An aggregate quality investigation of the Meramec River gravels

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AN AGGREGATE QUALITY INVESTIGATION OF

THE MERAMEC RIVER GRAVELS

BY

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THESIS

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ABSTRACT

This thesis represents a study which was made to evaluate and interpret the downstream variations in the quality of the Meramec River gravels as coarse aggregate for concrete.

Since gravel deposits constitute a valuable resource for a region, it is desirable that extent and quality variations of these deposits are known. It was hoped that an evaluation of certain properties of the Meramec River gravels would assist in determining the value of the Meramec River as an undeveloped aggregate source by indicating the relative quality of the gravels from alternate sites of the river.

For the purpose of this investigation, representative samples from selected sites along the river were collected; engineering tests and petrographic analysis were conducted on those samples to evaluate their quality for concrete aggregates. Also an attempt was made to evaluate the effect of geologic conditions on the aggregate quality.

It was found that gravels from the Meramec River, on the basis of their engineering properties, are a satisfactory coarse aggregate source. Chert is the dominant rock type of the gravels. Petrographic examinations indicate they are potentially reactive aggregates.

The results of the engineering tests showed little variation in the properties of gravel from the headwaters to the mouth. However, the lower portion of the river is judged to have the better quality aggregate. Although carbonate rocks constitute the most common bedrock in the basin, they form only a minor constituent of the gravels. Leaching and abrasion degradation are the main factors that cause the deficiency of carbonate rocks in the Meramec gravels.

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Chapter I

INTRODUCTION

Gravels, because of their widespread geographic occurrence, constitute one of the most important sources of aggregates for construction. Gravels are created by the action of running water and, as a result, deposits of these materials generally are elongated masses associated with past or existing river courses. The source materials for gravels are rocks within the river basin itself. Since most rivers will flow across numerous geologic boundaries, we should suspect the character of the gravel deposits will vary from place to place along a stream's course.

Aggregates will have a significant influence on the properties, character and economics of the composite material in which they are incorporated. For example, portland cement concretes, which are made up of different aggregate types, will exhibit different properties and durabilities. Many factors, such as change in rock types, secondary minerals, porosity and surface coatings, govern the effect aggregates have on concrete or other composite engineering materials. The reaction of the aggregate with portland cement and other constituents can be physical, chemical or a combination of the two.

Because of the detrimental effects harmful aggregates can impart to materials, engineers have set certain minimum standards for aggregate quality. The most commonly used aggregates (Normal-weight aggregates) such as sand, gravel, crushed stone and air-cooled blast-furnace slag should meet the requirements of the Standard

Specifications for Concrete Aggregates (American Society for Testing and Materials C 33) or Standards for Concrete and Reinforced Concrete (Canadian Standards Association A 23.1). These specifications limit the permissible amounts of deleterious substances and cover requirements for gradation, abrasion resistance, and soundness.

Gravels are hetrogeneous materials. At any given site their composition will reflect not only the local bedrock but also various percentages of rocks and minerals derived from upstream sources. Since they have hetrogeneous compositions, gravels must be examined and tested carefully because small percentages of deleterious substances can make the entire deposit an unsatisfactory aggregate source unless beneficiated.

The undesirable constituents and properties of gravels are many. Weak, friable or laminated aggregate particles are especially undesirable. Aggregates containing natural shale or shally particles, soft or porous particles, and certain types of chert should be viewed with suspicion since they have poor resistance to weathering. Chemical reactions between aggregate and cement, excessive volume changes in aggregates resulting in "popouts", and other such phenomena emphasized the role of aggregates in affecting durability of concrete.

Since gravel deposits constitute a valuable resource for a region, it is desirable that the extent and quality variations of these deposits are known.

The Meramec River is the largest source of sand and gravel in east-central Missouri. However, no evaluations have been made of the potential of the Meramec Basin as an aggregate source which would lead to better utilization of the aggregates in Missouri as a whole and would remove some of the pressure on reserves of other aggregate sources in this region.

This thesis represents a study which was made to evaluate and interpret the downstream variations in the quality of the Meramec River gravels as coarse aggregate for concrete. The initial phase of the investigation consisted of field studies which included the collection of representative samples from selected sites along the river. The main part of the investigation consisted of laboratory studies and included standard engineering tests to evaluate certain physical properties and petrographic analysis to determine the mineralogic, fabric and chemical factors of the gravel constituents.

Chapter II

REVIEW OF LITERATURE

A. The Meramec Basin

Various geologic and hydrologic studies have been made of the Meramec River Basin. The Corps of Engineers, U. S. Army (49), planned a flood control project in the Meramec River Basin in 1947-1948. Data concerning ground water aspect of the basin began to be published at that time. General hydrology, estimate of flood damage and recommendations for flood control with retarding basin reservoirs in the Meramec Basin were presented by I. K. Ozbilen (31) in 1950. In 1961, Ullman, Boyce and Volk (38) described water supplies, water quality and flood damage reduction in the Meramec Basin as part of an overall study of water development in the basin. Hydrology of the reservoir sites in the Meramec River Basin was studied by John H. Anderson (2) in 1963. The stratigraphy and structure of the north half of the Meramec Spring Quadrangle was studied by Mueller (30) in 1951. A similar study of the south half of the same quadrangle was made by Yorston (44) in 1954. However, none of these studies provided any specific information on aggregate evaluation of the Meramec River.

A publication of Missouri Bureau of Geology and Mines, presented by C. L. Dake (12) in 1918, gives a little information on the sand and gravel resources of Missouri, but not adequate to evaluate the quality of these materials as an aggregate source. This thesis is the first known study made on the Meramec River to evaluate quality of its gravels as a coarse aggregate source for concrete.

B. Similar Investigations

Variation in pebble composition of Wisconsin outwash deposits in the Wabash Valley, Indiana were studied by McCammon (26) in 1961. On the basis of observed downstream variations in the pebble composition, McCammon concluded that the influx of rock fragments derived from the local Paleozoic bedrock had significantly controlled the pebble composition of the outwash gravels along the downstream course of the river. Although he found the processes of selective abrasion and sorting were contributing factors, McCammon concluded for the size interval studied, that the local bedrock contamination was a major or critical factor which regulated the relative abundance of rock types. The results of this study provide an illustrative example of the concept of progressive dilution and also an affirmation of the statement made by Cayeux (10) to the effect that stream pebbles reflect to a large degree the local bedrock.

H. S. Sweet (36), as a result of a study of cherts as a deleterious constituents of aggregates in Indiana in 1942, came to the conclusion that the performance of cherts and other rock types was dependent upon their degree of saturation at the time they were frozen. He found the character of cherts in gravels are similar to those of the quarry cherts. Sweet also found the flotation bulk specific gravity of a gravel chert specimen was a good indication of its ultimate durability and the depth of dye penetration could be used to predict chert durability. Since freezing and thawing of dry chert caused no disruption, it follows that annual rainfall is an important variable influencing the relative durability of chert. Sweet speculated, since both the total amount of freezing weather and total number of cycles of freezing and thawing are greater in northern than in southern Indiana, these differences might influence the field durability of chert used in exposed concretes.

In 1963, Aughenbaugh et al. (3), made a study of degradation of base course aggregates during compaction. In this study, three carbonate aggregates of different textures and structures and a glacial gravel were selected as the test aggregates. It was concluded that petrographic analysis is a reliable means of evaluating aggregate quality and it should be used as a routine laboratory test. The continuation of this study was presented by West et al. (41) in 1966.

Papers by Lewis and Dolch (19), Lounsbury and Schuster (20), Mather (23), Mielenz (25), Rhoades and Mielenz (32), etc., yielded information concerning aggregate tests, aggregates and concrete, and petrographic examination of aggregates which were valuable to this investigation.

Chapter III

DESCRIPTION OF THE STUDY AREA

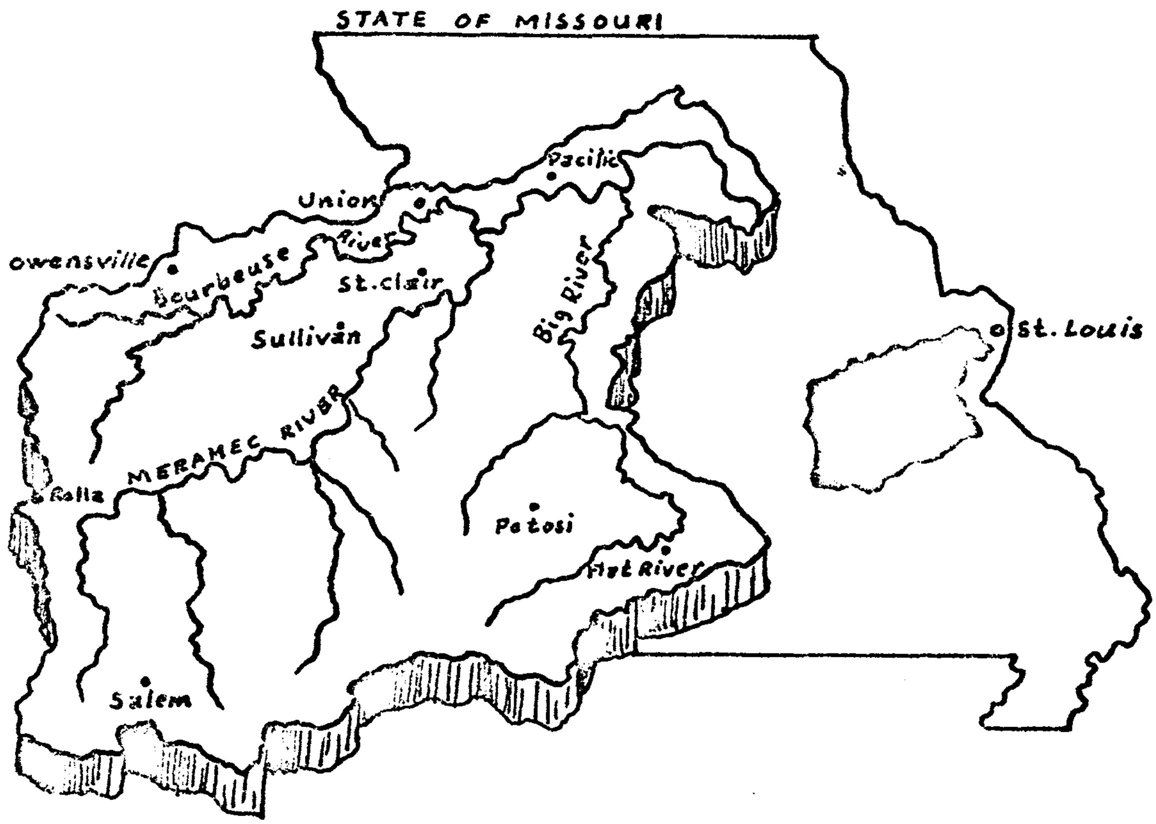
A. Geography

The Meramec Basin is located in east-central Missouri and extends about 100 miles southwesterly from St. Louis into the Ozark Highlands, Figure 1. The basin encompasses two entire counties and parts of eleven others, Figure 2. Total area of the watershed is about 3,980 square miles; the greatest north-south distance is about 70 miles and the east-west distance is about 80 miles. The length of the Meramec River itself is about 207 miles. Picture 1 shows a typical portion of the Meramec River at the junction of the Calvey Creek, Pacific, Missouri (49).

The basin has a population of about 210,000, approximately two-thirds of which is concentrated in Jefferson and St. Louis counties. Three railroads and a network of Federal and State paved highways traverse the region and provide good transportation. Paved or graveled county roads and other locally maintained roads form a system of secondary highways throughout the basin. Away from the St. Louis area, employment records indicate that between 25% and 30% of the working force is employed in agriculture, 50% to 55% in mining and manufacturing, and about 20% in service. Climate in the basin is temperate, humid, continental with a long summer phase (49).

B. Physiography

The Meramec Basin lies within the Salem Plateau section of the Ozark Plateaus' physiographic province as shown in Figure 3.



LOCATION MAP OF MERAMEC RIVER BASIN

FIGURE 1

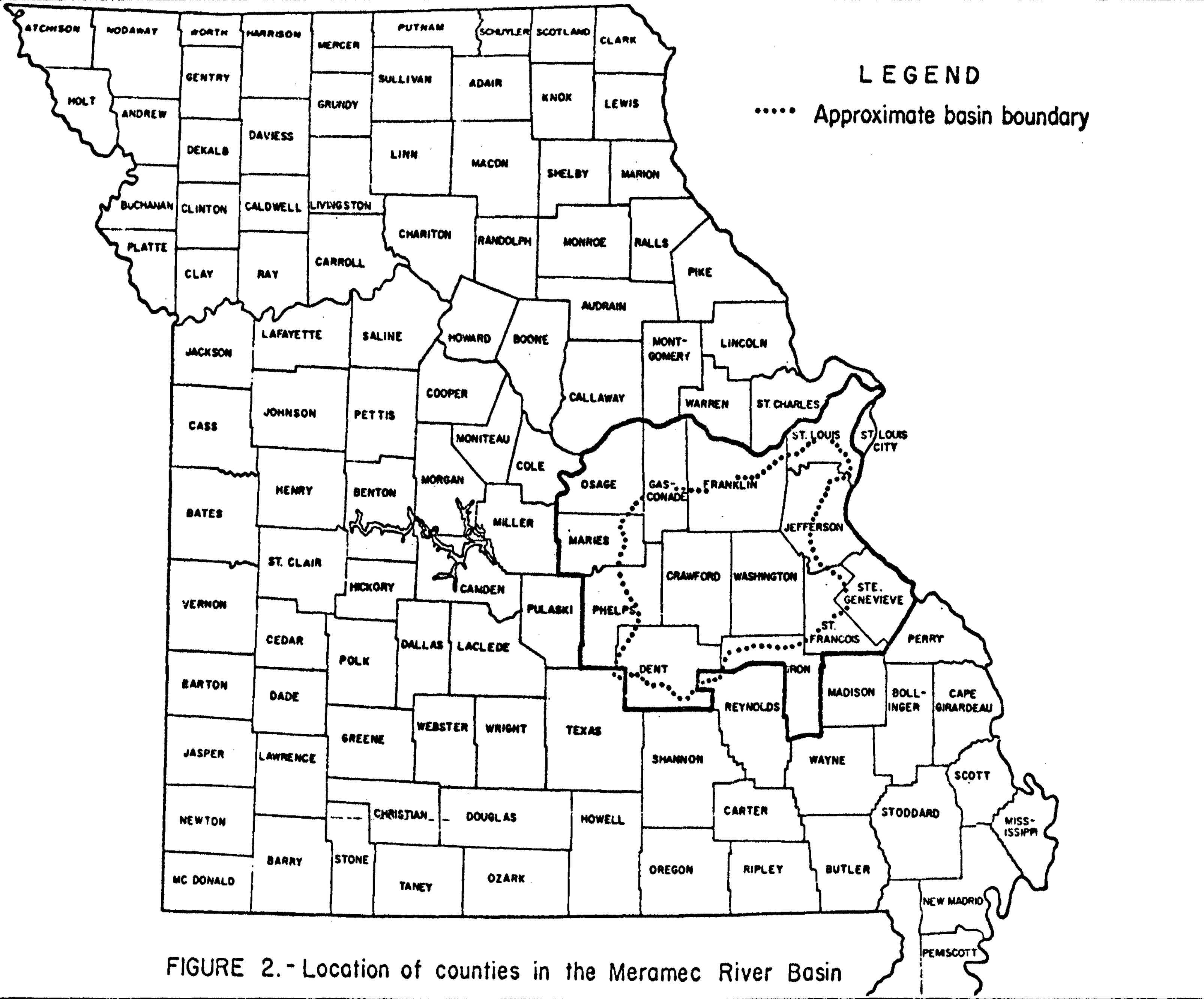


FIGURE 2.- Location of counties in the Meramec River Basin

PICTURE 1. The Meramec River at the junction of the Calvey Creek, Pacific, Missouri.

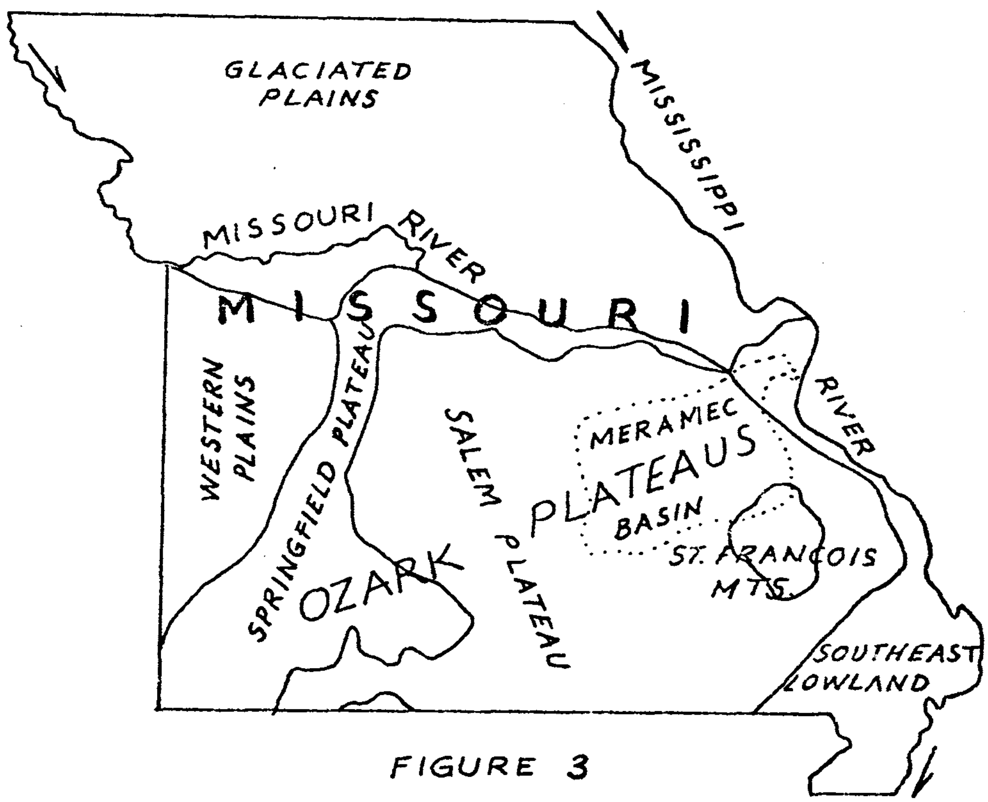


FIGURE 3

PHYSIOGRAPHIC SETTING—MERAMEC BASIN

The basin consists of three main sub-basins; the Bourbeuse River, the Big River and the Meramec River. The Bourbeuse River with a drainage area of 808 square miles joins the Meramec River near Union, Missouri; the Big River drains the northern portion of the St. Francois Mountain section. The Meramec River originates in the southwest corner of the basin, traverses the entire central region and empties into the broad Mississippi River plain a few miles below the city of St. Louis (49).

