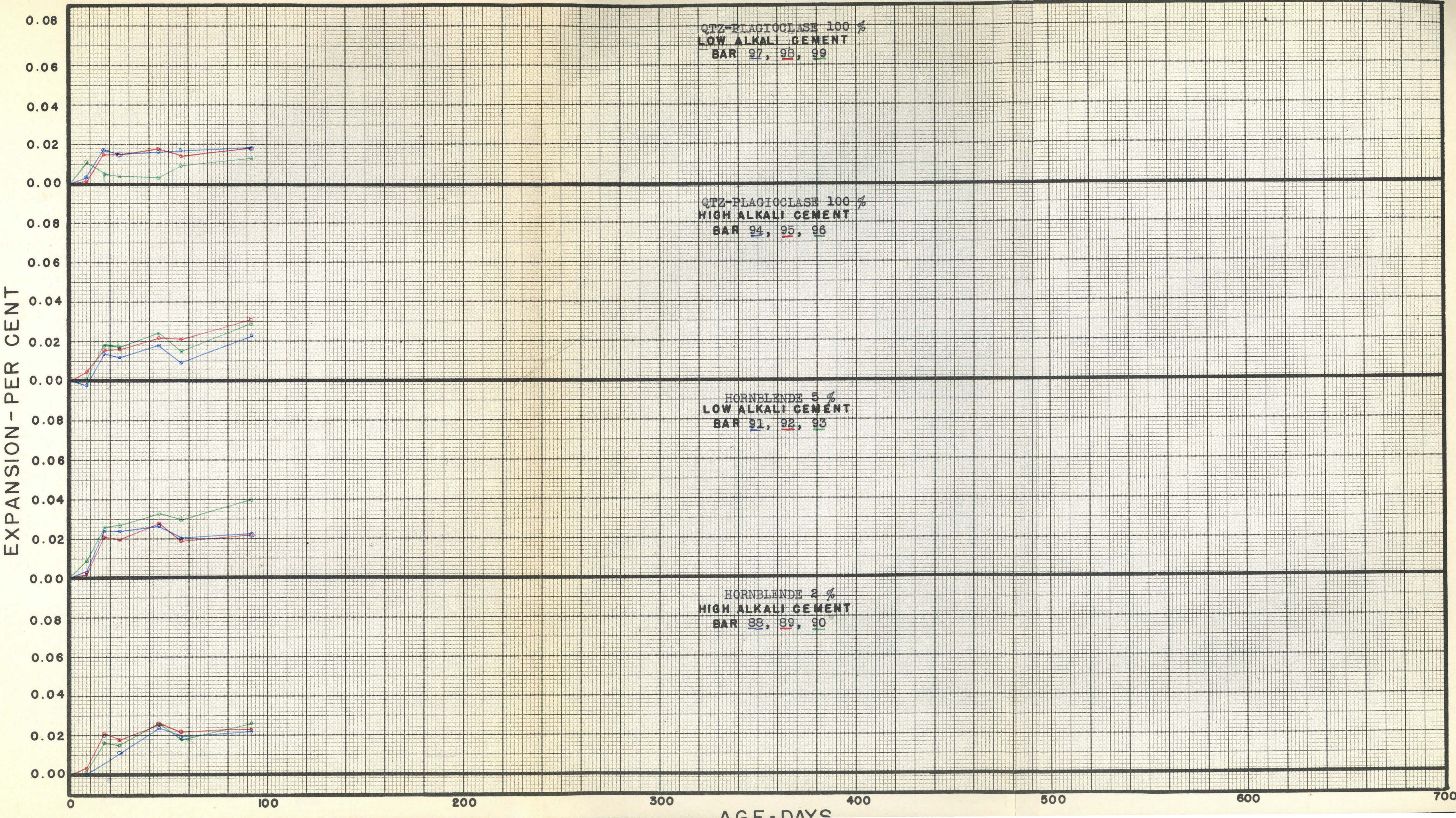
FLORENCE LAKE AGGREGATE INVESTIGATION

76-87



FLORENCE LAKE AGGREGATE INVESTIGATION

88-99



