DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 368
[Part of Vol. 22]

BUREAU OF STANDARDS SOIL-CORROSION STUDIES

I. SOILS, MATERIALS, AND RESULTS OF EARLY OBSERVATIONS

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April 28, 1928

PRICE 50 CENTS
$1.25 PER VOLUME ON SUBSCRIPTION
Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

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I. SOILS, MATERIALS, AND RESULTS OF EARLY OBSERVATIONS

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ABSTRACT

After a number of years of study of corrosion due to stray electric currents in the earth by the American Committee on Electrolysis and the Bureau of Standards it became evident that in some cases the cause of observed corrosion could not be decided until it was known whether serious corrosion could occur in uncontaminated soil where no stray currents were present.

The Bureau of Standards, therefore, undertook to conduct an investigation of the relation of soils to the corrosion of buried pipe. The original investigation, planned to be of a practical nature and quite limited in its scope, has been amplified by the burial of additional materials and by laboratory investigations.

A very wide interest has been manifested in soil corrosion, and many questions have been raised which can not be answered by the data which are being obtained.

The studies of soil corrosion were begun in 1922, and the field work has been so planned that specimens will be removed at about two-year intervals for a period of 10 years. Of the specimens buried, about one-seventh have been removed for examination.

The work is therefore in its initial stage and will not be finished for several years. However, because of the interest manifested in the work and the plans for corrosion studies that other organizations are considering, it seems advisable to set forth in some detail the plans and scope of the bureau's investigation and to publish and discuss such data as are now available as a result of the investigation. The data indicate that in certain regions soil corrosion is an active enemy of buried pipe lines, that the material best suited to resist the action of one soil is not necessarily the best for other soil conditions, and that the use of some form of a protective coating is desirable under a number of soil conditions.

Because the rates of corrosion so far observed may not continue and because the rate for one material may change more than the rate for another, no conclusions can be drawn at this time as to the ultimate life of any of the materials under test nor of the relative merits of materials that are nearly alike. So far as observations on the materials are concerned, this report is therefore preliminary in its nature and will be followed by such others as the data secured later seem to justify.

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I. INTRODUCTION

Within the last few years there has been manifested a wide interest in the effects of soils on buried metal. A number of the national technical societies have given the subject consideration, and several corporations have undertaken studies of the relation of soils to the products with which they are concerned. It is generally known that the Bureau of Standards is engaged in an investigation of the action of soils on metals, and many inquiries concerning its work have been received. It seems advisable, therefore, at this time to describe the work which is under way and to publish such data as are available, although the work is far from complete, in order that those interested in soil corrosion may know what the bureau is doing.

II. ORIGIN AND PURPOSE OF THE INVESTIGATION

The Bureau of Standards soil-corrosion investigation is an outgrowth of its study of stray current electrolysis. Since 1911 the bureau has been studying the effects of stray currents from street railway lines both independently and as a member of the American

Committee on Electrolysis. This work has necessitated the uncovering and examining of a large number of underground structures for the purpose of determining the extent to which they have been damaged by electrolysis. In many instances where rather severe corrosion was anticipated little damage was observed, while frequently more corrosion was found than seemed to be indicated by the electrical data associated with the corroded structure. These conditions induced the research subcommittee of the American Committee on Electrolysis to undertake, in 1921, a study of the relation of soils to corrosion, the Bureau of Standards becoming sponsor for the work. During the following year the American Committee issued its second report and thereafter ceased its activities for the time being, leaving the Bureau of Standards to carry on the soil-corrosion studies.

It is important to keep in mind this origin of the soil-corrosion investigation, for therein lies the explanation of why many things were done in certain ways and why other things were left undone. The work was planned chiefly to determine whether serious corrosion of ordinary pipe lines might occur under conditions which precluded the possibility of damage due to stray electric currents from street railway lines. It will be recognized that data quite satisfactory for answering this question may be entirely unsuited for answering questions regarding the theories of corrosion or the best methods of identifying or preventing soil action.

III. METHOD AND SCOPE OF THE INVESTIGATION

1. COOPERATING ORGANIZATIONS

The first step in the investigation after the general plan had been approved by the research subcommittee was to secure the cooperation of a number of manufacturers of pipes, the Bureau of Soils, Department of Agriculture, which undertook the supervision of the selection of the soils to be studied and of local public utility organizations in various parts of the country who agreed to furnish locations where specimens could be buried and the labor necessary for burying and removing them.