Typical of the Ozarks, the basin is characterized by a relatively rugged topography particularly adjacent to the streams. The divides often consist of gently rolling uplands containing sizeable flat areas locally called "flatwoods" or "Prairies". Many of these uplands contain sinkholes and are considered to be remnants of an old erosion surface of small relief. The trunk and tributary sub-basins are characterized by steep walled valleys containing many caverns and springs. These valleys are for the most part relatively narrow, with some nearly vertical rock bluffs extending over 200 feet above the valley flat; they have been mantled with previous, residual soils and laden with huge deposits of gravels (49).

The Meramec River and its two main tributaries exhibit contrasting forms of drainage patterns. The Bourbeus pattern is symmetrically dendritic with evenly spaced tributaries entering from both south and north. This type of drainage is in part a reflection of relatively soft rock underlying the Bourbeuse Basin. The Meramec pattern is asymmetrical with the preponderance of tributaries entering from the south. The abundance of north flowing streams here appears to be a consequence of the initial slope away from the axis of the uplifted area south and west of the St. Francois Mountains. The Big River in the headwater exhibits modified radial drainage, influenced by resistant igneous knobs and local high areas (Figure 4)(49).

C. Geology

Cambrian and Ordovician cherty dolomites, having a gentle regional dip to the north, underlie the middle and upper portions of the Meramec River watershed. In the lower portion of the drainage of the main stream, successively younger formations outcrop (See Plate I). In the vicinity of Sullivan in Washington County, deposits of high-grade Precambrian iron ore occur at depths between 1,500 and 3,000 feet. Production of lead in the southwest section of the sub-basin, near the juncture of Crawford, Dent and Iron counties has been started by the recently opened Viburnum Mines; and exploration for lead, copper and iron are continuing throughout the basin. Silica sand from the Ordovician St. Peter sandstone is quarried at Pacific, Missouri, and some building stone is produced from the Roubidoux sandstone for local consumption. The limestone of the Plattin, Kimmswick and St. Louis formations is quarried extensively for concrete aggregate, roadstone and agricultural lime (49).

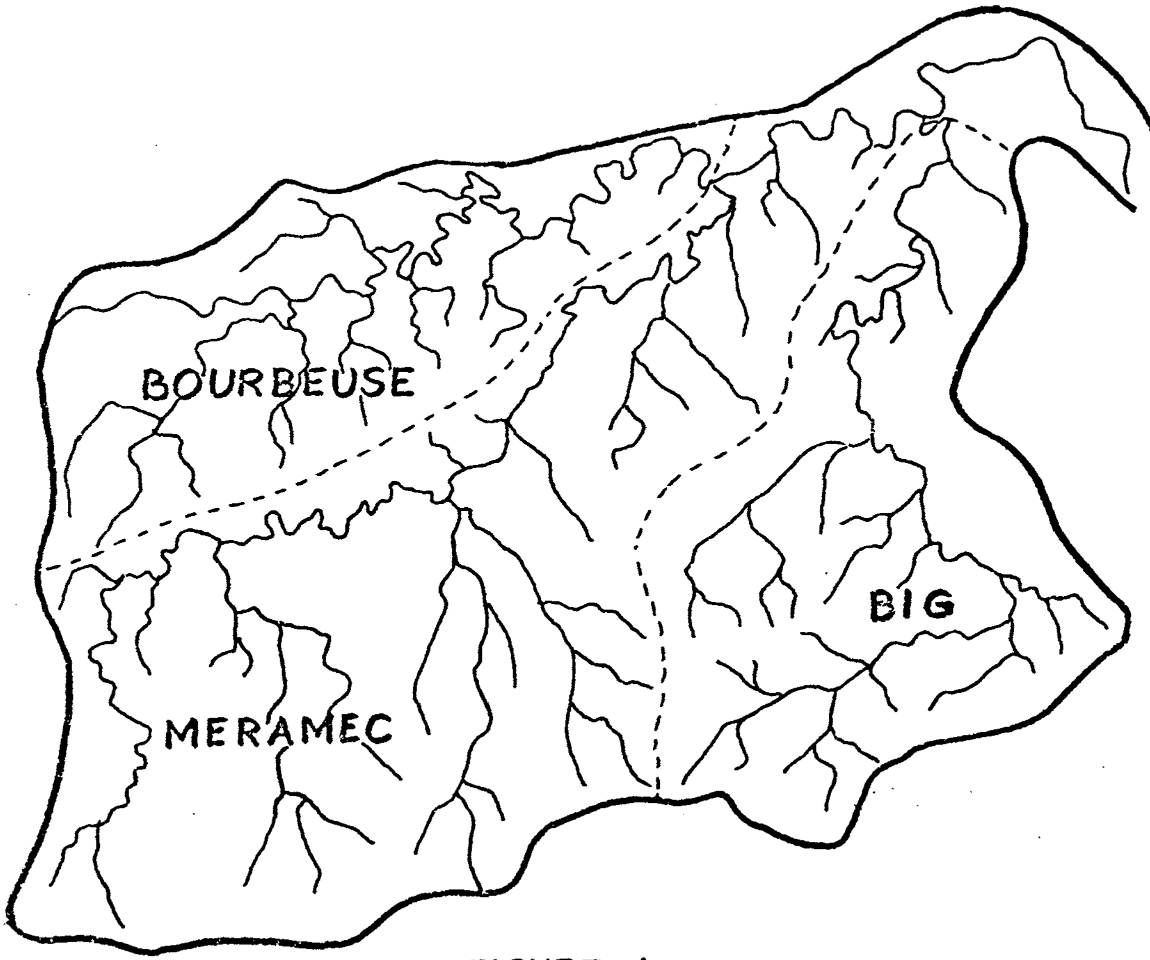


FIGURE 4

DRAINAGE PATTERNS OF MERAMEC BOURBEUSE AND BIG RIVERS

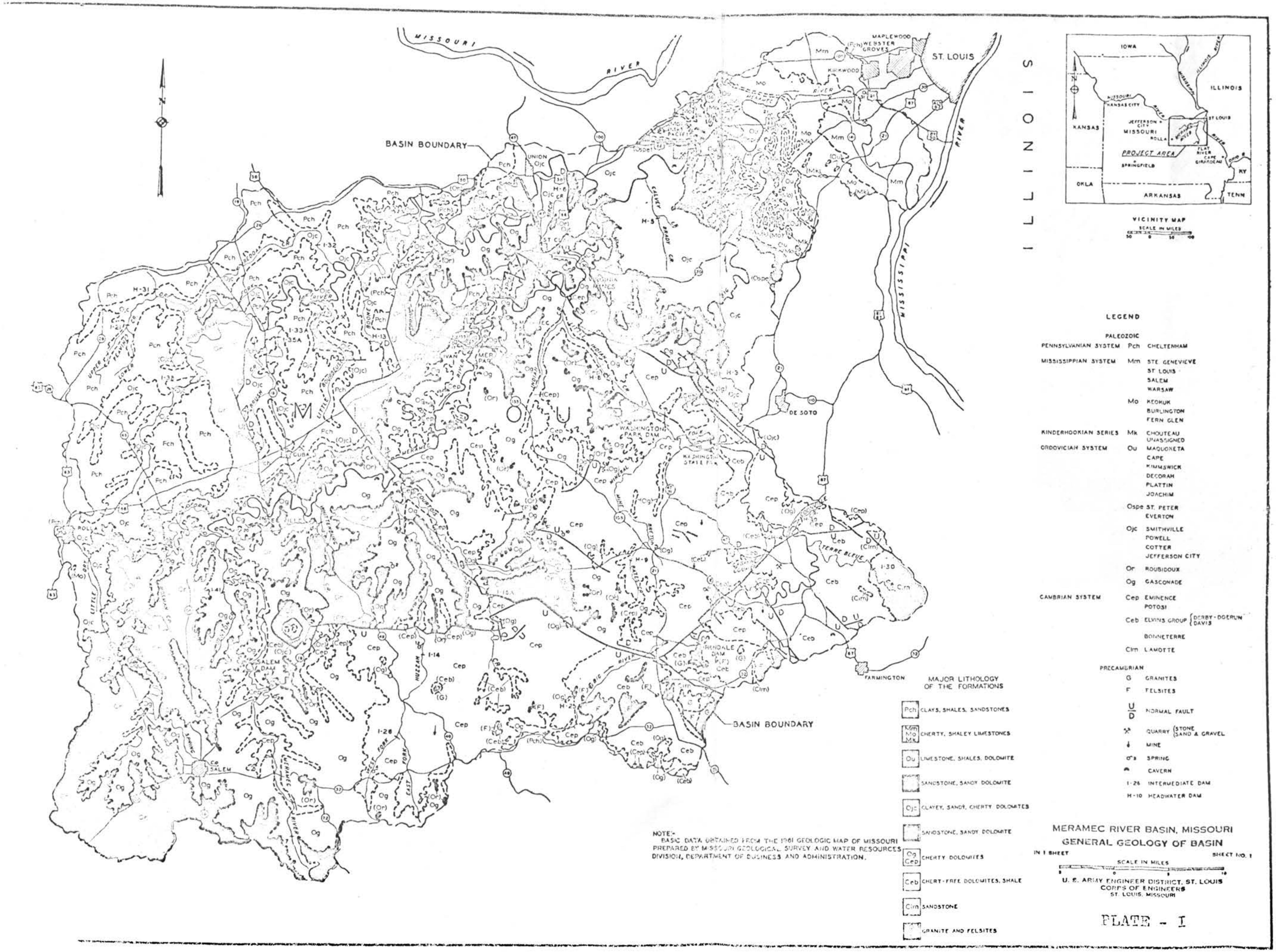

MISSOURI RIVER
BASIN BOUNDARY
ST. LOUIS
KIRKWOOD
MAPLEWOOD
WEBSTER GROVES
DE SOTO
FARMINGTON
ROLLA
SALEM
ILLINOIS
MISSISSIPPI RIVER
VICINITY MAP
SCALE IN MILES
IOWA
ILLINOIS
KANSAS
MISSOURI
OKLA
ARKANSAS
TENN
KY
PROJECT AREA
LEGEND
PALEOZOIC
PENNSYLVANIAN SYSTEM Pch CHELTENHAM
MISSISSIPPIAN SYSTEM Mm STE GENEVIEVE
ST LOUIS
SALEM
WARSAW
Mo KEOKUK
BURLINGTON
FERN GLEN
KINDERHOOKIAN SERIES Mk CHOUTEAU
UNASSIGNED
ORDOVICIAN SYSTEM Ou MAQUOKETA
CAPE
KIMMSWICK
DECORAH
PLATTIN
JOACHIM
Ospe ST. PETER
EVERTON
Ojc SMITHVILLE
POWELL
COTTER
JEFFERSON CITY
Or ROUBIDOUX
Og GASCONADE
CAMBRIAN SYSTEM Cep EMINENCE
POTOSI
Ceb ELVINS GROUP {DERBY-DOERUN DAVIS
BONNETERRE
Clm LAMOTTE
PRECAMBRIAN
G GRANITES
F FELSITES
U/D NORMAL FAULT
QUARRY {STONE SAND & GRAVEL
MINE
SPRING
CAVERN
I-26 INTERMEDIATE DAM
H-10 HEADWATER DAM
MAJOR LITHOLOGY OF THE FORMATIONS
Pch CLAYS, SHALES, SANDSTONES
Mm Mo Mk CHERTY, SHALEY LIMESTONES
Ou LIMESTONE, SHALES, DOLOMITE
SANDSTONE, SANDY DOLOMITE
Ojc CLAYEY, SANDY, CHERTY DOLOMITES
SANDSTONE, SANDY DOLOMITE
Og Cep CHERTY DOLOMITES
Ceb CHERT-FREE DOLOMITES, SHALE
Clm SANDSTONE
GRANITE AND FELSITES
NOTE:-
BASIC DATA OBTAINED FROM THE 1961 GEOLOGIC MAP OF MISSOURI PREPARED BY MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES DIVISION, DEPARTMENT OF BUSINESS AND ADMINISTRATION.
MERAMEC RIVER BASIN, MISSOURI
GENERAL GEOLOGY OF BASIN
IN 1 SHEET
SHEET NO. 1
SCALE IN MILES
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

PLATE - I

Chapter IV

FIELD STUDIES

A. Reconnaissance and Selection of Sample Sites

Before initiating the sampling and laboratory testing programs, an office study and field reconnaissance was made of the Meramec River. The purpose of the program was to examine topographic and geologic conditions in the area and prepare a suitable sampling program. From these preliminary studies it was decided to take the samples from the gravel bars located at the junctions of the main tributaries along the Meramec River. The main reason for these sites was to detect influence of the tributaries, which may carry different materials from different geologic sources into the Meramec River, on the quality of the gravels of the Meramec River.

Presumed locations of the gravel bars at those critical points were checked by studying the aerial photographs of the Meramec River Basin and the proposed sampling stations were marked precisely on both topographic and geologic maps of the area. Sizes of these gravel bars were also calculated from the aerial photographs. Then, a sampling plan was prepared for each sampling station in order to secure representative, unbiased samples.

Accessibility of the sampling stations was investigated from the topographic maps of the area. Although access to the river at those sampling stations was very easy by a field car, getting to the gravel bars was a problem at most of the stations due to the very harsh vegetation and absence of trails. Therefore, a canoe was used to reach many gravel bars.

Due to the lack of necessary devices for deep sampling, the samples were obtained by using a shovel, with the maximum depth of sampling being 8 inches. Problems in obtaining a sample appeared in some places where the gravel bars have been removed by the gravel companies working on the Meramec River. In such cases the next gravel bar close to the tributary junction was chosen for sampling. Actually, close to the mouth of the Meramec River no gravel bars were found to exist any more due to very high depth and velocity of the water.

Nineteen samples of gravel were collected from the upper and lower sampling stations. The upper sampling stations were gravel bars located above the junction of each tributary, whereas the lower sampling stations were the gravel bars located downstream from the junctions. Picture 2 shows the gravel bars on the Meramec River, located at the upper sampling station before the junction of the Bourbeus River. Sampling locations and the samples on the upstream gravel bar at station 2 are shown in Picture 3. One single station is located in the headwater zone of the Meramec River. Figure 5 shows the final locations of the upper and lower sample stations along the Meramec River. Sample numbers, identifications, and locations are shown in Table I.

B. Sampling

A sample is a small portion of a larger volume or group of materials about which information is desired. Sampling is the process of obtaining samples from the larger universe of population.

PICTURE 2. Gravel bars on the Meramec River.

PICTURE 3. Sampling locations and the samples.

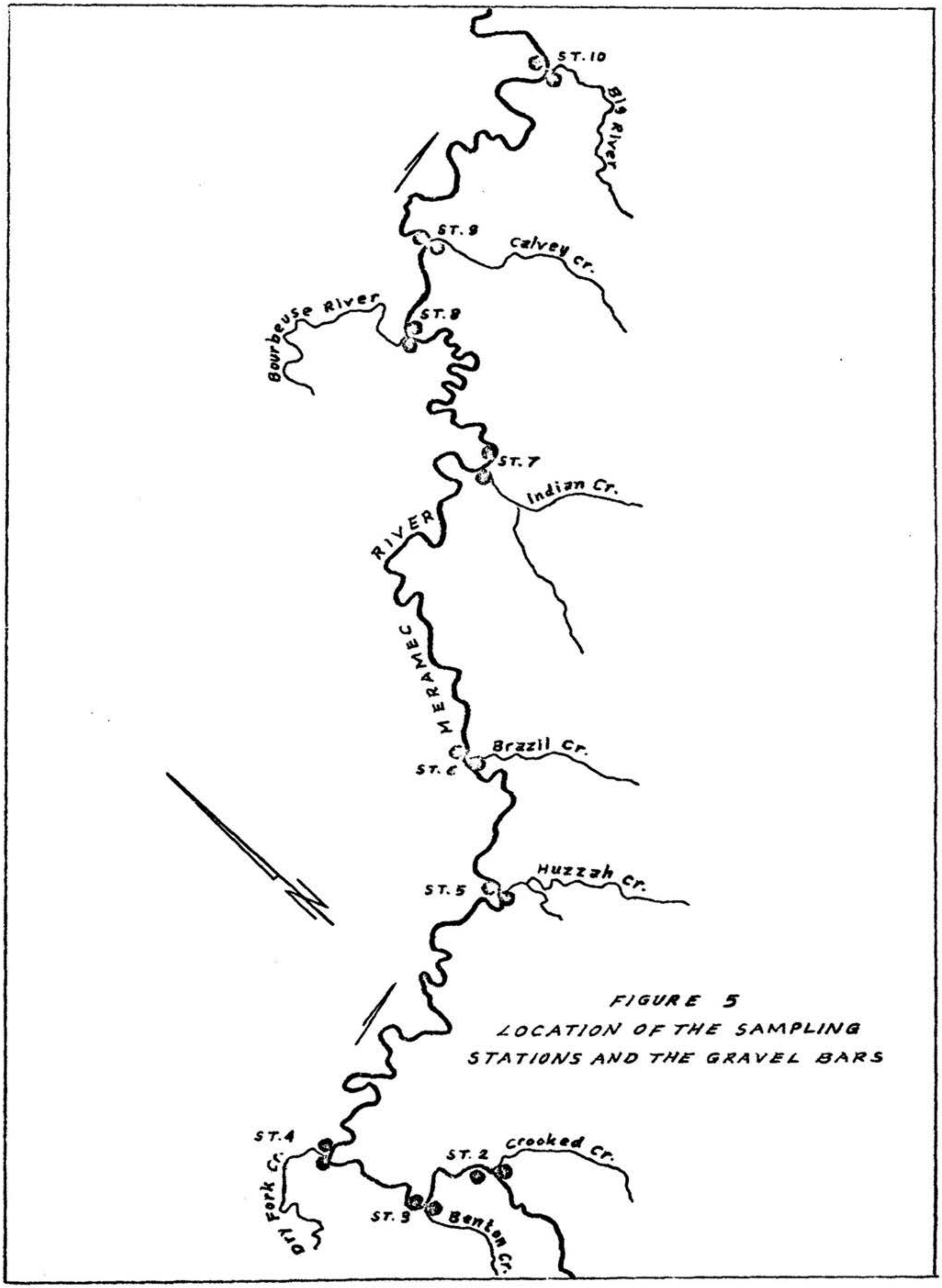


FIGURE 5
LOCATION OF THE SAMPLING STATIONS AND THE GRAVEL BARS

TABLE I- SAMPLE INDEX

ST.	LOCATION	SAMPLE NO.	IDENTIFICATION	MAP INDEX	
1	Stone Hill	1	1HW1	Stone Hill	Quad.
2	Crooked Cr.	2	2TC2	Steville	"
	"	3	2TC3	"	"
3	Benton Cr.	4	3TB4	Meramec	"
	"	5	3TB5	"	"
4	Dry Fork Cr.	6	4TD6	"	"
	"	7	4TD7	"	"
5	Huzzah Cr.	8	5TH8	Sullivan	"
	"	9	5TH9	"	"
6	Brazil Cr.	10	6TB10	"	"
	"	11	6TB11	"	"
7	Indian Cr.	12	7TI12	St. Clair	"
	"	13	7TI13	"	"
8	Bourbeus Rv.	14	8TB14	"	"
	"	15	8TB15	"	"
9	Calvey Cr.	16	9TC16	"	"
	"	17	9TC17	"	"
10	Big River	18	10TB18	House Spring	"
	"	19	10TB19	"	"

Where the universe is perfectly homogeneous, sampling becomes the simple physical act of lifting a sample from the unit being sampled. Unfortunately, natural deposits of earth materials, rarely if ever, present us with perfectly uniform and homogeneous universes of any material. The development of a sampling plan requires the application of probability sampling, an intimate knowledge of the product being sampled, and a high degree of skill, experience, background, and creativeness (25).