100-111

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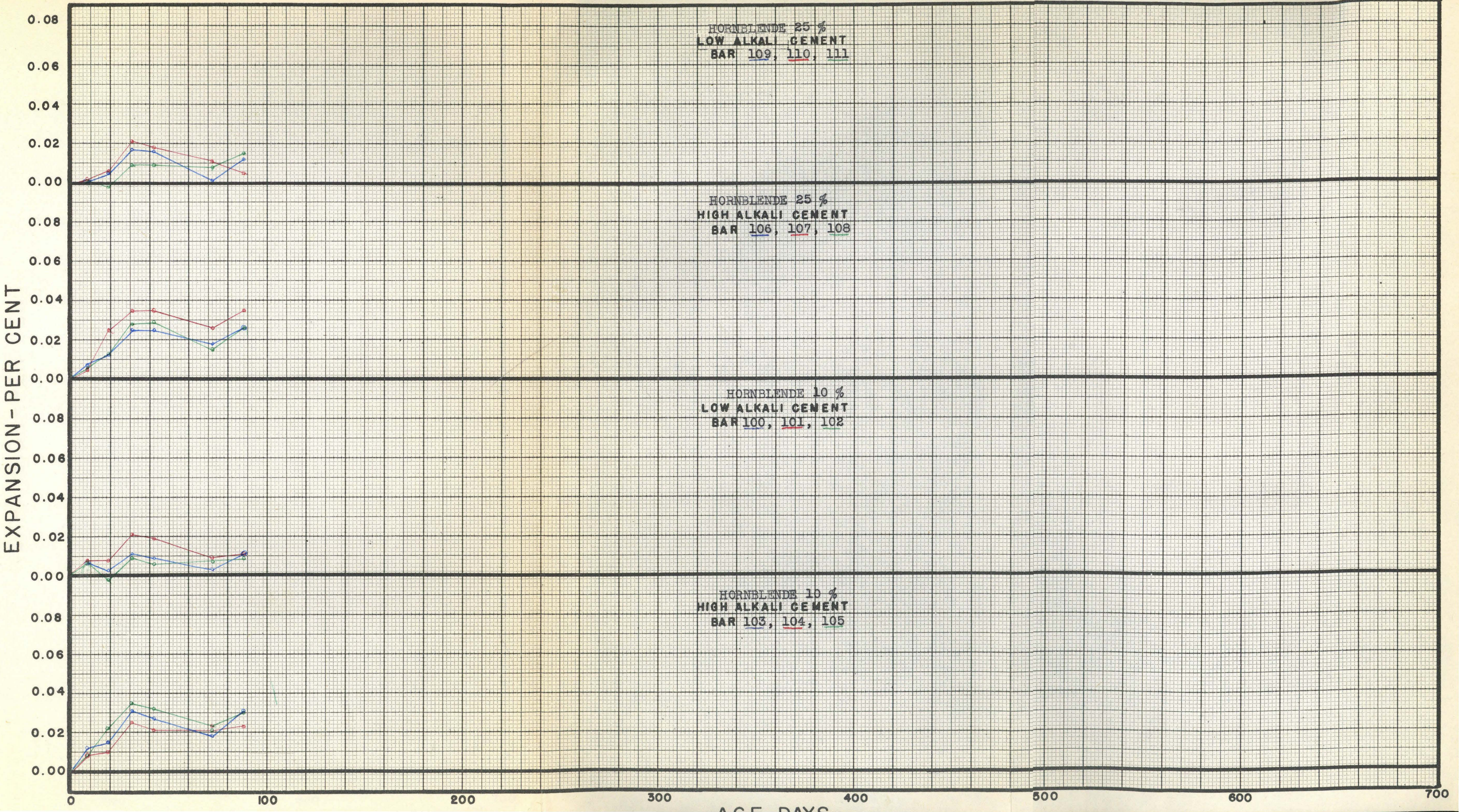
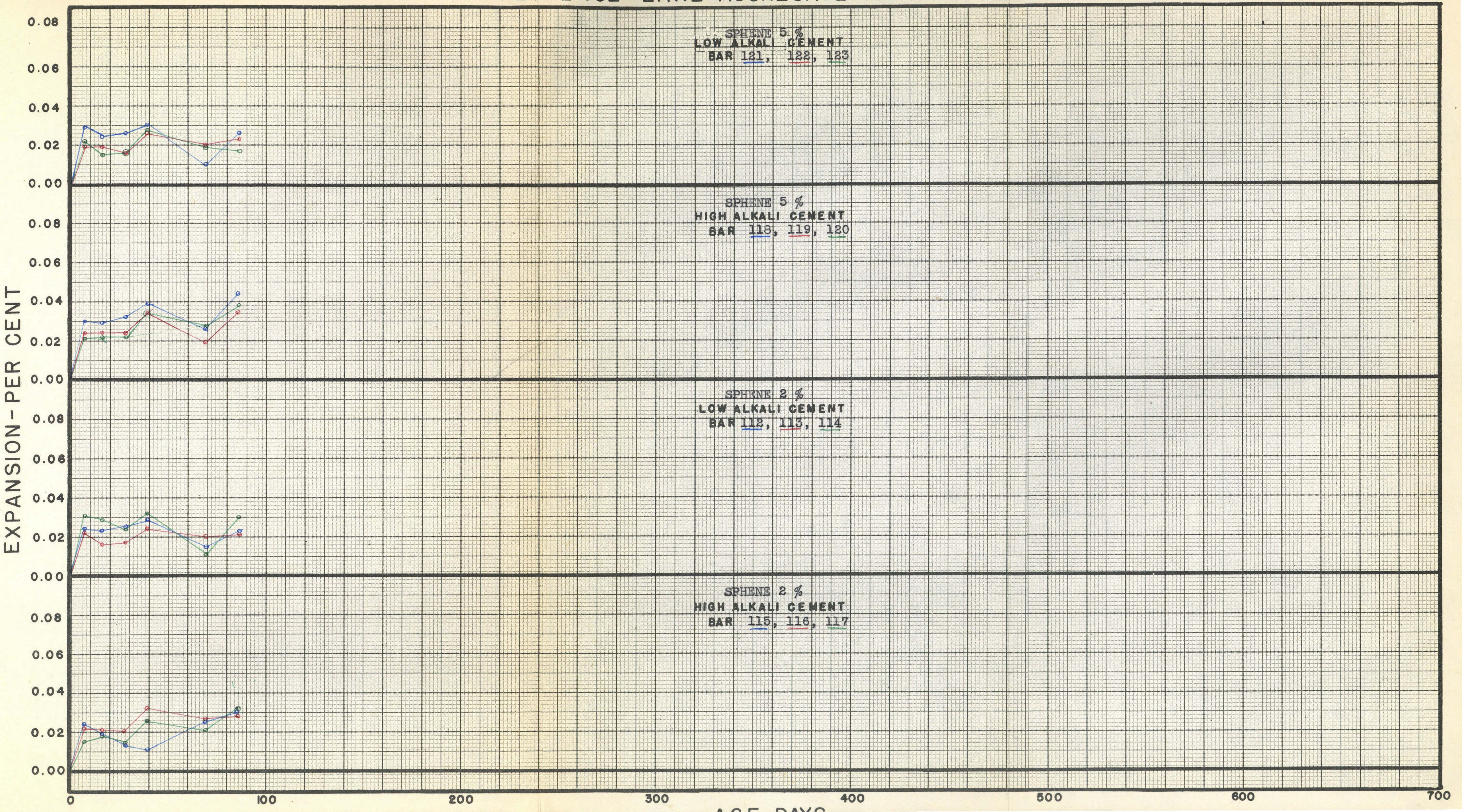