These organizations have not only incurred very considerable expense in cooperating in the investigation, but many of them have participated actively in planning the work and in interpreting the results as data became available. The investigation is to be regarded as a cooperative study in which each cooperator takes such part as his circumstances permit. It is proper, therefore, to record the names of those who have joined in the undertaking.

(a) MANUFACTURERS

The following manufacturers have supplied materials for test. In most instances they have also sent representatives to advisory meetings where tests were planned and reports on tests considered before publication.

Aluminum Co. of America.
The American Brass Co.
American Cast Iron Pipe Co.
American Machine & Foundry Co.
American Rolling Mill Co.
American Sheet & Tin Plate Co.
American Tar Products Co.
American Zinc Products Co.
Barber Asphalt Co.
Barrett Co.
Bell Telephone Co.
Bridgeport Brass Co.
Brown Co.
A. M. Byers Co.
Calorizing Co. of Pittsburgh.
The Cast Iron Pipe Research Association.
Duriron Co.
Electric Steel Foundries.
The Hoyt Metal Co.
U. T. Hungerford Brass & Copper Co.
Illinois Zinc Co.
Habirshaw Electric Cable Co.
Jones & Laughlin Steel Corporation.
Locomotive Terminal Improvement Co.
Lumen Bearing Co.
Mueller Brass Co.
Mueller Manufacturing Co.
National Carbon Co.
National Lead Co.
National Tube Co.
Nugents Steel Casting Co.
Paraffine Companies (Inc.).
Pioneer Asphalt Co.
Pittsburgh Valve, Foundry & Construction Co.
Reading Iron Co.
Republic Iron & Steel Co.
H. H. Robertson Co.
Standard Oil Co. of California.
Standard Underground Cable Co.
Stockham Pipe & Fittings Co.
The Texas Co.
Union Carbide & Carbon Co.
United Gas Improvement Co.
Youngstown Sheet & Tube Co.

(b) PUBLIC UTILITY ORGANIZATIONS

The following organizations have furnished ground for specimens, labor for burying them, or both. In most cases it has not been practicable for them to be represented on the advisory meetings except through their technical societies.

Alexandria Water Co.
City of Atlanta, department of waterworks.
City of Baltimore, department of public works.
Boston Consolidated Gas Co.
Camden Water Department.
City of Cleveland, department of public utilities.
Dallas Gas Co.
Des Moines Gas Co.
East Bay Water Co.
East Ohio Gas Co.
Georgia Railway & Power Co.
City commission of Jacksonville.
Jacksonville Gas Co.
Kansas City Gas Co.
Los Angeles Gas & Electric Co.
Memphis Board of Water Commissioners.
City of Meridian, Miss.
City of Middleboro, Mass.
Midwest Refining Co.
City of Milwaukee, department of public works.
Milwaukee Gas Light Co.
Mississippi Power Co.
Mobile Water Works.
New Orleans Public Service (Inc.).
Counties Gas & Electric Co.
City of Norwood, Mass.
Omaha and Council Bluffs Electrolysis Committee.
The Peoples Light Co.
Philadelphia Suburban Gas & Electric Co.
Public Service Co. of Colorado.
Pueblo Gas & Fuel Co.
City of Rochester, department of public works.

Rochester Gas & Electric Co.
San Antonio Public Service Co.
San Diego Consolidated Gas & Electric Co.
San Joaquin Light & Power Corporation.
City of Seattle, department of public works.
Sewerage & Water Board.
Southern California Gas Co.
City of Springfield, Ohio, water department.
Springfield Railway Co.
Standard Pipe Line Co.
St. Paul Gas Light Co.
Standard Oil Co. of New Jersey.
Tide Water Pipe Line Co.
Tri City Railway & Light Co.
Union Gas & Electric Co.
Union, Light, Heat & Power Co.
Union Light & Railway Co.
Utah Gas & Coke Co.
Wilmington Gas Co.

(c) GOVERNMENT DEPARTMENTS

The following Government departments have had a share in the investigation:

Department of Agriculture:
  Bureau of Soils—
    Division of soil chemistry.
    The soil survey.
Department of Commerce:
  Bureau of Mines.
  Bureau of Standards.
Department of Interior:
  Geological Survey—Water resources branch.