As a general rule, aggregate samples need only be large enough to include a representative portion of all materials and to provide ample material for all tests contemplated as specified by standard test procedures. The number of samples will vary with the size of the deposit; the size of the sample will vary with the maximum size of aggregate occurring in the deposit. For gradation analysis, for example, samples should be large enough to assure occurrence of particles of the largest dimension in sufficient number so that inclusion or exclusion of one of these large particles will not affect the grading. Size of samples required for different tests were provided in the A.S.T.M. Book of Standards and are shown in Tables II, III, and IV (25).

The sampling plan used in this study is based upon the principles of Simple Random Sampling which is a method of selecting a number of distinct samples of size (n) that can be drawn from the (N) units such that every one of the ${}_{N}C_{n}$ samples has an equal chance of being chosen. N is the number of units in the population and n is the size of samples. For a population which contains a finite

TABLE II - SIZE OF SAMPLE REQUIRED
FOR SIEVE OR SCREEN ANALYSIS OF AGGREGATES

Nominal Maximum Size of Particle, in	Minimum Weight of Sample, lb
3/8	5
1/2	10
3/4	15
1	25
1 1/2	35
2	45
2 1/2	55
3	100
3 1/2	150

TABLE III- GRADING OF TEST SAMPLES
FOR LOS ANGELES ABRASION TEST OF COARSE AGGREGATE

Sieve Size (Square Openings)		Weight of Indicated Sizes, g.			
		Grading			
Passing	Retained on	A	B	C	D
1½ in.	1 in.	1 250 ± 25	...	...	...
1 in.	¾ in.	1 250 ± 25	...	...	...
¾ in.	½ in.	1 250 ± 10	2 500 ± 10	...	...
½ in.	⅜ in.	1 250 ± 10	2 500 ± 10	...	...
⅜ in.	No. 3 (¼-in.)	...	...	2 500 ± 10	...
No. 3 (¼-in.)	No. 4 (4.76-mm)	...	...	2 500 ± 10	...
No. 4 (4.76-mm)	No. 8 (2.38-mm)	...	...	...	5 000 ± 10
Total		5 000 ± 10	5 000 ± 10	5 000 ± 10	5 000 ± 10

TABLE IV - SIZE OF SAMPLE REQUIRED
FOR PETROGRAPHIC EXAMINATION

Size Fraction	Weight of 300 Particles
3 to 1 1/2 in.	57 lb
1 1/2 to 3/4 in.	19 lb
3/4 to 3/8 in.	2.6 lb
3/8 to 3/16 in.	0.75 lb
No. 4 to 8	15 g
No. 8 to 16	2.1 g
No. 16 to 30	0.28 g
No. 30 to 50	0.033 g
No. 50 to 100	0.0066 g

number N of units; if these units can all be distinguished from one another, the number of distinct samples of size n that can be drawn from the N units is given by the combinatorial formula:

$$\binom{N}{n} = {}_N C_n = \frac{N!}{n!(N-n)!}$$

In practice, the surface area of each gravel bar was measured; considering the surface area of each gravel bar as a population of samples, it was divided into smaller units of the surface area of 10x10 square feet which was the most suitable size. The units in each population were numbered from 1 to N. A series of random numbers (n)*, between 1 and N was drawn by means of a table of random numbers. The units which bear these numbers constituted the samples. A schematic sampling plan for station 2 is shown in Figure 6.

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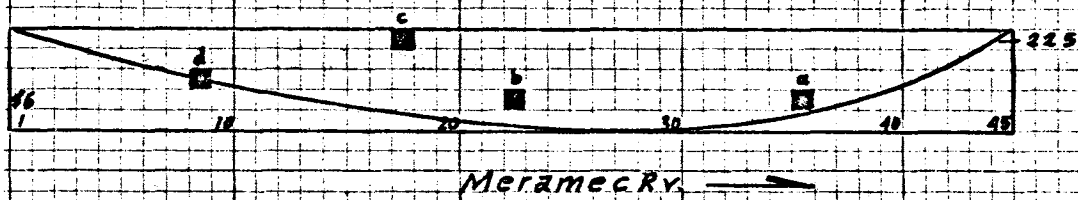
* Number of increment (n) was chosen as (4) for the purpose of this study.

ST. 2
Location - Before the junction "Crooked Creek".
Sample No. - 2
Identification - 2TC2 (a,b,c,d)
Approximate Surface Area - 450' X 50'
Sampled Spots - 81(a), 68(b), 198(c), 99(d)
N = 225
n = 4



ST. 2
Location - After the junction of "Crooked creek".
Sample No - 3
Identification - 2TC3 (a,b,c,d)
Approximate Surface Area - 600' X 120'
Sampled Spots - 148(a), 681(b), 678(c), 645(d)
N = 720
n = 4

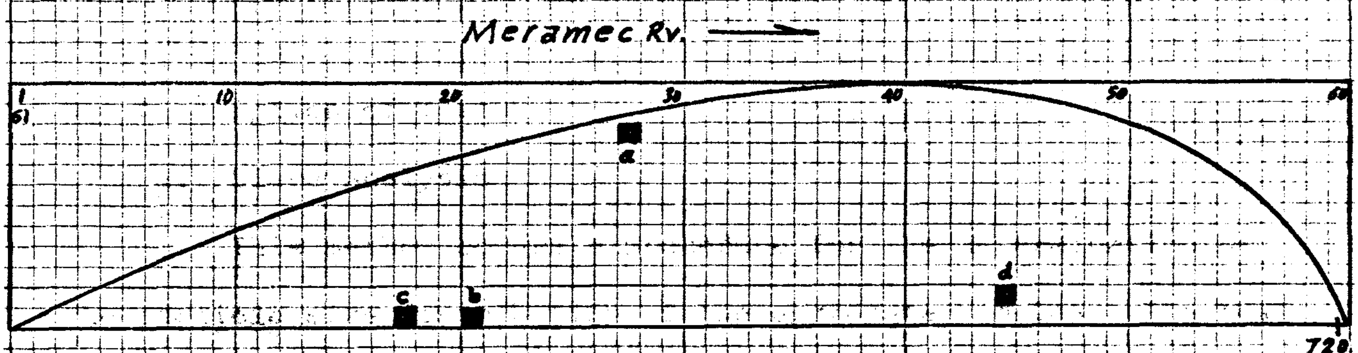


FIGURE 6

SAMPLING PLAN FOR ST. 2

Chapter V

ENGINEERING TESTS

A. General

A part of the study of Aggregate Quality Investigation of the Meramec River Gravels was directed to testing various engineering properties of the materials by the following testing methods:

a) Sieve Analysis

b) Specific Gravity and Absorption Test

c) Los Angeles Abrasion Test

The test procedures used for the study conformed to the standard methods of tests as outlined by A.S.T.M. specifications.

Correlation of field and laboratory data and petrographic analysis of the samples allowed a critical evaluation of each test to be made with regard to its feasibility in accurately evaluating aggregate quality.

B. Description of Tests

1. Sieve Analysis

This method covers a procedure for the determination of the particle size distribution of the aggregate samples. The test procedure conformed to the Standard Method of Test for Sieve or Screen Analysis of fine and coarse aggregates as outline by A.S.T.M. Designation: C 136-63.

Since the samples contained both fine and coarse particles, it was necessary to make a preliminary separation using a No. 4 sieve.

The materials used in this study were the coarse fraction retained on No. 4 sieve.

After the preliminary separation using the No. 4 sieve, the coarse samples were dried to a constant weight at a temperature of 230°, ±9°F (110°, ±5°C). The oven-dried material was then further separated into different size fractions by sieving (Picture 4). The sieving operation was performed by a mechanical apparatus as shown in Picture 5.

The weight of each size increment was determined to the nearest 0.1 percent of the weight of the sample. The total percentage of material passing each sieve, the total percentage of material retained on each sieve, and the percentage of material retained between consecutive sieves were calculated on the basis of the total weight of the sample, including the material finer than No. 4 sieve. The percentages were reported to the nearest whole number.

2. Specific Gravity and Absorption Test

These methods of testing were made for making determinations of the following basic properties:

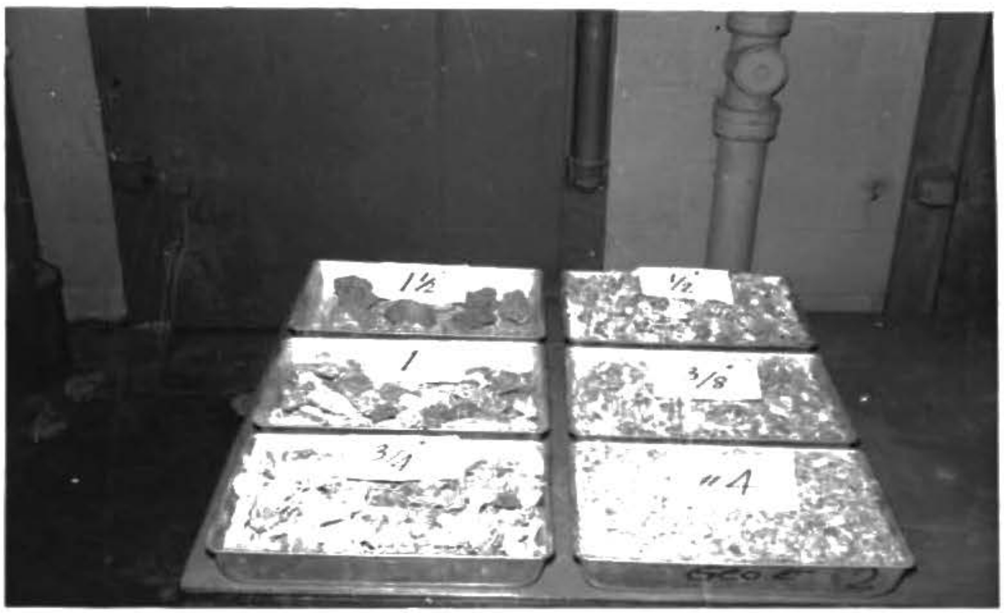
a) Bulk Specific Gravity

b) Bulk Specific Gravity (Saturated surface-dry basis)

c) Apparent Specific Gravity

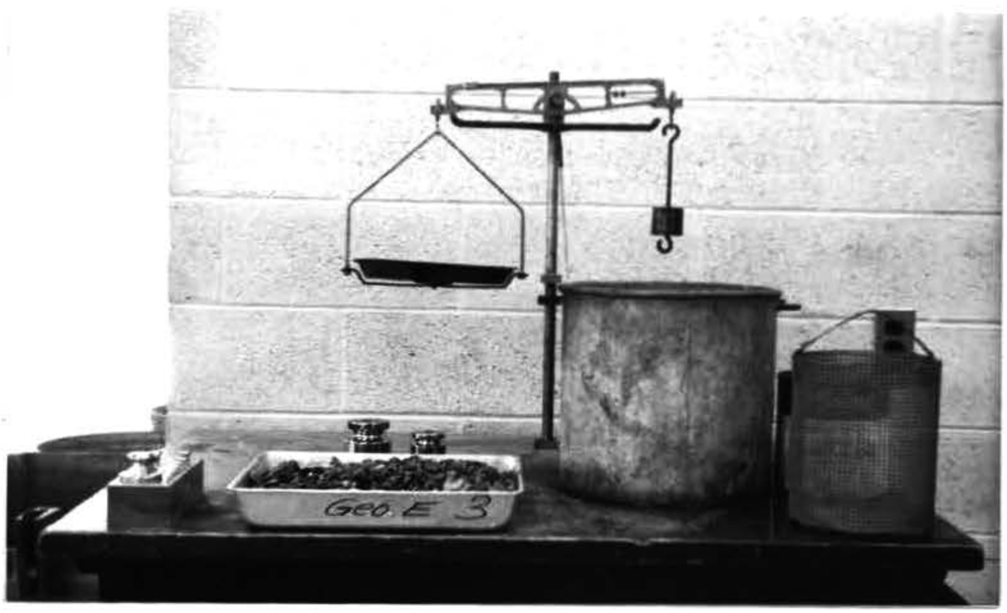
d) Absorption

Determinations were made for each aggregate sample using the standard method of test as outlined by A.S.T.M. Designation: C 127-59, Specific Gravity and Absorption of Coarse Aggregates. Picture 6 shows the apparatus which was used for the specific gravity tests.



PICTURE 4. Series of sizes of coarse aggregates separated by using sieves.

PICTURE 5. Sieving operation by mechanical apparatus.



PICTURE 6. Apparatus for Specific Gravity Test.

3. Los Angeles Abrasion Test

This method covered the procedure for testing coarse aggregate of B-grading for resistance to abrasion using the Los Angeles testing machine of standard design and meeting the qualifications specified by A.S.T.M., Picture 7 and Figure 7. The test procedure used for the study conformed to the standard method of test as outlined by A.S.T.M. Designation: C 131-66.

C. Results

Sample data sheets used for the engineering tests are illustrated in Appendix A. Tabulation of the computerized sieve data are in Appendix B. Results of the Specific Gravity and Absorption Tests are shown in Table V. Results of the Standard Los Angeles Abrasion Resistance Tests, using ASTM Grading-B, at 500 revolutions of the drum with steel shots, are presented in Table VI.

1. Gradation

Sieve analysis of aggregates provide the basis on which gradation is controlled and by which compliance with specific grading requirements is checked. Sieve analysis of coarse aggregates can be used to determine proportions of each particle size needed to produce a desired grading (45).

There are several reasons for specifying grading limits and maximum aggregate size. The grading and maximum size of aggregates affect relative aggregate proportions as well as cement and water

PICTURE 7. Los Angeles Testing Machine.

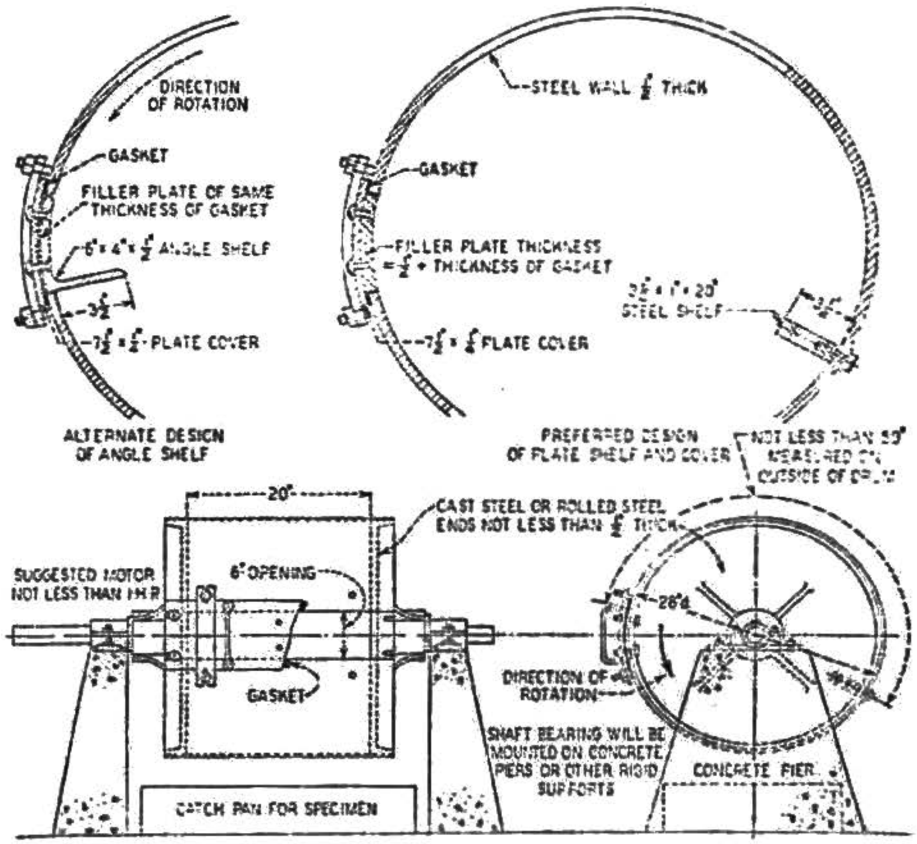


FIGURE 7. Los Angeles Abrasion Testing Machine.

TABLE V
RESULTS OF SPECIFIC GRAVITY AND ABSORPTION TESTS

STATION NO.	SAMPLE IDENTIFICATION	BULK SP.GR. (DRY BASIS)	BULK SP.GR. (SATURATED BASIS)	APPARENT SP.GR.	ABSORPTION %
1	1HW1	2.327	2.416	2.555	3.83
2	2TC2	2.355	2.430	2.546	3.20
	2TC3	2.356	2.435	2.558	3.36
3	3TB4	2.377	2.456	2.580	3.31
	3TB5	2.383	2.458	2.576	3.13
4	4TD6	2.361	2.440	2.562	3.32
	4TD7	2.358	2.437	2.560	3.34
5	5TH8	2.386	2.458	2.571	3.02
	5TH9	2.331	2.409	2.527	3.33
6	6TB10	2.331	2.416	2.548	3.65
	6TB11	2.354	2.433	2.557	3.37
7	7TI12	2.365	2.440	2.557	3.18
	7TI13	2.309	2.399	2.537	3.89
8	8TB14	2.394	2.459	2.559	2.68
	8TB15	2.401	2.466	2.568	2.70
9	9TC16	2.394	2.464	2.575	2.92
	9TC17	2.368	2.443	2.561	3.18
10	10TB18	2.476	2.518	2.584	1.68
	10TB19	2.448	2.497	2.576	2.03

TABLE VI
RESULTS OF LOS ANGELES TESTS

STATION NO.	SAMPLE IDENTIFICATION	PERCENT L.A. VALUE
1	1HW1	26.3
2	2TC2	22.4
	2TC3	21.6
3	3TB4	21.0
	3TB5	22.3
4	4TD6	23.6
	4TD7	25.0
5	5TH8	23.1
	5TH9	25.5
6	6TB10	24.7
	6TB11	23.6
7	7TI12	25.9
	7TI13	22.7
8	8TB14	24.8
	8TB15	22.9
9	9TC16	23.3
	9TC17	22.6
10	10TB18	20.4
	10TB19	20.7

requirements, workability, economy, porosity and shrinkage of concrete. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve produce the most satisfactory results. Lack of two or more successive sizes may result in segregation problems (22,47).