FLORENCE LAKE AGGREGATE INVESTIGATION

112-123



124-134

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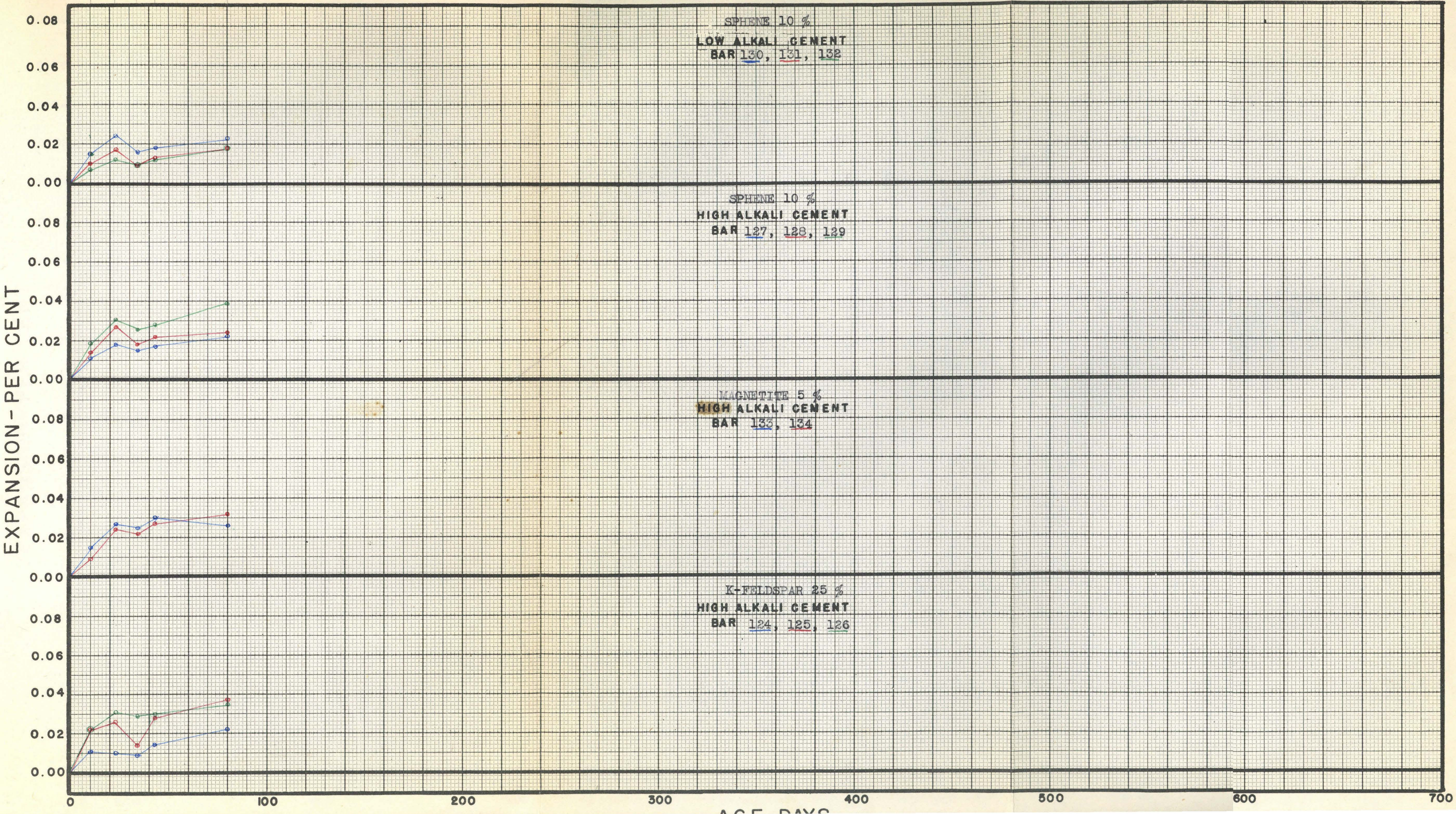

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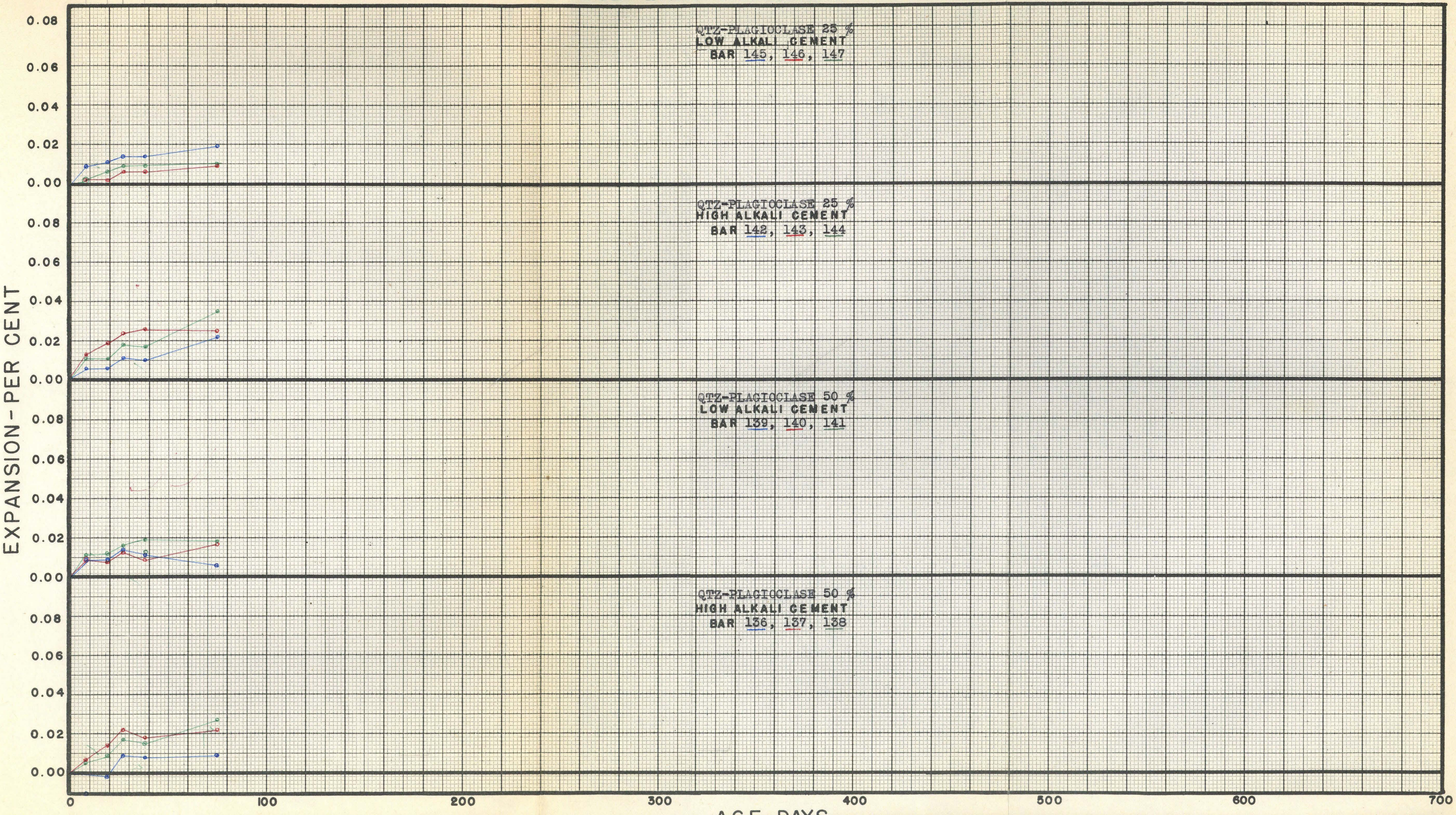
136-147