(d) ADVISORY ORGANIZATIONS

The scope of the work has become so extended that it calls for special knowledge along several widely divergent lines. Partly for this reason and partly in order that others studying corrosion might keep informed as to the bureau's work and plans, it has seemed advisable to submit plans and data to a number of experts for their suggestions and criticisms. In addition to the manufacturers of the products to be discussed, the following organizations have participated in one or more of the soil corrosion advisory meetings:

American Committee on Electrolysis, research subcommittee.
American Engineering Standards Committee sectional committee on specifications for zinc coating of iron and steel.
American Foundrymen's Association.
American Gas Association.
American Petroleum Institute.
American Society for Testing Materials.
American Waterworks Association.
American Zinc Institute (Inc.).
Armco Culvert and Flume Manufacturers Association.
Asphalt Association.
New Jersey Zinc Co., research laboratory.

2. MATERIALS STUDIED

Since the primary purpose of the investigation was to secure data which would indicate whether corrosion observed on working pipe lines might be attributed to causes other than stray current electrolysis, it appeared best that the pipe materials used in the investigation should be selected from stock and include the various kinds and grades of pipe ordinarily purchased by public utility companies.

This decision materially affected the data subsequently obtained, for stock pipes and fittings necessarily vary somewhat in size, composition, and metallurgical history; these variations result in inconsistencies in the corrosion data and interfere with the construction of a theory as to why certain results were obtained.

The lack of uniformity in the materials tested and the lack of complete knowledge concerning these materials make them somewhat unsuitable for the study of the fundamental principles of corrosion. If the purpose of the investigation had been such fundamental studies, the arrangements would have been altogether different. The results which may be obtained should have a considerable value for the public utility owners interested in the maintenance of underground pipe systems.

To the original materials selected for study there have been added so many others of widely different characteristics that a logical arrangement of the data on the tests is difficult. On this account the data applicable to all or most of the materials will be given first, while the data on the individual materials will be presented in that section of the paper dealing with the tests of the group of specimens to which the material can best be assigned. In order that the general reader may get a picture of the materials involved, they are listed below. The materials tested were buried at different times, and it will be necessary to refer to detailed data sheets in order to determine dates of burial and removal. The figures preceding the names of the specimens indicate the approximate number of specimens buried.

Numbers and kinds of specimens buried

A. Unprotected pipe and other specimens buried in 1922 in approximately 46 soils:
    552. Bessemer steel, butt-welded, 1½-inch pipe.
    552. Bessemer steel, butt-welded, treated, 1½-inch pipe.
    552. Bessemer steel, lap-welded, 3-inch pipe.
    552. Cast-iron, De Lavaud process, 6-inch pipe.
    552. Cast-iron, 14+ per cent silicon, 3-inch pipe.
    276. Cast-iron, northern ore, 6-inch pipe.
    276. Cast-iron, southern ore, 6-inch pipe.
    552. Open-hearth pure iron, 1½-inch pipe.
    552. Open-hearth steel, 3-inch pipe.
    552. Open-hearth steel, 0.2+ per cent copper, 3-inch pipe.
    552. Wood fiber, 3-inch pipe.
    552. Wrought-iron, butt-welded, 1½-inch pipe.
    552. Wrought-iron, lap-welded, 3-inch pipe.
    276. Antimony lead cable sheath.
    276. Commercial lead cable sheath.
    276. Parkway cable.

B. Unprotected ferrous pipe fittings buried in 1923 and 1924 in six soils at the suggestion of the American Foundrymen's Association:
  48. Cast steel, 3-inch ells.
  48. High tensile cast-iron 2-inch nipples.
  48. Malleable 2-inch ells.

C. Additional cast-iron pipe specimens buried in 1924 in six soils:
  48. Southern, 6-inch.
  48. De Lavaud, 6-inch, outside only exposed.
  48. Monocast, 6-inch.
  24. De Lavaud, 6-inch, machined.
  24. Sand mold, 4-inch, machined.

D. Brass fittings buried in 1923 and 1924 in 46 soils:
  2208. Four mixtures each attached to brass, lead, and galvanized iron (12 combinations).