Particle size distributions of aggregate samples from various stations along the Meramec River, as determined by sieve analysis, were plotted on the Grading Chart, Figure 8, for comparison to the A.S.T.M. Specifications. According to the results of the sieve analysis tabulated in Table XII, there is no gap-graded aggregate. However, the grading chart shows that some samples do not meet the A.S.T.M. Specification Limits for Grading of Coarse Aggregates. Although it is apparent from the chart that the majority of the samples lie between the limit lines on most of the sieves, only samples 6, 8, and 19 have gradation curves that satisfy the specification limits completely (being completely within the limit lines).

The fineness modulus of an aggregate is a measure of its relative fineness. It is determined by adding together the cumulative percents retained on a specified series of sieves and dividing by 100. The fineness modulus does not provide information as to the grading of an aggregate, but it is useful in comparing the relative fineness of different aggregates, Table VII.

Although the first preliminary separation of the aggregate samples was made on No. 4 sieve, the results of the actual sieve analysis on the coarse aggregate portion of the samples (retained

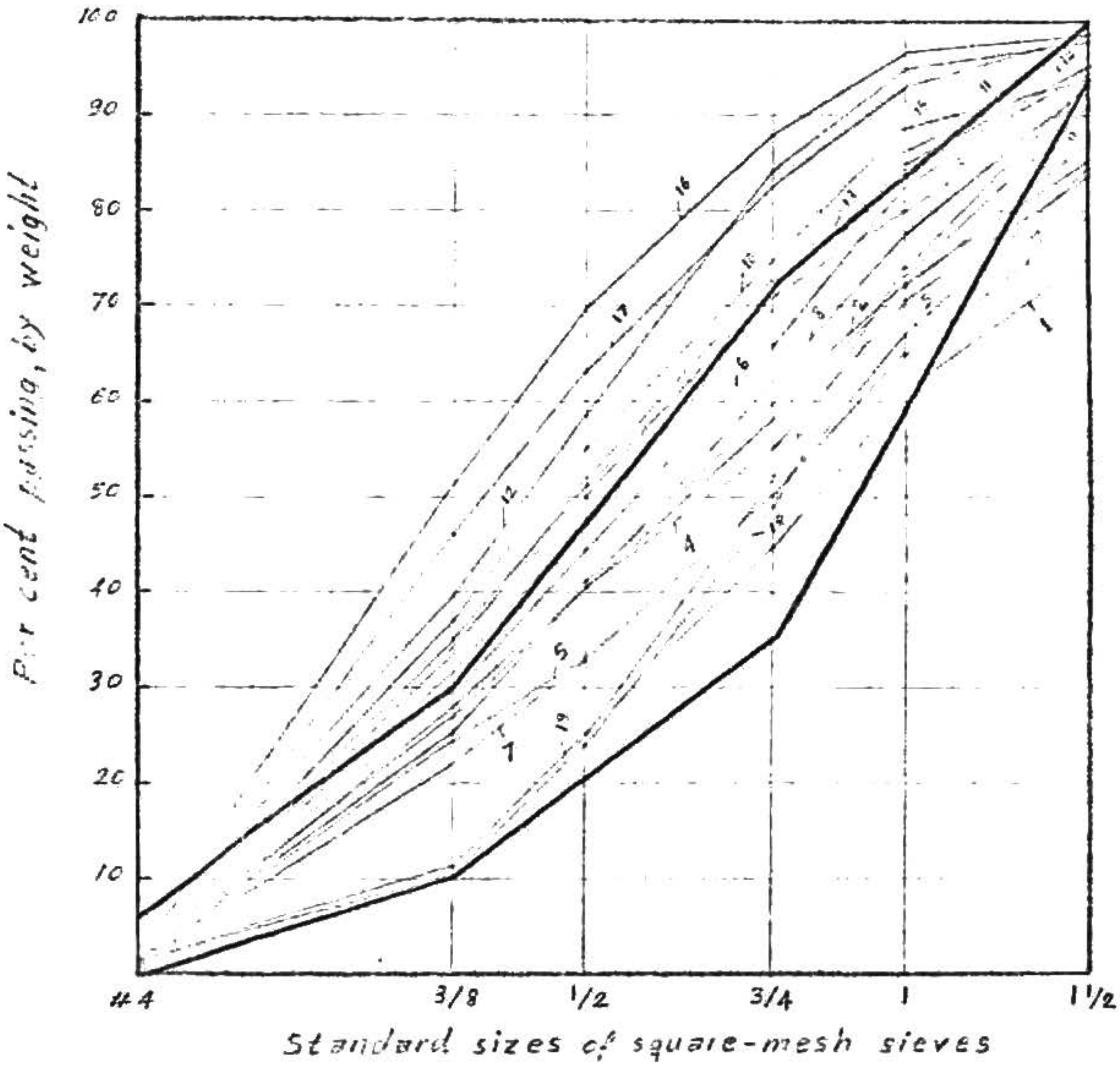


FIGURE 8. Grading Chart for the coarse aggregate samples under test.
(Heavy lines indicate the limits specified in ASTM C33 and CSA A23.1)

TABLE VII- FINENESS MODULUS OF AGGREGATE SAMPLES

STATION NO.	SAMPLE IDENTIFICATION	FINENESS MODULUS
1	1HW1	7.25
2	2TC2	7.26
	2TC3	7.03
3	3TB4	7.37
	3TB5	7.44
4	4TD6	7.48
	4TD7	7.56
5	5TH8	7.21
	5TH9	7.31
6	6TB10	6.93
	6TB11	6.98
7	7TI12	6.72
	7TI13	6.99
8	8TH14	6.97
	8TH15	7.00
9	9TC16	6.59
	9TC17	6.81
10	10TB18	7.50
	10TB19	7.45

on No. 4 sieve) indicate some percent of material still passing No. 4 sieve. This basically is due to degradation of samples during the sieving process; and, it did not correlate with the other properties of the samples, such as specific gravity and percent L. A. values. Degradation resulting from aggregate processing and handling can usually be attributed to a combination of several variables. These variables will include not only the effects of different characteristics of the individual aggregates concerned, but also the effects from the handling, mixing and compaction equipment. Each of these will produce specific amounts of degradation, although in many cases its total effect is virtually insignificant. This aspect of the problem is out of the scope of this study.

It must be recognized that aggregates and particularly coarse aggregates vary somewhat within gravel bars; hence, the significance of any single test is limited. Therefore, each analysis should be averaged with at least two or other analyses of the same material to obtain more representative data and to determine if grading requirements are met.

2. Specific Gravity and Absorption Test

Three different specific gravity values, Bulk Specific Gravity (dry basis), Bulk Specific Gravity (saturated surface-dry basis), and Apparent Specific Gravity, were computed for this study. The reason for this was to provide data for different usage purposes. For use with saturated surface-dry aggregates, the specific gravity should be based on the surface-dry condition. Practically all calculations relating to concrete mixes are made on the basis of the aggregate being in the saturated surface-dry condition. For this reason, the definition of specific gravity in most general usage for concrete work is that of bulk specific gravity (saturated surface-dry basis). However, in the cases where calculation of the materials relating to concrete mixes is needed to be made on the basis of the aggregate being in the oven-dry condition, specific gravity (oven-dry basis) is to be used.

Downstream variation of the Bulk Specific Gravity (saturated surface-dry basis) shown in Figure 9, indicates no regular variation along the river. There are some differences between the values of different sampling stations, and between the values of two different sections of each station. Since there is not much variation in pebble composition of these stations, such random variation in the specific gravity values probably can be sttributed to the variations in degree of weathering to which the gravel deposits at different stations have been subjected. This is evidenced by the results of petrographic analysis (pebble counts). For example, sample 13, which had the lowest specific gravity value, had the lowest percentage of weathered pebbles. It seems that tributaries had no significant effect on this variation.

Downstream variation of the percent absorption values, shown in Figure 10, also indicates no regular trend along the river. There are some differences between the values of different sampling stations, and between the values of two different sections of each

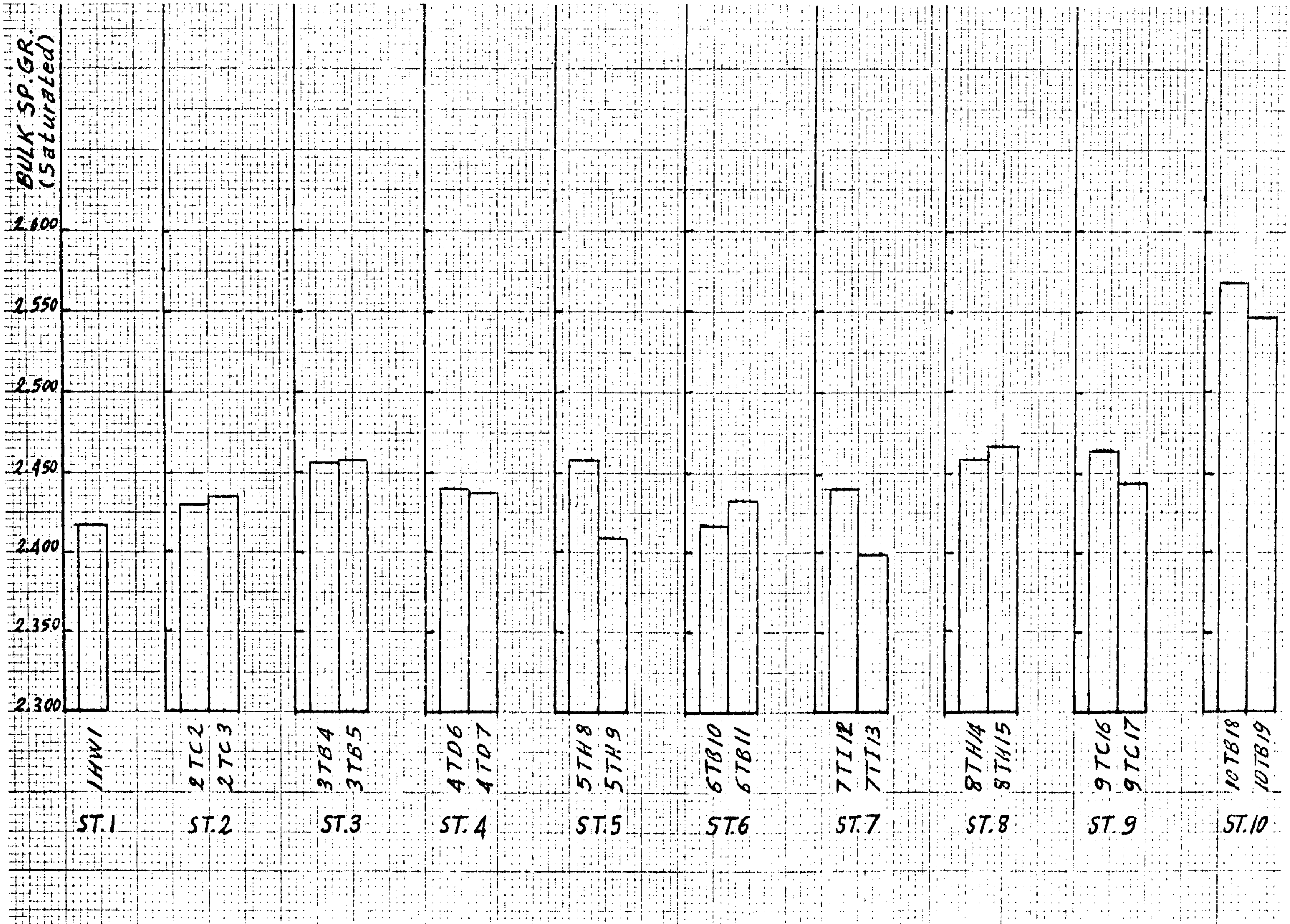


FIGURE 9. DOWNSTREAM VARIATION OF THE BULK SPECIFIC GRAVTY

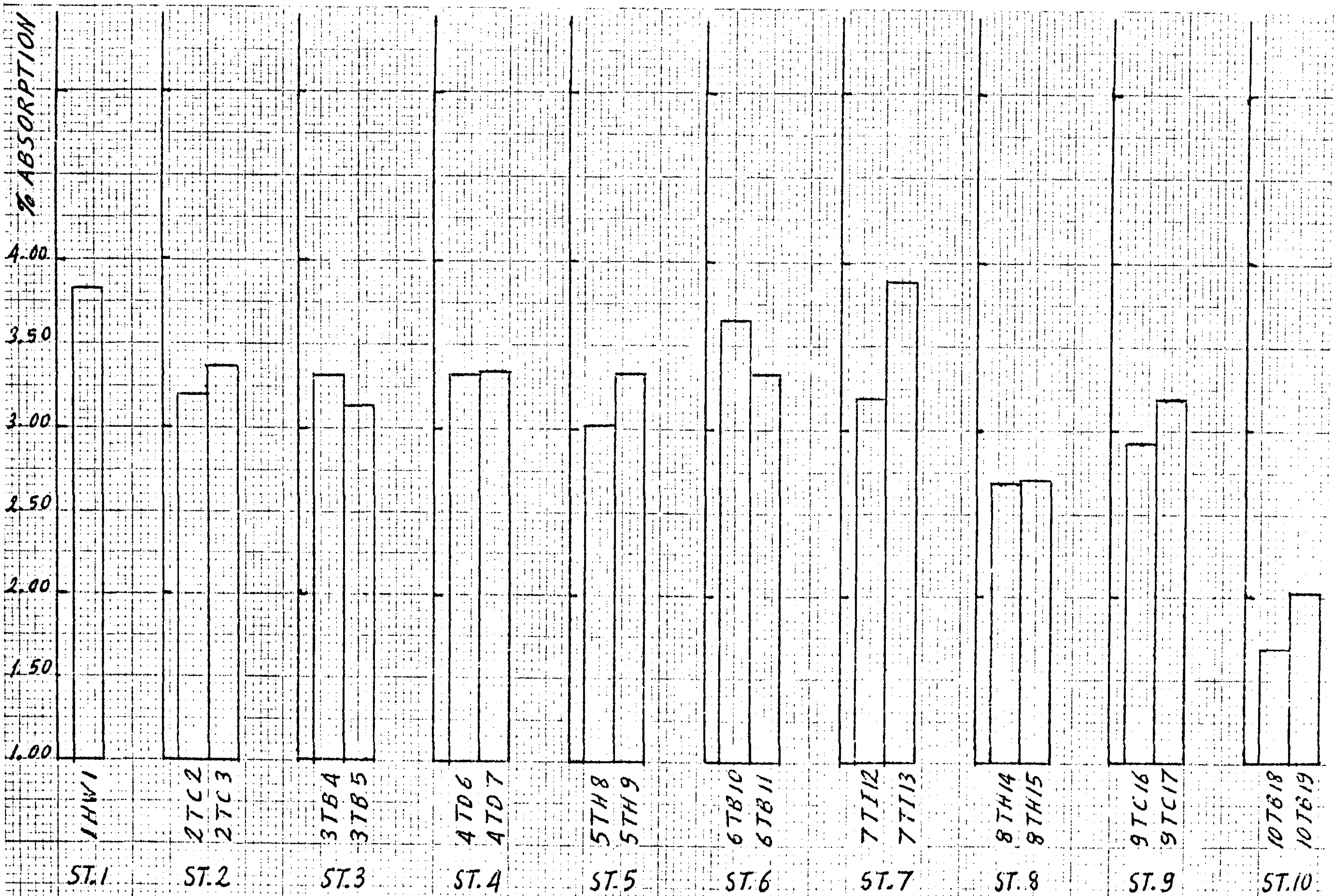


FIGURE 10. DOWNSTREAM VARIATION OF PER CENT ABSORPTION

station. This variation can also be attributed to the same reason as mentioned above for the specific gravity values.

In general, it seems there is a correlation between the percent absorption and the specific gravity values such that specific gravity values increase as percent absorption values decrease. Actually, this should be expected from inspection of the definition of absorption capacity and bulk specific gravity (saturated surface-dry basis) or bulk specific gravity. However, it is evidenced by sample 18 which had the lowest percent absorption and the highest bulk specific gravity of saturated surface-dry basis. Likewise, sample 13 with the highest percent absorption value, had the lowest bulk specific gravity value of saturated surface-dry basis. Exceptions do exist to this generalization and they are probably due to the variation in mineral composition so that a sample containing denser minerals may have higher specific gravity value even though it has larger absorption capacity. They may also be due to the variations in the size, shape and interconnection of the pores.

The values for the sample 18 of station 10 indicated it to be the best quality aggregate sample, as far as the specific gravity and percent absorption values are concerned. The specific gravity and absorption values of the other samples would be rated less desirable than the sample 18.

3. Los Angeles Abrasion Test

Abrasion resistance is one of the most important tests for aggregate evaluation. Since cement paste cannot resist abrasive forces adequately, the aggregate must be hard enough to make concrete abrasion resistant. This is especially important for concrete subjected to heavy wear such as might be encountered on industrial floors and highway pavements (22).

Results from the standard Los Angeles abrasion resistance test of concrete aggregates show good correlation not only with the actual wear of the aggregate when used in concrete, but also with the compressive and flexural strength of the concretes made with the given aggregates. Some investigators have modified the Los Angeles test by excluding the steel shot. They contend that by having particle to particle abrasion, the character of the fines generated more closely duplicates what is found in the field. This might be a feasible idea in case of aggregate degradation studies. The use of steel shot was preferred in this study because it simulates the conditions more similar to those which the concrete made of these aggregates may be exposed to, such as being subject to heavy wear and impact resistance. B-grading of test samples was used because, as specified by A.S.T.M., it constitutes the aggregates of 3/4" to 3/8" size which is the most common aggregate size used in concrete construction. Five hundred revolutions of the drum was used as recommended in the standards. Studies have shown it gives the best definition of abrasion resistance of different aggregates.