148-159

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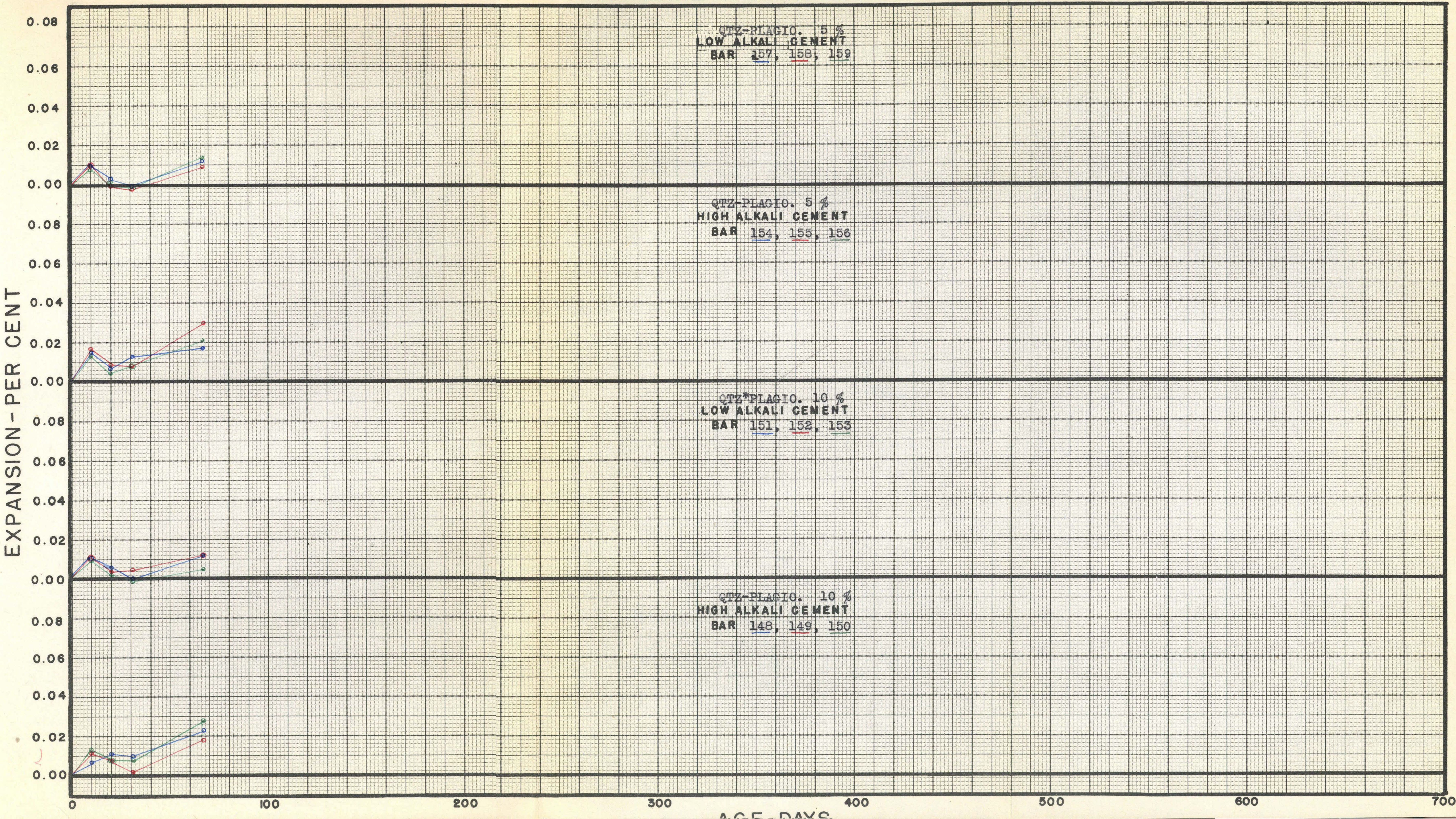

160-171A

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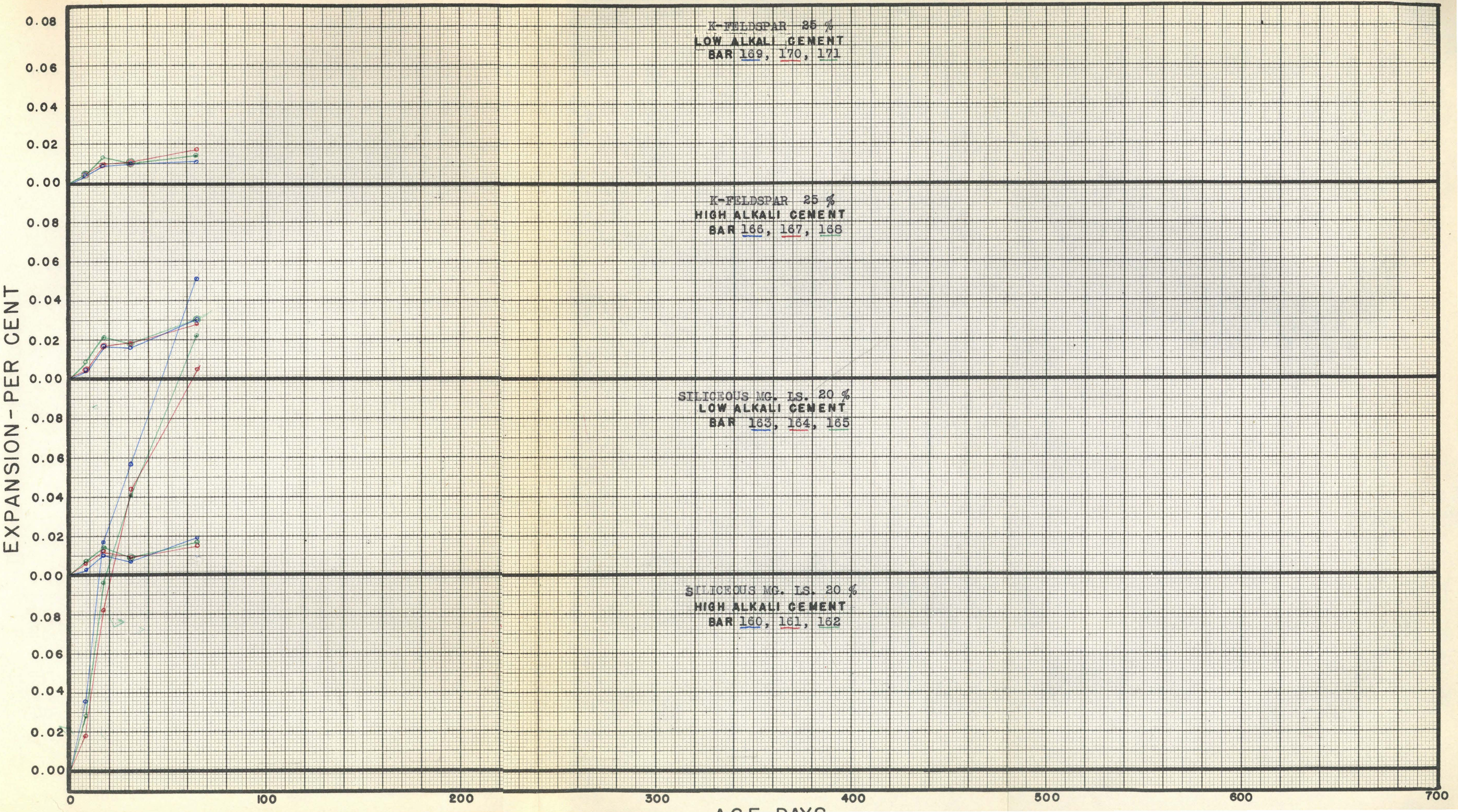
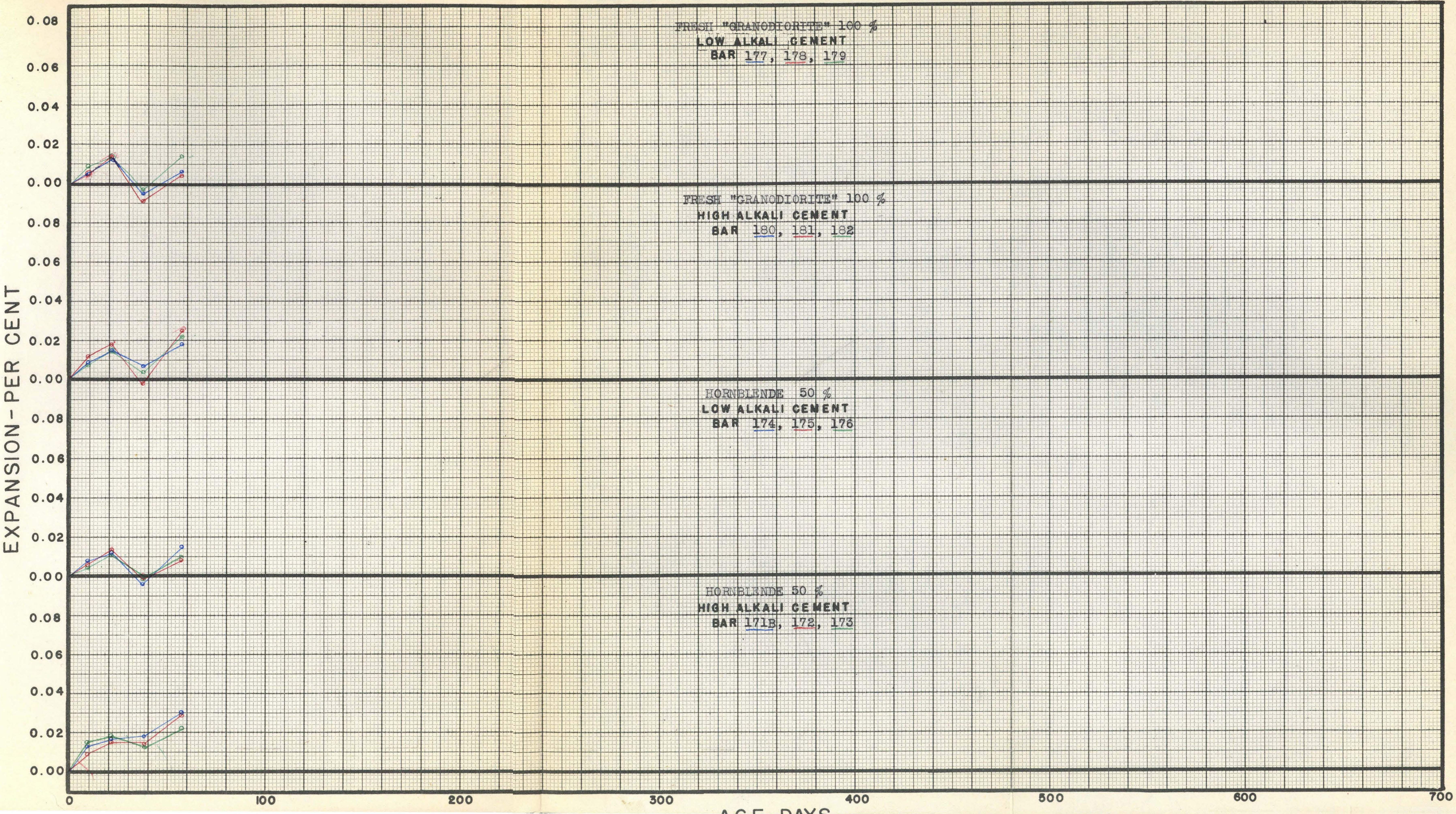