The results of the Los Angeles abrasion resistance tests, tabulated in Table VI and illustrated in Figure 11, show an increase toward, and decrease away from the mid-portion of the river, in

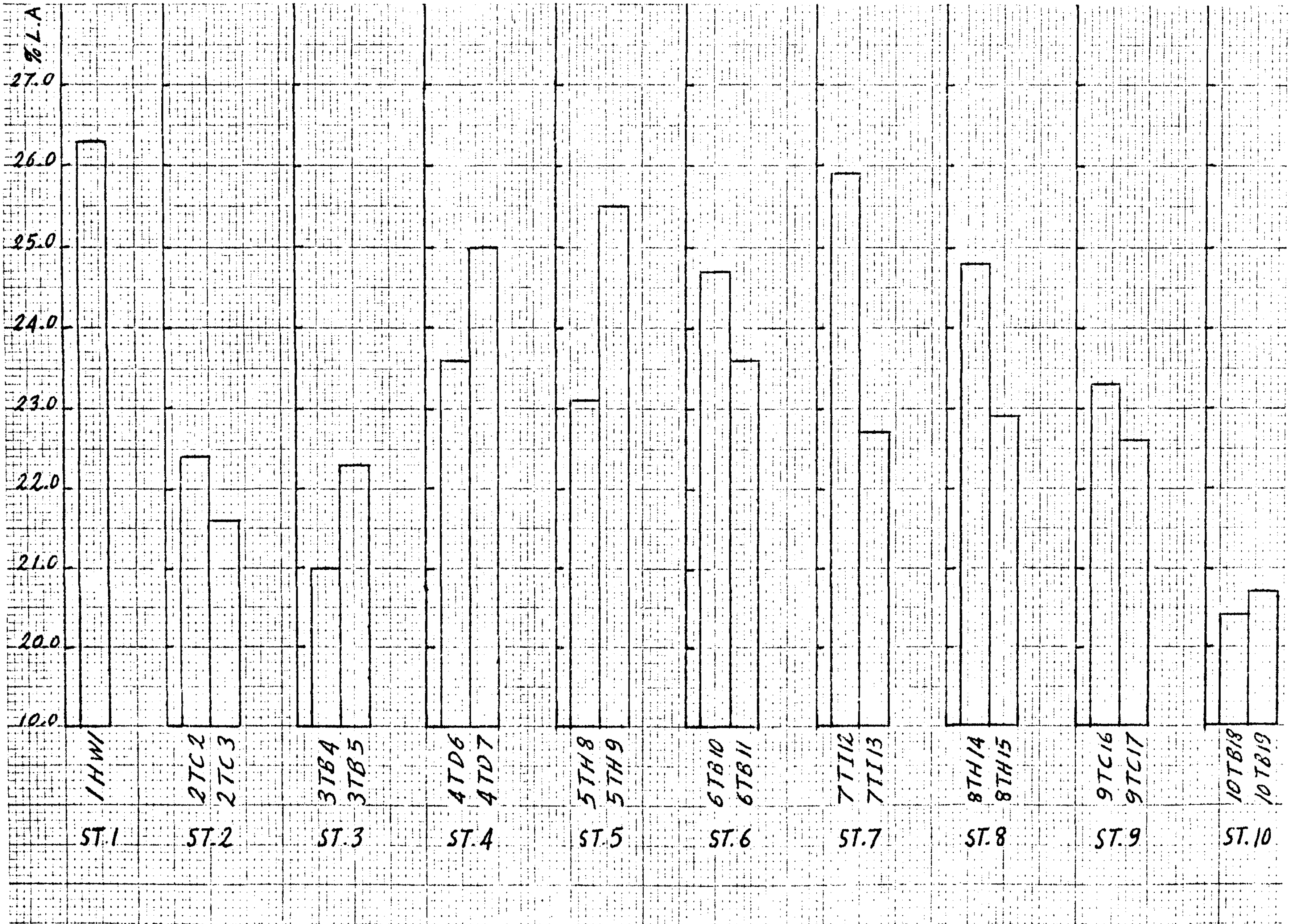


FIGURE 11. DOWNSTREAM VARIATION OF PER CENT L.A. VALUES

variation of the percent L. A. values. There are also differences in percent L. A. values of the samples before and after the tributary junctions. This trend of variation in percent L. A. values seems closely related to the weathering conditions of the samples, so that the percentage of the weathered particles in the samples show almost the same trend of variation; and naturally, more weathered samples have higher percent L. A. values than less weathered samples. However, the range of percent L. A. values is very small (20%-26%). This is, possibly, the consequence of the very slight differences in the degree of weathering of the samples. The aggregate sample 1 had the most abrasion loss (26.3%); but, it is still much below the maximum allowable loss specified by A.S.T.M., which is 50% by weight for coarse aggregates. Actually, each of the samples tested had the percent L.A. value below this limit.

4. Correlation of Results

Study of results obtained from various engineering tests, performed under this investigation, indicated that those results which can be correlated all agree in general. However, exceptions do exist to this generalization.

Gradation of the aggregate samples is quite uniform. There is not much variation in overall gradation of the samples from different stations. However, there is a slight decrease in the size and in the fineness modulus of the aggregate samples in the flow direction of the river. This appears as a natural consequence of river deposition, that is, coarse particles are deposited first and those carried downstream are subjected to abrasion wear. Exceptions that occur to this general trend may be attributed to the larger tributaries flowing into the Meramec River at its lower portion carrying coarse material.

Specific gravity and percent absorption values agree quite well, specific gravity values increase, in general, as the percent absorption values decrease. Exceptions do exist also to this generalization. There is no regular downstream trends in these values.

Neither the specific gravity values nor the percent absorption values correlate well with the percent L. A. values. This is possibly due to the variations in certain physical and chemical properties of the aggregate particles such as fracturing, banding, hardness, density, pore and weathering characteristics.

The author feels the results of the engineering tests can be explained adequately by the petrographic analysis which is discussed in the next section.

Chapter VI

PETROGRAPHIC ANALYSIS

A. General

The petrographic studies formed an important part of the aggregate quality investigation of the Meramec River gravels. They were initiated with selection of the sampling stations, and were continued throughout all phases of the investigation.

Petrographic analysis of aggregates is examination and evaluation of both the lithology and the properties of the individual particles. The procedure requires use of a hand lens and petrographic and stereoscopic microscopes. X-ray diffraction and differential thermal analysis may also be used to supplement the visual examinations.

Petrographic examination contributes in several ways to the investigation, selection, testing and control of aggregates. The probable performance of concrete aggregate is estimated in two general ways by petrographic examination. First, the examination reveals the composition, physical and chemical characteristics of the constituents. From this information, the probable response of aggregates to such phenomena as attack by cement alkalies, freezing-thawing, wetting-drying, and heating-cooling usually can be estimated. Second, petrographic examination establishes the fundamental nature of aggregates so that aggregates from unfamiliar sources can be compared with aggregates for which information is available.

Petrographic analysis of aggregates under this investigation were made for the following purposes:

1) To determine the physical and chemical properties of the material that may be observed by petrographic methods and that have a bearing on the quality of the material for its intended use.
2) To describe and classify the constituents of the sample.
3) To determine the relative amounts of the constituents of the samples, which is essential for proper evaluation of the sample.

For the purpose of this investigation, petrographic analysis consisted of the following examinations:

1) Megascopic Examination (Pebble Counts)
2) Microscopic Studies
3) X-ray Diffraction Analysis

Some of the factors studied by these methods of analysis were:

a) Lithologic composition
b) Particle shape
c) Particle surface
d) Mineral composition
e) Grain size
f) Texture and structure (particle orientation)
g) Presence or lack of interlocking grain boundaries
h) Microstructures and fractures
i) Voids
j) Presence and nature of coatings

k) Degree of leaching of soluble constituents

l) Alteration of mineral constituents

m) Presence of inclusions

n) Presence of constituents known to cause deleterious chemical reaction in concrete.

Samples of aggregate for petrographic examination should be representative of the source. The samples were taken on the basis of requirements of aggregates for concrete according to the A.S.T.M. Method of Sampling Stone, Slag, Gravel, Sand and Stone Block for use as Highway Materials (A.S.T.M. Designation: D 75), and Recommended Practice for Petrographic Examination of Aggregates for Concrete.

The petrographic examination was performed on 1/2" size fractions comprising a minimum of 300 particles. Samples for petrographic examination were separated from these sieve fractions on the basis of their estimated weight of 300 particles (Table VIII) by the splitting method.

The 1/2" to 3/4" size range was selected for the detailed laboratory studies for several reasons. This particular size is a critical size for freeze-thaw deterioration and for sulfate soundness. As noted by Aughenbaugh (3) and by McCammon (26), the 1/2" to 3/4" size also is a critical size for an effective visual inspection in pebble counting and for making proper thin sections for microscopic examination. The 1/2" to 3/4" size range also is one of the most common aggregate fractions that are used in concrete construction.

TABLE VIII - MINIMUM REPRESENTATIVE SAMPLES FOR PETROGRAPHIC EXAMINATION

Size Fraction	Weight of 300 Particles
3 to 1 1/2	57 lb.
1 1/2 to 3/4	19 lb.
3/4 to 3/8	2.6 lb.
3/8 to 3/16	0.75 lb.
No. 4 to 8	15 g.
No. 8 to 16	2.1 g.
No. 16 to 30	0.28 g.
No. 30 to 50	0.033 g.
No. 50 to 100	0.0066 g.

B. Description of Analysis

1. Megascopic Examination

The aggregate samples were kept under close megascopic survey throughout all testing programs of the investigation.

Megascopic examination consisted of unaided visual inspection of the aggregate pieces, some hand lense observation, and recording of significant features with photography, such as particle shape, surface texture, etc.

Different rock types present in the aggregate samples were identified and classified megascopically on the basis of their physical properties. Lithologic composition of the samples was calculated by pebble counts and relative amount of each rock type was expressed as the percentage of both the total number of particles and the total weight of particles. Both the calculation and the tabulation of the particle counts was done by computer programming, Appendix D.

2. Microscopic Examination

The microscopic studies consisted of two parts:

a) The examination of aggregate particle surfaces and of cut and polished sections with a stereoscopic-binocular microscope.

b) The study of thin sections with a petrographic microscope.

The stereo-microscope studies were done with "Spencer Biobjective-Binocular Microscope" with a magnification range of 15X to 90X. The thin section examinations were made with a "Ernst Leitz GmbH-Wetzlar Petrographic Microscope" with a magnification range of 280X to 360X.

Specimens selected for microscopic study were first examined intact with the stereo-microscope. A typical sample was then cut into two pieces. One half of the cut specimen was polished and re-examined with the stereo-microscope. The other half was used to make a thin section for slide studies. Total of forty-two polished sections and thin sections were examined.

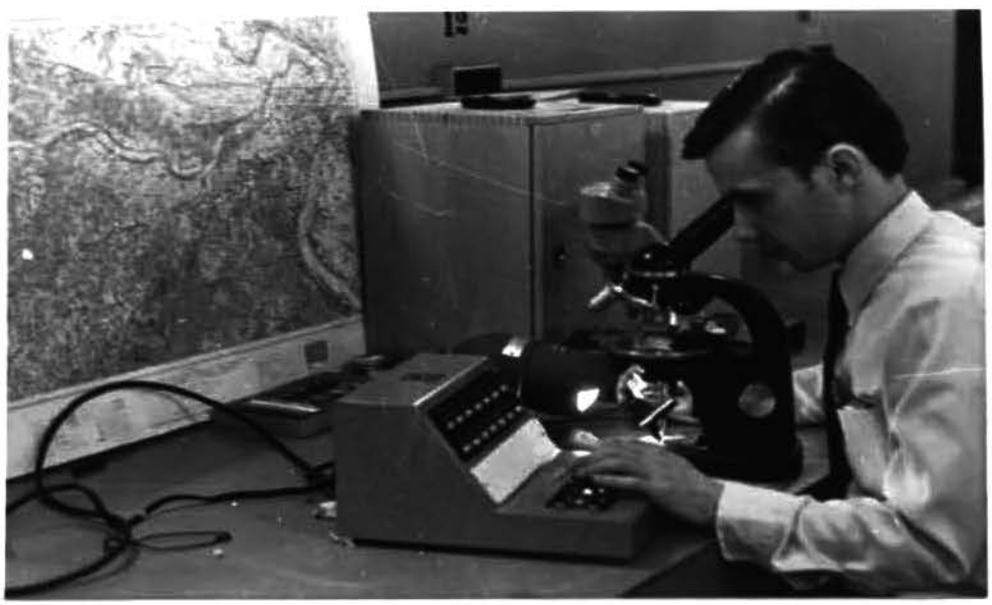
Some of the features looked for in the stereo-microscopic examination were surface conditions, weathering characteristics, banding, porosity, crystallinity, impurities, fractures, partings and coatings.

Thin section examination gave more detailed information on most of the above features plus good appraisal of the detailed mineralogy, grain sizes, grain shapes, grain boundary relationship, microstructures and fractures, incipient alterations and cementing. Relative percentages of different minerals, and percentage of voids were also calculated from the thin sections by the point counting method using a mechanical stage, attached to the petrographic microscope, and electro-point counter (Picture 8).

3. X-ray Analysis

The diffractometer method of analysis was used for the x-ray studies. Diffractometer traces of the samples were made using a General Electric XRD-5 Diffractometer. Copper radiation was used on the samples. Diffraction angles were recorded on the charts at 0.4°/min.

X-ray analyses were made on the samples by grinding up the same aggregate pieces that were used for microscopic analysis. This



PICTURE 8. Performing the petrographic examination of aggregates with stereoscopic microscope, petrographic microscope, mechanical stage and electro-point counter.

method of analysis was employed to supplement the microscopic examinations.

C. Results

Sample data sheets used for petrographic analysis are illustrated in Appendix C. Tabulation of the computerized pebble composition data are in Appendix D. Description of some of the physical properties of different rock types, as determined by petrographic analysis, is presented in the Table IX. Results of the microscopic examination were tabulated in Table X. Typical examples of diffractometer tracing are shown in Figures 12, 13 and 14.

1. Megascopic Examination

The characteristics of particle shape and surface texture of aggregate particles have an important effect on performance of concrete. The smoother and more rounded particles generally produce a more workable mixture. Surface texture affects the bond between the aggregate particles and the cement paste due to penetration and interlock; and, generally speaking, a rougher surface results in a better bond. More angular particles generally produce better bonding than rounded particles. This was thought to be due to the rougher surface texture generally found on angular particles. However, results of megascopic examination of the aggregate particles under this investigation indicate that this is just the opposite in the case of Meramec River gravels; so that, more angular chert particles have a glossy surface texture whereas the surface texture of rounded chert particles are rougher.

TABLE IX- PHYSICAL PROPERTIES OF AGGREGATE PARTICLES OF THE MERAMEC RIVER

Rock type	Particle shape	Surface texture	Pore size*	Hardness
Non-weathered chert	Angular	Glossy	Small	7
Slightly weathered chert	Subangular to subrounded	smooth	Medium	7 to 6
Highly weathered chert	Rounded	Rough	Large	6
Sandstone	Well rounded	Granular	Large	6 to 5
Dolomite	Well rounded	Crystalline	Medium	4 to 3

* Small: 1 to 10μ Medium: 10 to 200μ Large: 200 to 500μ

TABLE X- RESULTS OF MICROSCOPIC ANALYSIS

Mineral Composition, %	Rock Types							
	CHERT(A)	CHERT(B)	CHERT(C)	CHERT (D)	CHERT (E)	CHERT(F)	SANDSTONE	DOLOMITE
Quartz	90.08	73.50	87.19	96.84	86.38	99.65	99.97	1.24
Chalcedony	4.46	21.80	0.00	0.00	11.45	0.00	0.00	0.00
Dolomite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.87
Iron oxide	4.78	5.40	12.82	3.26	2.71	0.00	0.03	0.00
Organic matter	0.28	0.00	0.00	0.09	0.68	0.40	0.00	0.00
	99.60	100.70	100.01	100.19	101.22	100.05	100.00	100.11
Voids, %	1.60	2.13	17.21	1.31	3.16	39.70	30.80	2.17

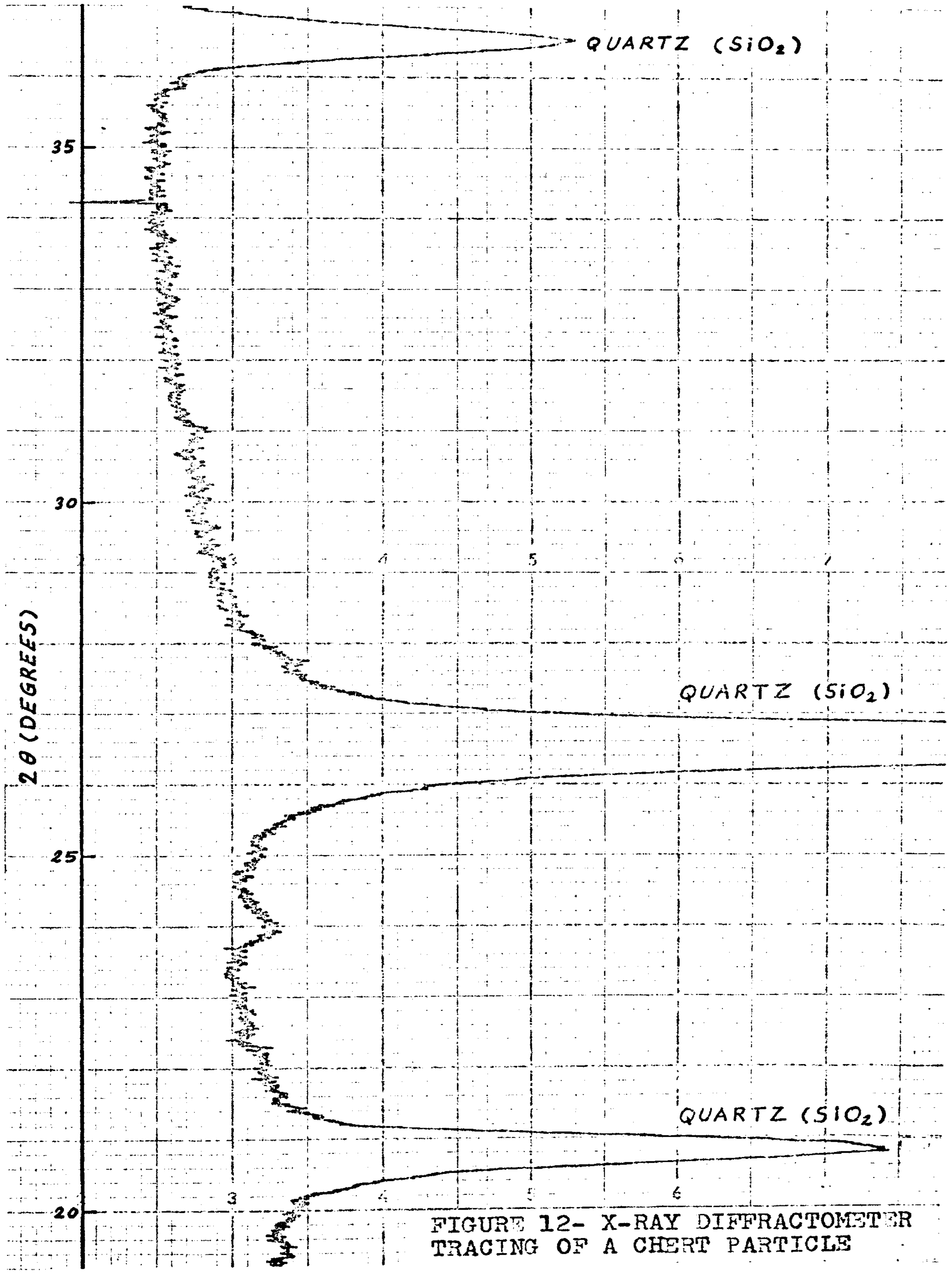


FIGURE 12- X-RAY DIFFRACTOMETER TRACING OF A CHERT PARTICLE

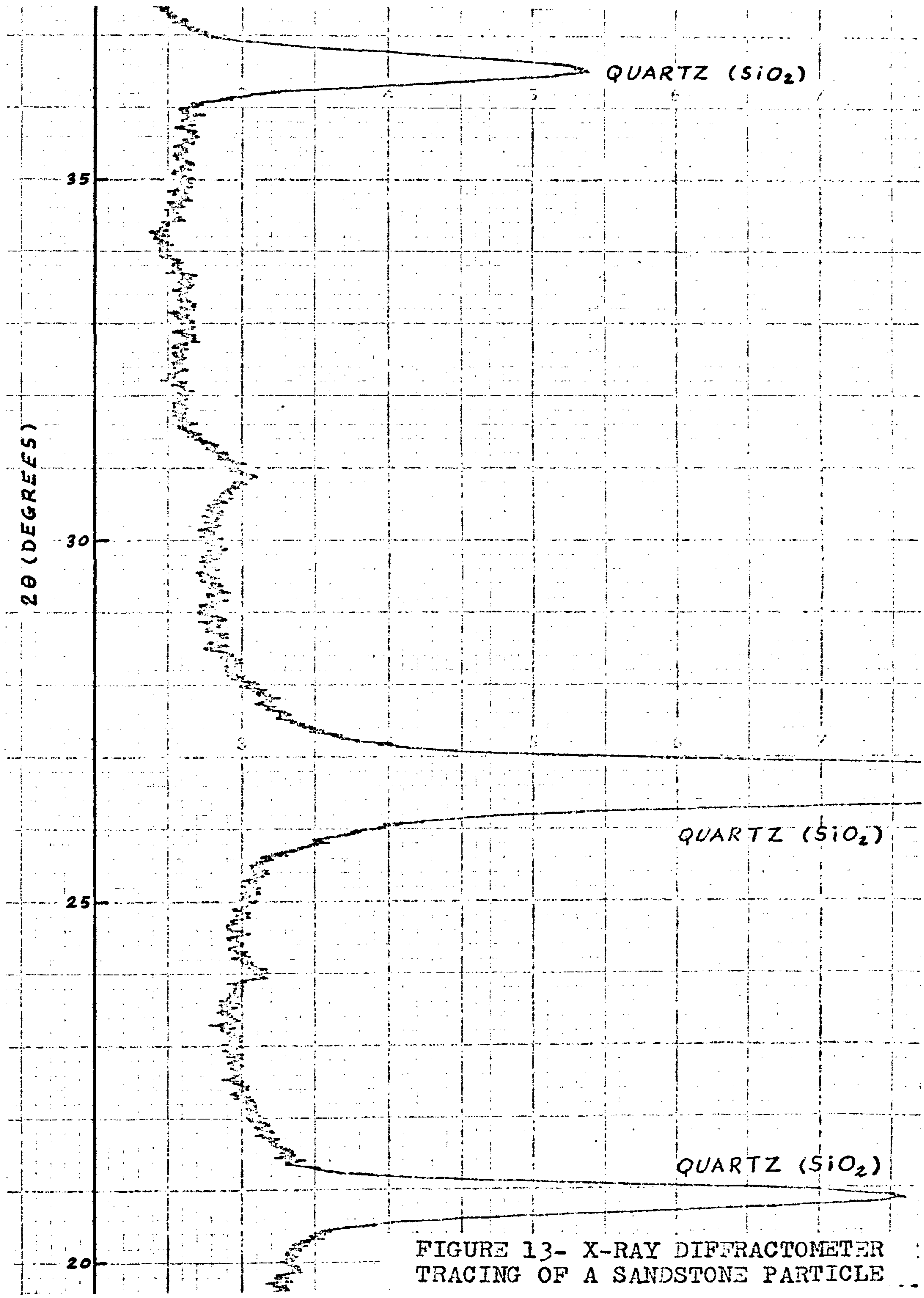


FIGURE 13- X-RAY DIFFRACTOMETER TRACING OF A SANDSTONE PARTICLE

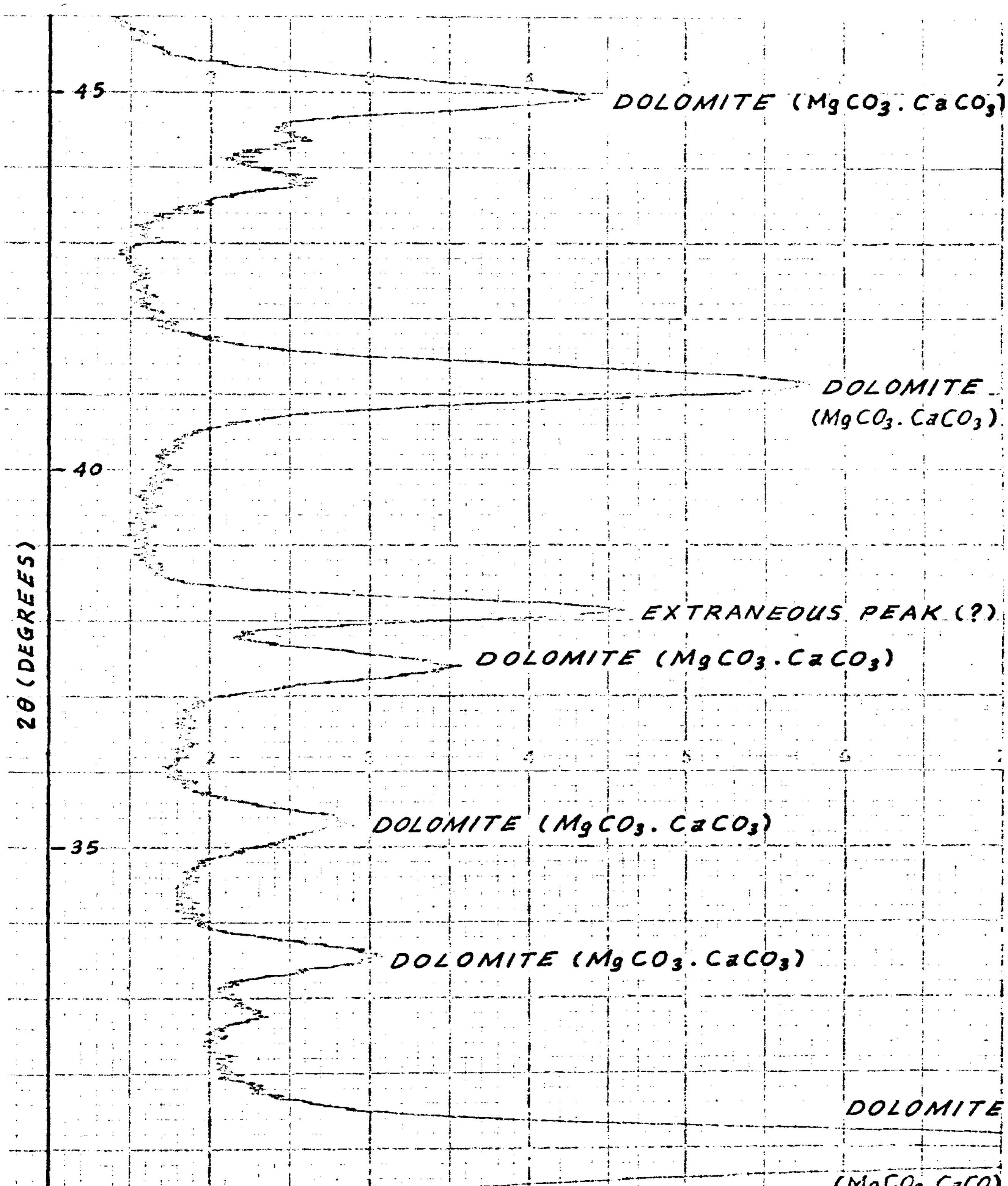


FIGURE 14- X-RAY DIFFRACTOMETER TRACING OF A DOLOMITE PARTICLE

Megascopic analysis of the Meramec River gravels revealed little variation in pebble composition. The only rock types identified by megascopic examination were chert, sandstone and dolomite. The pebble composition reflects the general local lithology along the river which constitutes cherty dolomite and sandstone. Chert is the major constituent of the samples. Dolomite and sandstone appear as minor constituents in some of the samples. However, not all the chert particles are identical in appearance. The appearance classification of the chert particles was made on the basis of their color and weathering condition. Some of the chert particles are brown-stained due to iron-oxide coating on the particle surface; the others are white colored. Both brown-stained and white colored cherts were also classified according to their weathering condition such as non-weathered, slightly weathered and highly weathered chert particles.

In general, particle shape of non-weathered cherts, both the brown-stained and white colored particles, appeared more angular with a little evidence of wear. Most of them had a conchoidal fracture although some were hackly or irregular, Picture 9. The surface textures of the non-weathered chert particles were glossy and relatively impermeable because of very small pores. The hardness of non-weathered cherts were around 7. The particle shapes of the slightly weathered cherts is best described as "subangular to subrounded" and showing evidence of some wear, Picture 10. The surface textures of the particles of this class of chert are relatively smooth, and appear more porous than the non-weathered chert particles. The pores also are larger. The highly weathered

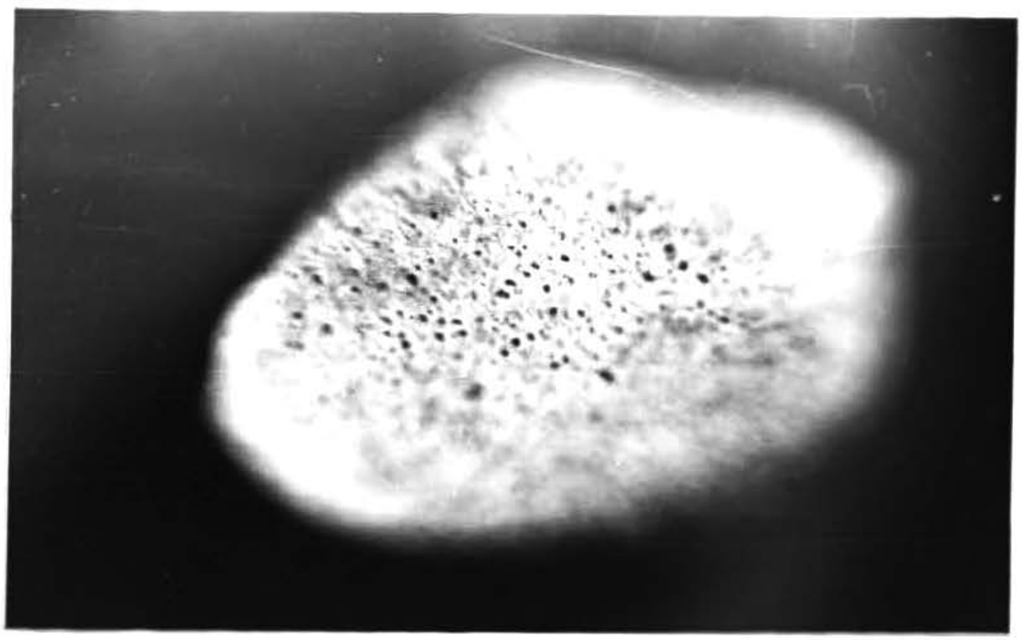
PICTURE 9. Particle shape and surface texture of a non-weathered chert particle, (X3).

PICTURE 10. Particle shape and surface texture of a slightly weathered chert particle, (X3).

cherts are rounded particles with the faces almost gone, Picture 11. Their surfaces appeared rougher and had larger pores. Some of the highly weathered cherts also had a whitish outer band rimming the particle.

Particles of sandstone and dolomite were fairly well rounded with no original faces. The sandstones had granular surface textures whereas the dolomites particles were generally crystalline. Both of their pore structures were different from that of the chert particles in that they varied in size and were irregular in shape. Voids in chert particles are more or less circular and more uniform in size. Megascopic fractures are not too common in any of the aggregate particles.

The purpose of selecting the sampling stations at the junction of the main tributaries of the Meramec River was to examine the influence of these tributaries to the pebble composition of the Meramec River gravels. The results of the pebble counts, shown in Table XIII, Appendix D, indicated that these tributaries do not have an overly significant effect on the general composition of the gravel samples; and chert is the dominant rock type in each sample. Sandstone pebbles are present in very small amount as compared to the abundant chert particles. They are even absent in some of the samples. Some sandstone pebbles consist of clear quartz grains of moderately fine size and have a reddish color due to iron-oxide cementing and probably belong to the Roubidoux formation which is present in the area. Other sandstone pebbles have a white to gray color and consist almost entirely of pure



PICTURE 11. Particle shape and surface texture of a highly weathered chert particle, (X3).

silica. These type of sandstone pebbles are present in the samples from the lower stations and they are possibly derived from the St. Peter sandstone which outcrops in the lower portion of the Meramec River. The absence of dolomite particles in most of the samples, or their presence as a very minor constituent in some of the samples, in spite of existence of large dolomitic formations along the Meramec River, can be attributed to a very high degree of leaching of the carbonate minerals by the river water and to their lower resistance to abrasion wear. The relative resistance to abrasion is probably the main reason for the abundance of chert particles in all of the samples. Solution of carbonates or fossil inclusions appeared as a coating, in form of a whitish outer band, developed on the surface of some of the highly weathered chert particles. On the other hand, replacement of fossils by silica was consequent to weathering; the cavities formed in highly weathered chert particles by solution of fossil debris are generally filled with coarse quartz crystals or fibrous chalcedony spherulites of secondary origin.

2. Microscopic Studies

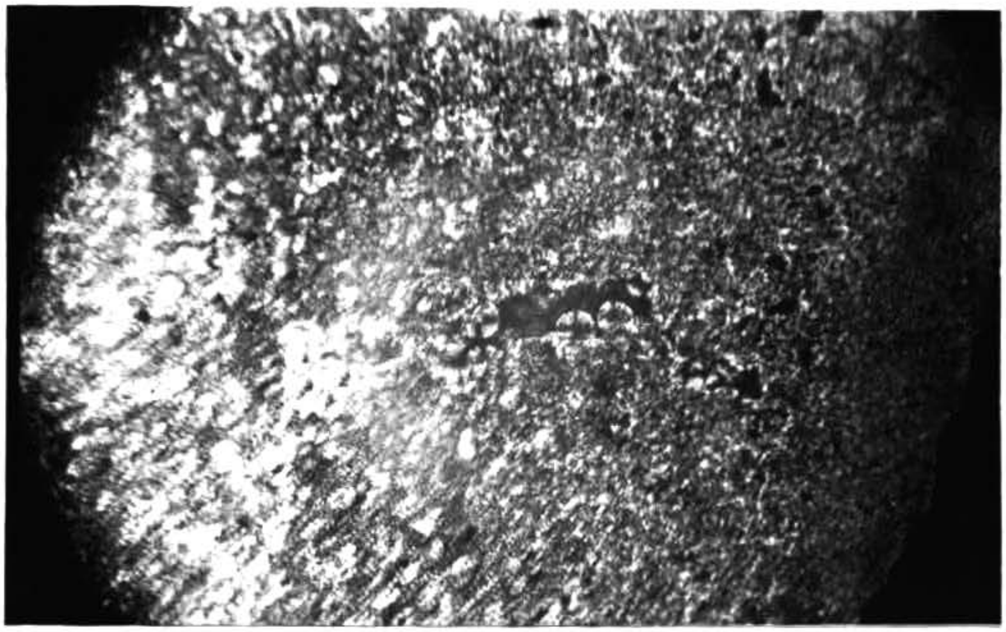
The characteristics of the pore spaces in aggregates are the most important of all aggregate physical properties. The importance of pore characteristics is due to their influence on the other physical and chemical properties of the aggregates and their influence on the durability to freezing and thawing. The pore characteristics determine the amount of water the aggregate can absorb, its absorption rate, its ease of draining, its internal surface area, and the portion of its bulk volume that is occupied by solid matter. Generally, with an increase of percent voids there is a decrease in strength. The solution voids give lines and planes of weakness through which fracturing occurs (3).

Bulk grain or crystal size has a perceptible effect on strength. The fine-grained rocks are stronger than coarser textured rocks. The grain or crystal shape will also influence the strength of aggregate. With an increase in grain angularity, there is an increase in strength. There is also a relation between grain interlock and aggregate strength. The better the interlocking texture the better the strength. Grain interlock is dependent to large degree upon the grain size. Also, as the grains become more angular, the interlocking nature becomes better. However, there are some exceptions to this rule. The grain orientation contributes some to the strength of an aggregate. Orientation though is closely associated with grain interlock. As grains become better oriented they loose their interlocking nature. Orientation is also related with grain shape. Actually, grain orientation will have very little influence on the aggregate strength unless the lineation is very profound(3). On the other hand, strength of aggregate particles is, at the present time, considered to be relatively unimportant as regards strength of the concrete since most concretes are much weaker than the aggregates from which they are made (22).

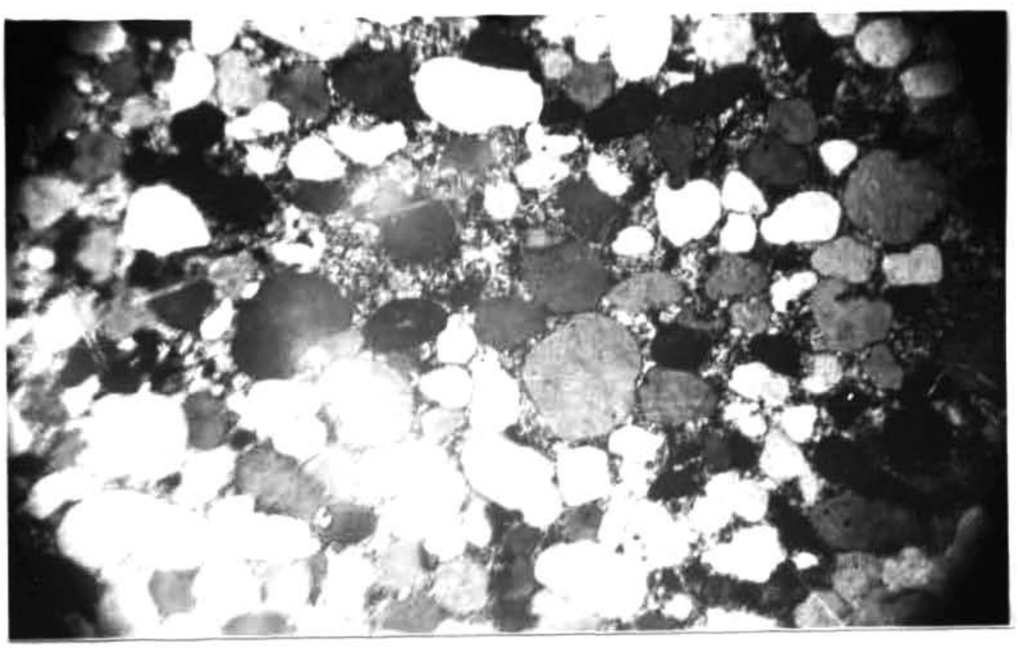
Results of the microscopic studies, tabulated in Table XII, Appendix B, give only a general idea about certain mineralogical characteristics of the aggregates from the Meramec River. Since the number of particles tested consists of only a small portion of the whole aggregate sample, these results cannot be generalized, accurately, for the whole of the Meramec River due to the possible variations of these properties from particle to particle.