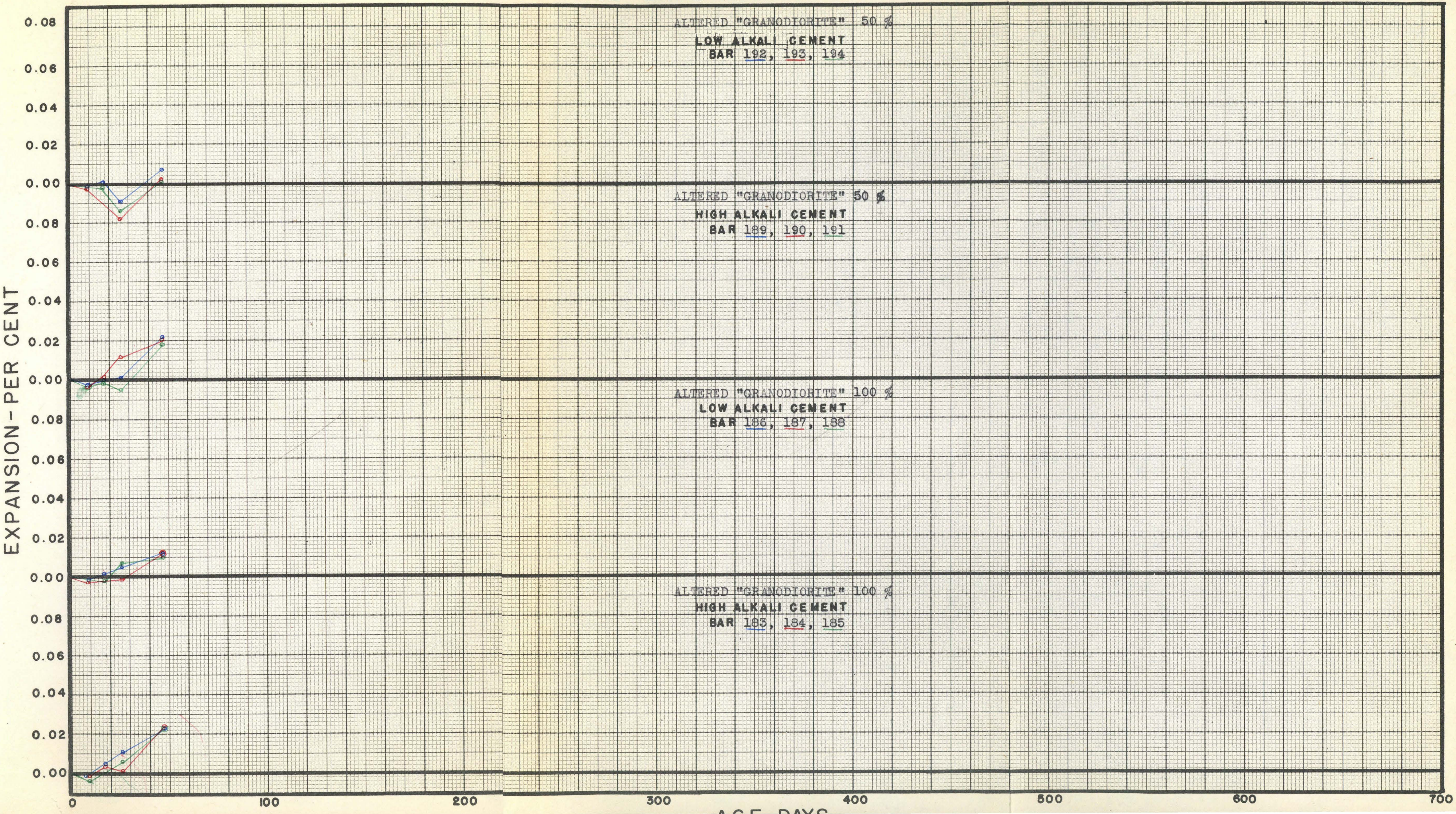
FLORENCE LAKE AGGREGATE INVESTIGATION

171B-182



FLORENCE LAKE AGGREGATE INVESTIGATION

183-194



195-204

FLORENCE LAKE AGGREGATE INVESTIGATION