The microscopic studies revealed that the bulk mineralogy of the chert particles, generally consisted of microcrystalline to cryptocrystalline quartz. Chalcedony of secondary origin is present in the form of fibrous spherulites in some of the chert particles, Picture 12. Quartz and chalcedony, collectively make up more than 90% by volume, of the chert particles. Brown minerals, generally associated with chalcedony spherulites, are probably limonite crystals present as a secondary mineral in the form of iron-oxide staining. Chalcedony, associated with limonite crystals is usually brown-stained. Fossil matter is present in some of the thin sections of the chert particles as a very minor constituent. Carbonate minerals are absent in all chert particles.

In most of the chert particles, the cement is predominantly very fine grained silica, that is, microcrystalline quartz. Oolitic texture, formed by rounded coarse crystals of quartz imbedded in a matrix of microcrystalline fibrous chalcedony, is present in some of the chert particles, Picture 13. Microstructures are not very common in chert particles. The mineral composition does not vary much from non-weathered to highly weathered particles of both stained and non-stained white chert, but there are differences in microscopic structures of these particles. Non-weathered, stained chert particles have an almost equigranular, dense texture, with an average grain size of 50 μ, and good interlocking grain boundaries.



PICTURE 12. Fibrous chalcedony spherulites imbedded in a matrix of microcrystalline quartz. Nicols crossed, (X25).



PICTURE 13. Oolitic texture of chert formed by rounded coarse crystals of quartz imbedded in a matrix of microcrystalline fibrous chalcedony. Nicols crossed, (X25).

Presence of non-connected micro-voids can be recognized under the microscope. Banding is slightly visible in form of stained layers in some of the particle sections. Radial orientation of fibrous chalcedony crystals is the characteristic of the texture. Stained rims of iron-oxide (limonite) around the particle section, average thickness of 0.25 mm, is a very common feature, Picture 14.

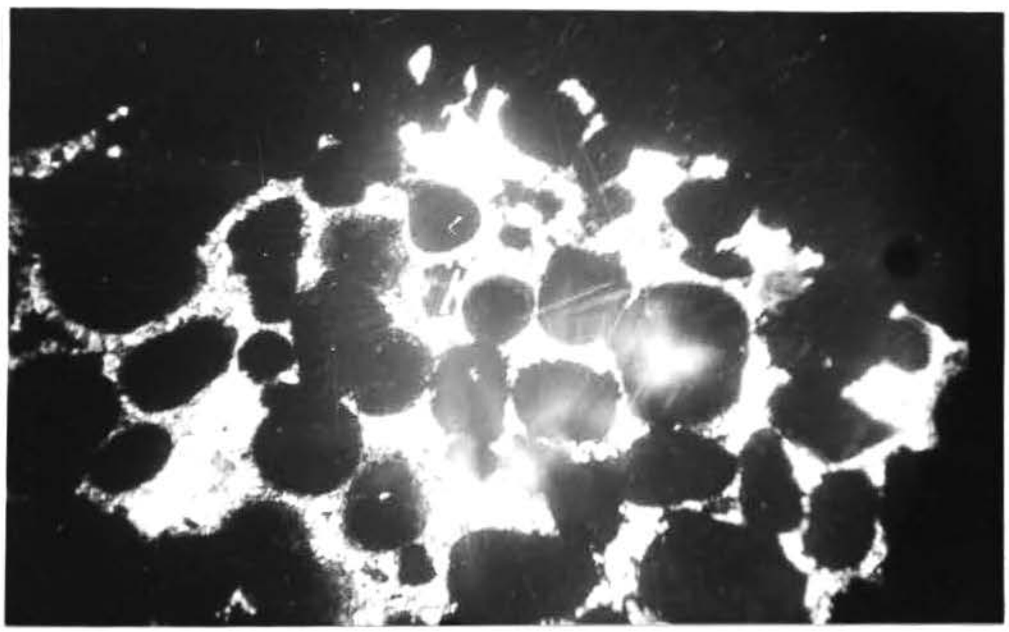
In case of slightly weathered stained cherts, the matrix is composed of chemically precipitated microcrystalline quartz and chalcedony. The cementing material is silica. Limonite inclusions into the matrix of microcrystalline chalcedony can be recognized. The voids are relatively larger and semi-connected.

Highly weathered stained chert contains considerable amounts of iron-oxide, and high percentages of voids that are interconnected, Picture 15. The matrix is composed of silica, microcrystalline quartz, with imbedded dark colored opaque minerals of gross size, probably decomposed limonite or hematite. Large, irregular voids are visible even megascopically. The more or less angular grains exhibit good interlocking grain boundaries. Due to the large voids, interlocking grains do not form a good particle orientation. Varying grain size also forms a loose structure.

Variation of micro-structure in the non-stained, white colored cherts, both the non-weathered and highly weathered particles, is generally the same as it is in the case of stained cherts with the exception that a few coarse crystals of quartz, probably of secondary origin, are present in the fine-grained matrix.

The mineralogy of sandstone pebbles consisted almost entirely of quartz. Some fossil evidence was noted. The microcrystalline and

PICTURE 14. Polished section of a stained chert particle, showing iron-oxide staining around the particle, (X3).



PICTURE 15. Large size pores associated with highly weathered chert particles. Nicols crossed, (X25).

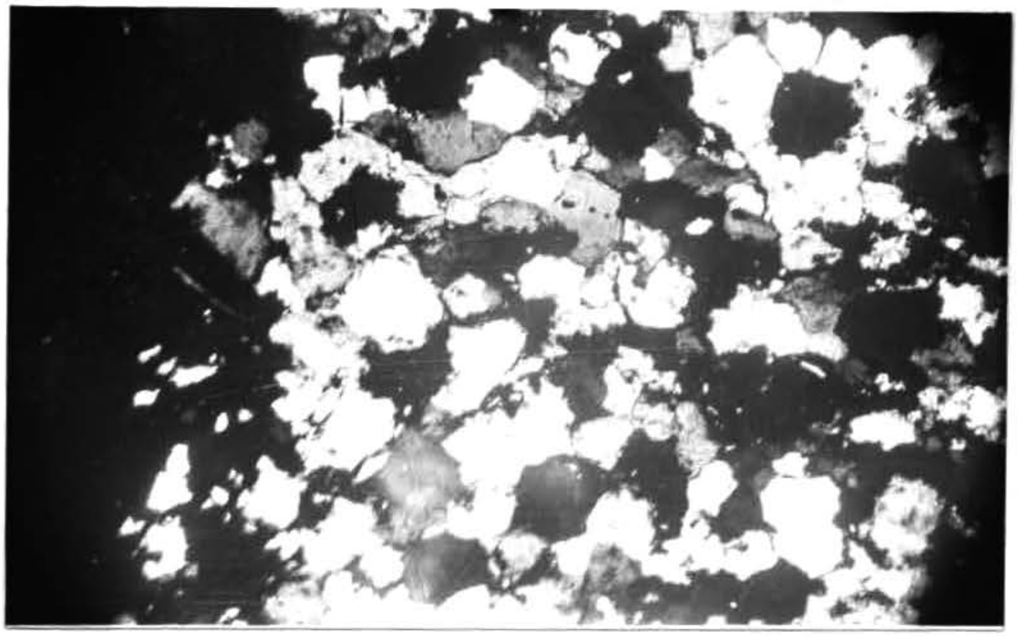
cryptocrystalline quartz forms a highly porous texture with a very high percentage of irregular voids of large size, Picture 16.

The dolomite particles, which were present as very minor constituents in the Meramec River gravels, were composed of more than 90% of the mineral dolomite and small percentage of secondary quartz. The coarsely crystalline, more or less angular grains of dolomite form a good interlocking texture with medium size, irregular voids between the grains, which seems to be non-connected. Particle orientation is very poor due to the variation in grain size and large solution cavities. Inclusions of quartz in forms of cavity filling are recognizable. No distinct cracking or fracturing was found, Picture 17.

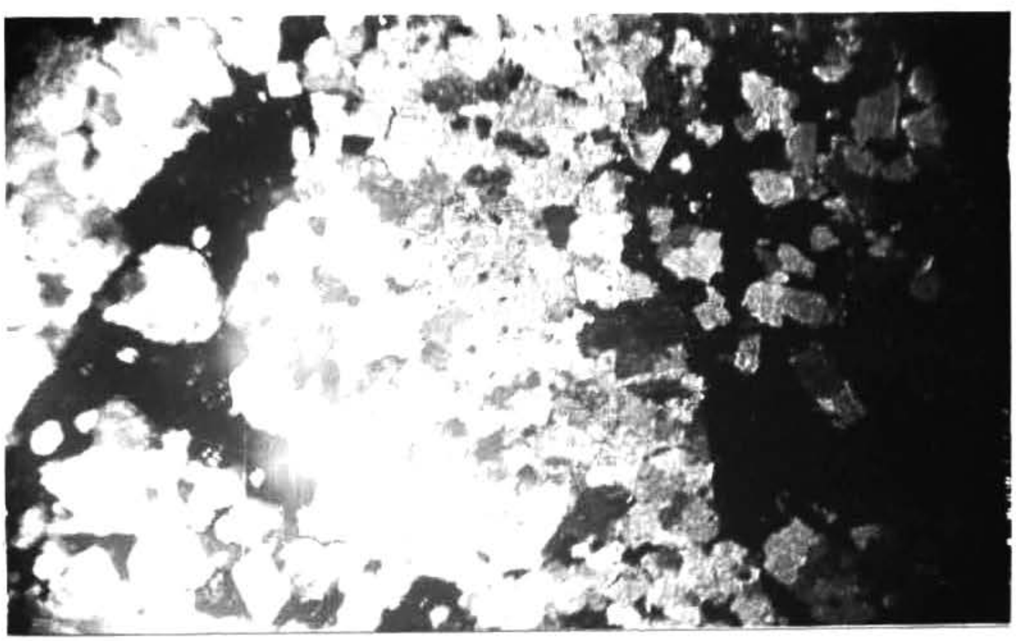
In general, alteration of the rock constituents due to chemical weathering is not an overly significant factor in this study. The minerals have been altered very little. Small amounts of secondary minerals are present in the form of iron-oxide staining. These stains possibly result from the oxidation of pyrite. The pores present in non-weathered chert particles are very small and discontinuous. They are distinctly a part of the texture, but the porosity developed in highly weathered chert particles, due to leaching of carbonates and fossil structures, are larger and connected and truncate textural trends.

3. X-ray Analysis

The diffractometer method of analysis, used for the x-ray studies, was employed to supplement the microscopical examination. Figures 12, 13 and 14 are the typical tracings of laboratory powdered aggregate pieces of chert, sandstone and dolomite pebbles, respectively.



PICTURE 16. Highly porous texture of sandstone particle formed by microcrystalline to crypto-crystalline quartz. Nicols crossed, (X25).



PICTURE 17. Photomicrograph of dolomite particle showing interlocking grain boundaries between dolomite crystals. Nicols crossed, (X25).

The x-ray results for the mineral composition of three different rock types present in the samples agree well with the results obtained from the same samples by microscopic analysis. The minor constituents present in the samples, such as iron oxides, and secondary quartz, did not show any significant peaks in the diffractometer tracings of these samples. This is probably due to their relatively very small amounts as compared to the abundance of quartz or dolomite minerals. One single peak with $2\theta=38^{\circ}14'$ and dR=2.3575, present in tracing of dolomite and in some of the chert samples, which could not be identified due to the absence of other peaks. One of these peaks was labelled "Extraneous" in the diffractometer tracing of dolomite particles, Figure 14.

Comparison of the traces of the laboratory powdered aggregate particles of chert and sandstone shows no difference in composition. Both consisted almost entirely of quartz. The trace of dolomite in the samples has strong peaks which belong only to dolomite minerals. X-ray analysis of the aggregate samples did not indicate presence of any clay minerals.

Chapter VII

SUMMARY AND CONCLUSIONS

The present investigation was made to evaluate the quality of the Meramec River gravels as an aggregate source for concrete. For this purpose, samples were collected from the gravel bars located at the junction of the main tributaries of the Meramec River. Engineering tests and petrographic analysis conforming to the Standard Methods of Tests as outlined by ASTM Specifications were conducted on the coarse aggregate portion of these samples. Included in the engineering tests were sieve analysis, specific gravity and absorption, and Los Angeles abrasion test. Petrographic analysis consisted of megascopic examination by pebble counts, microscopic studies, and x-ray diffractometer analysis. Method of sampling, procedure for the tests, results, and discussion of the results were presented in preceeding sections.

The results of these various studies lead to the following general conclusions on the qualitative evaluation of the Meramec River gravels:

1. According to the results of the sieve analysis tabulated in Table XII, Appendix B, aggregates from the Meramec River gravels are not gap-graded. However, the grading chart presented in Figure 8 indicates that, as far as the gradation is concerned, not all of the samples fall within the ASTM Specification Limits for Grading of Coarse Aggregates. It is apparent from the chart that the majority of the samples conform reasonably well with the limits. Samples 6, 8, and 19 conform the best to the gradation

specifications. Generally speaking, on the basis of gradation, aggregates from the Meramec River can be classified as satisfactory.

2. The maximum aggregate size is 2 inches.

3. The bulk specific gravity of the aggregates, on a dry basis, varies from 2.309 to 2.476; bulk specific gravity on a saturated basis varies from 2.399 to 2.518; apparent specific gravity varies from 2.527 to 2.584. In general, specific gravity values can be considered as low. Sample 18 has the highest specific gravity value in each case (Table V).

4. Percent absorption values vary between 1.68 and 3.89. An average value is 2.78. Sample 18 has the lowest absorption capacity (1.68%), (Table V).

5. The average percent L. A. value for the aggregate samples is 23.3 which is satisfactory according to the ASTM Specification for concrete aggregates. Aggregate sample number 1 had the most abrasion loss (26.3%), but it was still below the maximum allowable loss specified by ASTM, which is 50% by weight for coarse aggregates. Each of the samples tested had an L. A. value below this limit. Sample 18 had the lowest L. A. value (20.4%) of all those tested. The variation of the L. A. values were very small (20.4% to 26.3%), (Table VI).

6. More than 90% of the gravel particles were chert. Cherts are known to react with the alkalies in the cement paste of concrete. Some aggregates from the Meramec River may be considered as potentially reactive and should be investigated for this phenomenon.

7. An average of 20.2% of the aggregate particles, of the petrographic analysis samples, are angular and have a glossy

surface texture with very small non-connected voids. An average of 45.2% are subangular to subrounded and have smooth particle surface with medium size, semi-connected voids. An average of 34.5% are well rounded particles with a rough surface texture and have high percentage of large voids.

8. The average percent of voids in the aggregates was 11%.

9. The bulk mineralogy of the aggregate particles consisted of more than 90% of microcrystalline quartz including certain amounts of chalcedony, which was present in some of the samples. It is also known as a highly reactive constituent (Table X).

10. Leaching of the carbonate minerals by the river water and replacement of fossil structures by secondary silica, which is consequent to weathering, are the two most significant factors which seem affecting the aggregate quality of the Meramec River gravels.

11. The tributaries flowing into the Meramec River do not have an overly significant effect on the aggregate quality of its gravels.

Consequently, on the basis of their engineering properties, as determined by sieve analysis, specific gravity, absorption and Los Angeles abrasion tests, gravels from the Meramec River can be considered a satisfactory coarse aggregate source for concrete. However, on the basis of their mineralogical properties, as determined by petrographic analysis, they may be potentially reactive due to very high percentage of chert (more than 90%) which consists almost entirely of potentially reactive silica in the form of microcrystalline quartz and chalcedony.

Weathering of the chert particles was the consequence of leaching of its fossil structures. Therefore, the relative abundance of weathered cherts varies from place to place with the variation in the fossil content of the local bedrock. The general trend of this variation is such that percentages of the weathered cherts decrease along the downstream course of the river, as following the same trend of variation in fossil content of the local bedrock. This phenomena had significantly controlled the quality of the aggregates. There is a general trend downstream of quality such that it increases along the downstream course of the river, due to the decrease in the degree of weathering of the chert particles as a consequence of decrease in the amounts of fossils in the local bedrock downstream. The general aggregate size also decreases in the downstream direction due to more abrasion wear and sorting of the particles.

In general, the lower portion of the Meramec River provides relatively better quality of aggregate materials. The gravels from the upstream portion of the station 10, located above the junction of the Big River, on the basis of its overall properties as determined by various tests on sample 18 of the station 10, can be evaluated as the best quality material for the concrete aggregate present on the Meramec River.

Chapter VIII

RECOMMENDATIONS

From this investigation it is evident that the aggregates from the Meramec River gravels consist almost entirely of chert; therefore, more information about these cherts is required for a better evaluation of the aggregate properties.

At the present time, these materials are viewed with suspicion. It should be noted that not all cherts are reactive or deleterious in concrete. The determination of the reactivity of these materials was not within the scope of this investigation.

It is generally recognized that some types of chert are deleterious because of their lack of durability in freezing and thawing. A method for distinguishing durable and non-durable cherts is the most critical need at the present time.

For a better evaluation of the aggregate materials from the Meramec River, more extensive studies consisting of the following procedures are recommended:

1. The Meramec River Basin area should be thoroughly examined by a team consisting of a materials engineer and a geologist familiar with engineering use of rocks.

2. Since the present gravel bars are continuing underneath the water, samples should also be taken from the river bed for a better evaluation of the whole river as an aggregate source.

3. Routine laboratory testing consisting of Freeze-thaw, Soundness and Mortar-bar Expansion tests should be conducted on the

samples. The samples used in these tests should have petrographic examination made on them for possible quality deterioration.

4. A more extensive petrographic analysis should be made on the samples. Methods other than those used in this investigation should be used if more information is needed, such as differential thermal analysis and insoluble residue tests.

5. Examination of some concrete structures made with aggregates from the Meramec River is also recommended to evaluate the results obtained from the laboratory tests.

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VITA

Kadri Ercin Kasapoglu was born in Istanbul, Turkey on December 14, 1945.

He completed his primary education in the Atikali Ilkokulu, Istanbul in 1956. He received the major portion of his high school education in Erzurum Lisesi. However, he graduated from Yenimahalle Erkek Lisesi, Ankara in June 1962.

In October of 1962 he entered the Middle East Technical University in Ankara, Turkey and graduated in June 1967 with a Bachelor of Science Degree in Mining-Geological Engineering.

During his undergraduate school years he had the chance to work in Heilbronn Rock-Salt Mine of West-Germany in the summer of 1965, and also had the good fortune to work for the M. T. A. Institute of Turkey on Barite Deposits of Anamur in the summer of 1966.

After his graduation from the Middle East Technical University, he worked for CENTO for two months on Geological Mapping Techniques in Hindubagh, West Pakistan, before enrolling at the University of Missouri at Rolla, in September 1967, as a candidate for the degree of Master of Science in Geological Engineering.

APPENDIX A

(Engineering Tests Data Sheets)

DATA SHEET
FOR
SIEVE ANALYSIS

Place:________________ Project:____________________

Material:______________ Source:_____________________

Sampled from:______________________________________

Sample No:_____________ Identification:______________

Date Sampled:__________ Date Tested:________________

REMARKS:

Sieve Size	Wt. Sieve & Sample	Wt. Sieve	Wt. Sample Retained	% Retained	% Passing	Sp.

DATA SHEET
FOR
SPECIFIC GRAVITY AND ABSORPTION TESTS

Place:________________ Project:____________________

Material:______________ Source:_____________________

Sampled from:_____________________________________

Sample No:_____________ Identification:______________

Date Sampled:__________ Date Tested:_________________

REMARKS:

(A) Wt. of Oven-dry Sample in Air:_______________ grams

(B) Wt. of Saturated Surface-dry Sample in Air:____ grams

(C) Wt. of Saturated Sample in Water:_____________ grams

BULK SPECIFIC GRAVITY (Dry Basis):____________________

BULK SPECIFIC GRAVITY (Saturated Surface-dry Basis):_____

APPARENT SPECIFIC GRAVITY:___________________________

ABSORPTION:______________________________________ %

DATA SHEET
FOR
LOS ANGELES ABRASION TEST

Place:__________________ Project:________________________

Material:_______________ Source:_________________________

Sampled from:____

Sample No:______________ Identification:________________

Date Sampled:____________ Date Tested:___________________

Grading:_________________

Wt. of _____ size:_________ gm.

Wt. of _____ size:_________ gm.

Original Oven-dry Weight of Sample:________________ grams

Final Oven-dry Weight of Sample > # 12:____________ grams

L. A. Value:____ %

REMARKS:

APPENDIX B

(Sieve Analysis Data)

TABLE XI

PRELIMINARY SEPARATION OF SAMPLES ON #4 SIEVE

STATION NO.	SAMPLE IDENTIFICATION	TOTAL % RETAINED ON #4 (COARSE AGGREGATE)	TOTAL % PASSING #4 (FINE AGGREGATE)
1	1HW1	52.9	47.1
2	2TC2	62.2	37.8
	2TC3	56.9	43.1
3	3TB4	60.5	39.5
	3TB5	73.8	26.2
4	4TD6	72.7	27.3
	4TD7	62.4	37.6
5	5TH8	73.2	26.8
	5TH9	67.9	32.1
6	6TB10	49.8	50.2
	6TB11	62.2	37.8
7	7TI12	43.2	56.8
	7TI13	63.2	36.8
8	8TB14	64.8	35.2
	8TB15	64.0	36.0
9	9TC16	54.7	45.3
	9TC17	37.4	62.6
10	10TB18	62.2	37.8
	10TB19	60.1	39.9

TABLE XII

RESULTS OF SIEVE ANALYSIS

STATION NO. 1 SAMPLE IDENTIFICATION- 1HW1

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	10.2	89.8	10.2
1 1/2''	23.5	76.5	13.3
1''	38.7	61.3	15.2
3/4''	55.3	44.7	16.7
1/2''	74.8	25.2	19.5
3/8''	88.4	11.6	13.5
#4	98.1	1.9	9.8

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 2 SAMPLE IDENTIFICATION- 2TC2

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	14.6	85.4	14.6
1''	27.4	72.6	12.8
3/4''	40.8	59.2	13.3
1/2''	58.7	41.3	17.9
3/8''	71.8	28.2	13.1
#4	99.5	0.5	27.7

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 2 SAMPLE IDENTIFICATION- 2TC3

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	3.2	96.8	3.2
1 1/2''	7.3	92.7	4.1
1''	15.7	84.3	8.5
3/4''	29.1	70.9	13.3
1/2''	48.9	51.1	19.8
3/8''	64.7	35.3	15.9
#4	98.7	1.3	34.0

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 3 SAMPLE IDENTIFICATION- 3TB4

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	7.4	92.6	7.4
1 1/2''	16.1	83.9	8.6
1''	29.5	70.5	13.4
3/4''	43.0	57.0	13.5
1/2''	59.5	40.5	16.5
3/8''	72.0	28.0	12.5
#4	99.3	0.7	27.3

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 3 SAMPLE IDENTIFICATION- 3TB5

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	2.5	97.5	2.5
1 1/2''	15.6	84.4	13.1
1''	33.2	66.8	17.5
3/4''	49.3	50.7	16.1
1/2''	66.8	33.2	17.5
3/8''	77.9	22.1	11.2
#4	99.2	0.8	21.3

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 4 SAMPLE IDENTIFICATION- 4TD6

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	4.5	95.5	4.5
1''	17.3	82.7	12.8
3/4''	34.3	65.7	17.0
1/2''	56.0	44.0	21.7
3/8''	70.7	29.3	14.6
#4	99.1	0.9	28.4

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 4 SAMPLE IDENTIFICATION- 4TD7

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	8.4	91.6	8.4
1 1/2''	20.4	79.6	12.0
1''	35.0	65.0	14.6
3/4''	50.0	50.0	15.0
1/2''	67.3	32.7	17.3
3/8''	78.1	21.9	10.8
#4	99.1	0.9	21.0

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 5 SAMPLE IDENTIFICATION- 5TH8

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	3.1	96.9	3.1
1 1/2''	6.7	93.3	3.6
1''	22.4	77.6	15.7
3/4''	38.0	62.0	15.6
1/2''	60.0	40.0	22.0
3/8''	74.5	25.5	14.5
#4	98.7	1.3	24.2

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 5 SAMPLE IDENTIFICATION- 5TH9

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	4.4	95.6	4.4
1 1/2''	12.4	87.6	8.0
1''	27.8	72.2	15.4
3/4''	42.3	57.7	14.4
1/2''	60.1	39.9	17.8
3/8''	72.9	27.1	12.8
#4	99.1	0.9	26.2

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 6 SAMPLE IDENTIFICATION- 6TB10

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	2.3	97.7	2.3
1 1/2''	6.2	93.8	3.9
1''	12.3	87.7	6.2
3/4''	24.4	75.6	12.1
1/2''	45.2	54.8	20.8
3/8''	62.5	37.5	17.2
#4	98.3	1.7	35.8

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 6 SAMPLE IDENTIFICATION- 6TB11

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	1.1	98.9	1.1
1 1/2''	5.6	94.4	4.5
1''	14.4	85.6	8.9
3/4''	26.6	73.4	12.1
1/2''	47.9	52.1	21.4
3/8''	66.1	33.9	18.1
#4	99.2	0.8	33.1

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 7 SAMPLE IDENTIFICATION- 7TI12

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	1.5	98.5	1.5
1''	7.1	92.9	5.6
3/4''	17.3	82.7	10.2
1/2''	36.9	63.1	19.6
3/8''	54.0	46.0	17.2
#4	99.3	0.7	45.2

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 7 SAMPLE IDENTIFICATION- 7TI13

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.8	99.2	0.8
1 1/2''	5.0	95.0	4.2
1''	15.2	84.8	10.2
3/4''	28.9	71.1	13.7
1/2''	50.0	50.0	21.1
3/8''	65.9	34.1	15.8
#4	99.1	0.9	33.2

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 8 SAMPLE IDENTIFICATION- 8TB14

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	3.9	96.1	3.9
1''	15.8	84.2	11.9
3/4''	28.0	72.0	12.2
1/2''	49.9	50.1	21.9
3/8''	66.0	34.0	16.1
#4	99.1	0.9	33.1

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 8 SAMPLE IDENTIFICATION- 8TB15

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	3.3	96.7	3.3
1''	14.0	86.0	10.6
3/4''	30.2	69.8	16.2
1/2''	52.9	47.1	22.7
3/8''	68.3	31.7	15.4
#4	98.6	1.4	30.3

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 9 SAMPLE IDENTIFICATION- 9TC16

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	0.4	99.6	0.4
1''	3.4	96.6	3.0
3/4''	11.9	88.1	8.5
1/2''	30.3	69.7	18.4
3/8''	48.7	51.3	18.4
#4	98.1	1.9	49.4

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO. 9 SAMPLE IDENTIFICATION- 9TC17

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	0.0	100.0	0.0
1 1/2''	2.1	97.9	2.1
1''	5.1	94.9	3.0
3/4''	15.9	84.1	10.8
1/2''	41.4	58.6	25.5
3/8''	66.2	33.8	24.8
#4	97.6	2.4	31.4

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO.10 SAMPLE IDENTIFICATION-10TB18

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	1.6	98.4	1.6
1 1/2''	9.0	91.0	7.4
1''	27.5	72.5	18.5
3/4''	51.1	48.9	23.5
1/2''	76.0	24.0	24.9
3/8''	90.1	9.9	14.1
#4	98.6	1.4	8.4

TABLE XII (CONTINUED)

RESULTS OF SIEVE ANALYSIS

STATION NO.10 SAMPLE IDENTIFICATION-10TB19

SIEVE SIZE	TOTAL % RETAINED ON EACH SIEVE	TOTAL % PASSING EACH SIEVE	% RETAINED ON CONSECUTIVE SIEVES
2''	2.4	97.6	2.4
1 1/2''	6.4	93.6	4.0
1''	26.2	73.8	19.8
3/4''	48.5	51.5	22.3
1/2''	75.2	24.8	26.7
3/8''	89.2	10.8	14.0
#4	98.7	1.3	9.4

APPENDIX C

(Petrographic Analysis Data Sheets)

DATA SHEETS
FOR
PETROGRAPHIC ANALYSIS
(Pebble Counts)

Place:______________________ Project:____________________________

Material:__________________ Source:______________________________

Sampled from:____

Sample No:_________________ Identification:__________________

Date Sampled:______________ Date Tested:______________________

Number of particles:____ Wt. of _____ particles:________

Retained on:______ sieve

REMARKS:

Rock types	Number of particles	Percent by particles	Percent by weight	Wt. Comp.

MINERALOGY

Slide No.____________ Date:____________

Megascopic Identification:____________ By ____________

Bulk Minerals:	Volume (%)	Average Grain Size
1. __________	__________	__________
2. __________	__________	__________
3. __________	__________	__________
4. __________	__________	__________
5. __________	__________	__________

Shape of Grains and Crystals:

Mineral	1.______	2.______	3.______	4.______	5.______
Euhedral	______	______	______	______	______
Subhedral	______	______	______	______	______
Anhedral	______	______	______	______	______
Rounded	______	______	______	______	______
Elongated	______	______	______	______	______

Composition and Nature of Matrix and Cementing Materials:

PETROFABRICS

Percent Voids_____: Connected______ Semi._____ Non._______

Remarks____

<u>NATURE OF THE GRAIN BOUNDARIES:</u>

Interlocking________________, Non.________________

Remarks____

<u>FRACTURING AND CRACKING:</u>

High______, Medium______, Low______, None__________

Remarks____

<u>PARTICLE ORIENTATION:</u>

Excellent_____, Good_____, Fair_____, Poor______,

None______.

Remarks____

<u>BANDING AND MICROLAYERING:</u>

Distinct_________, Moderate________, None________

Remarks____

PRESENCE OF SEGRAGATIONS___________

PRESENCE OF INCLUSIONS_____________

PRESENCE OF FOSSILS________________

OTHERS_____________________________

Remarks____

WEATHERING

DECOMPOSITION: Total % ______

General Distribution: Pockets ________, Seams ______

Throughout _____.

Individual Particles: Rim ____________, Core ________

Throughout _____.

Remarks: ____

DEGREE OF LEACHING:

SECONDARY MINERALS: Total % (Vol.) ________

Types: 1. __________ 2. ____________ 3. ______________

Distribution: Seams __________, Coatings _____________

Others _________.

SECONDARY CEMENTATION:

Present _______, Absent _______, Crystal Overgrowths __

Others ________.

____

APPENDIX D

(Petrographic Analysis Data)

TABLE XIII
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 1 SAMPLE IDENTIFICATION- 1HW1

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	0.0	0.0
CHERT (B)	8.5	9.0
CHERT (C)	8.5	7.5
CHERT (D)	13.7	12.3
CHERT (E)	29.3	29.6
CHERT (F)	36.2	36.5
SANDSTONE	3.9	5.0
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 2 SAMPLE IDENTIFICATION- 2TC2

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	11.6	12.6
CHERT (B)	10.9	10.8
CHERT (C)	16.7	18.4
CHERT (D)	14.8	15.0
CHERT (E)	20.3	18.6
CHERT (F)	22.5	22.3
SANDSTONE	2.3	1.7
DOLOMITE	0.6	0.6

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 2 SAMPLE IDENTIFICATION- 2TC3

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	16.6	15.8
CHERT (B)	25.6	24.4
CHERT (C)	16.2	17.1
CHERT (D)	8.1	7.7
CHERT (E)	16.6	16.0
CHERT (F)	15.6	17.7
SANDSTONE	1.3	1.4
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 3 SAMPLE IDENTIFICATION- 3TB4

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	18.9	19.6
CHERT (B)	28.5	29.6
CHERT (C)	11.6	10.6
CHERT (D)	8.9	7.7
CHERT (E)	16.9	18.0
CHERT (F)	13.6	13.2
SANDSTONE	1.7	1.3
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 3 SAMPLE IDENTIFICATION- 3TB5

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	9.6	8.8
CHERT (B)	27.7	28.9
CHERT (C)	9.9	8.6
CHERT (D)	6.9	6.5
CHERT (E)	26.1	24.9
CHERT (F)	16.8	18.4
SANDSTONE	3.0	4.1
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 4 SAMPLE IDENTIFICATION- 4TD6

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	12.8	13.7
CHERT (B)	31.6	33.2
CHERT (C)	13.5	12.4
CHERT (D)	7.9	6.8
CHERT (E)	18.1	18.1
CHERT (F)	14.8	14.2
SANDSTONE	1.3	1.5
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 4 SAMPLE IDENTIFICATION- 4TD7

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	10.0	10.1
CHERT (B)	28.1	28.8
CHERT (C)	9.4	9.6
CHERT (D)	7.1	7.2
CHERT (E)	23.9	23.8
CHERT (F)	19.7	18.6
SANDSTONE	1.9	2.0
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 5 SAMPLE IDENTIFICATION- 5TH8

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	18.1	16.9
CHERT (B)	31.3	32.6
CHERT (C)	11.2	13.1
CHERT (D)	5.3	4.8
CHERT (E)	15.1	15.8
CHERT (F)	17.1	14.7
SANDSTONE	1.6	1.6
DOLOMITE	0.3	0.4

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 5 SAMPLE IDENTIFICATION- 5TH9

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	6.4	5.5
CHERT (B)	19.3	21.3
CHERT (C)	6.1	12.3
CHERT (D)	10.0	10.1
CHERT (E)	21.5	20.2
CHERT (F)	29.9	30.2
SANDSTONE	0.3	0.4
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 6 SAMPLE IDENTIFICATION- 6TB10

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	10.9	14.6
CHERT (B)	27.1	31.9
CHERT (C)	12.9	6.9
CHERT (D)	5.3	5.7
CHERT (E)	23.4	28.1
CHERT (F)	19.8	12.4
SANDSTONE	0.7	0.4
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 6 SAMPLE IDENTIFICATION- 6TB11

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	11.0	11.1
CHERT (B)	22.1	24.4
CHERT (C)	11.4	11.3
CHERT (D)	7.8	6.7
CHERT (E)	17.9	18.0
CHERT (F)	28.2	25.7
SANDSTONE	1.6	2.8
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 7 SAMPLE IDENTIFICATION- 7TI12

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	9.4	9.2
CHERT (B)	25.8	27.2
CHERT (C)	14.8	16.4
CHERT (D)	8.1	8.0
CHERT (E)	14.5	12.9
CHERT (F)	26.5	25.7
SANDSTONE	1.0	0.7
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 7 SAMPLE IDENTIFICATION- 7TI13

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	4.9	5.6
CHERT (B)	13.9	14.9
CHERT (C)	14.6	13.9
CHERT (D)	11.7	10.2
CHERT (E)	20.4	21.5
CHERT (F)	34.6	34.0
SANDSTONE	0.0	0.0
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 8 SAMPLE IDENTIFICATION- 8TB14

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	16.5	14.5
CHERT (B)	35.3	37.4
CHERT (C)	17.8	18.1
CHERT (D)	4.2	4.1
CHERT (E)	9.1	9.3
CHERT (F)	15.9	15.0
SANDSTONE	1.3	1.5
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 8 SAMPLE IDENTIFICATION- 8TB15

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	15.7	15.9
CHERT (B)	43.5	45.1
CHERT (C)	16.7	15.3
CHERT (D)	2.6	2.6
CHERT (E)	5.9	5.9
CHERT (F)	13.4	13.4
SANDSTONE	2.3	1.8
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 9

SAMPLE IDENTIFICATION- 9TC16

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	17.3	17.9
CHERT (B)	42.0	45.2
CHERT (C)	16.0	15.0
CHERT (D)	2.0	1.9
CHERT (E)	6.2	5.8
CHERT (F)	14.7	12.3
SANDSTONE	2.0	1.9
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO. 9 SAMPLE IDENTIFICATION- 9TC17

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	20.0	22.5
CHERT (B)	38.7	39.9
CHERT (C)	16.7	14.7
CHERT (D)	2.3	2.1
CHERT (E)	6.6	6.0
CHERT (F)	15.4	14.7
SANDSTONE	0.0	0.0
DOLOMITE	0.3	0.2

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO.10 SAMPLE IDENTIFICATION-10TB18

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	22.5	21.0
CHERT (B)	47.6	48.2
CHERT (C)	17.9	17.9
CHERT (D)	1.0	1.3
CHERT (E)	3.6	4.5
CHERT (F)	6.2	5.9
SANDSTONE	1.3	1.1
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT

TABLE XIII (CONTINUED)
RESULTS OF PETROGRAPHIC ANALYSIS
(PEBBLE COUNTS)

STATION NO.10 SAMPLE IDENTIFICATION-10TB19

ROCK TYPES	PERCENT BY PARTICLES	PERCENT BY WEIGHT
*CHERT (A)	23.0	22.0
CHERT (B)	53.1	52.8
CHERT (C)	11.5	12.5
CHERT (D)	0.3	0.3
CHERT (E)	3.3	3.5
CHERT (F)	8.2	8.2
SANDSTONE	0.7	0.6
DOLOMITE	0.0	0.0

*(A)=STAINED CHERT
(B)=SLIGHTLY WEATHERED STAINED CHERT
(C)=HIGHLY WEATHERED STAINED CHERT
(D)=WHITE CHERT
(E)=SLIGHTLY WEATHERED WHITE CHERT
(F)=HIGHLY WEATHERED WHITE CHERT