E. Nonferrous materials buried in 1926 in 46 soils:
  552. Copper service pipe, 2 kinds, ¾-inch.
  276. Brass pipe (Muntz metal), ¾-inch.
  276. S. A. E. brass forged elbows, ½-inch.
  276. Copper-nickel rod, ½-inch.
  276. Aluminum bronze rod, ½-inch.

F. Miscellaneous materials buried in six soils in 1924 or 1926:
  36. Copper tube, ¾-inch (1926).
  36. Brass tube, ¾-inch (1926).
  96. Lead-coated bolts and nuts, ¾ by 3½ inch (1924).
  96. Sherardized bolts and nuts, ¾ by 3½ inch (1924).
  96. Wrought-iron bolts and nuts, ¾ by 3½ inch (1924).
  54. Chrome iron tube (1926).
  18. Copper steel tube, 2-inch (15 per cent copper) (1926).
  18. Bessemer steel tube, 2-inch (1926).
  18. Surfaced Bessemer tube, 2-inch (1926).
  18. Wrought-iron pipe, 2-inch (1926).
  18. Surfaced wrought iron pipe, 2-inch (1926).

G. 2 by 6 inch sheet specimens buried in five soils in 1924 at the request of the Bureau of Mines:
  40. Pure open-hearth iron.
  40. Chemical lead.
  40. Hearth refined lead.
  40. Zinc, 0.625 inch thick.
  40. Zinc, ¼ inch thick.
  40. Copper-tin bronze.
  40. Commercial aluminum.
  40. Aluminum + 1½ per cent manganese.
  40. Duralumin.
  40. Cartridge brass.
  40. Copper.
  27. Zinc, miscellaneous.

H. Metallic protective coatings applied to steel pipes and buried in 46 soils, 1922 and 1924:
  62. Galvanized steel pipe, 2-inch (31 soils) (1922).
  184. Galvanized open-hearth iron pipe (1924).
  368. Lead-coated steel pipe, 1½-inch (1924).
  184. Bessemer galvanized sheet, 16-gauge, 2-ounce coat (1924).
  184. Copper-bearing open-hearth galvanized sheet, 16-gauge, 2-ounce coat (1924).
  184. Open-hearth iron galvanized sheet, 16-gauge, 2-ounce coat (1924).

I. Metallic protective coatings applied to steel pipes and buried in six soils; buried in 1924 and 1926:
  48. Calorized pipe, dry process.
  48. Calorized pipe, wet process.
  36. Lead-coated pipe.
  96. Galvanized pipe (3 base materials).
  72. Galvanized copper-bearing Bessemer sheet, 16-gauge, 3 weights of coating.
  48. Galvanized open-hearth iron sheet, 16-gauge, 2 weights of coating.
  24. Galvanized open-hearth iron sheet, 18-gauge, 1 weight of coating.
  48. Galvanized copper-bearing Bessemer sheet, 18-gauge, 2 weights of coating.
  72. Black sheet, 18-gauge, 3 materials (checks).
J. Bituminous coatings applied to steel pipe and buried in 1922 in 31 soils:
  62. Asphalt dip.
  62. Asphalt-impregnated fabric wrapping.
  62. Coal-tar pitch dip.
  62. Coal-tar pitch impregnated fabric wrapping.
K. Bituminous coatings applied to steel pipe and buried in 46 soils in 1924 and 1926:
  138. Asphalt-impregnated fabric.
  138. Asphalt dip.
  138. Coal-tar dip.
L. Nonmetallic coatings applied to steel pipe and buried in 6 to 10 soils in 1924 and 1926:
  36. Asphalt-impregnated felt wrapping.
  18. Sulphur-impregnated cloth wrapping.
  120. Asphalt dips, five kinds.
  75. Tar dips, three kinds.
  12. Asphalt mastic, one kind.
M. Miscellaneous special tests:
  Partial sets of materials have been buried for special purposes in four additional locations, one of which contains a nearly complete set of specimens.

3. GENERAL METHOD OF TESTING

As the primary purpose of the investigation was to obtain data which would be helpful in determining the cause of corrosion found in the course of electrolysis studies rather than to make a study of the fundamental causes of corrosion, it seemed desirable to subject representative samples of commercial pipe materials to the conditions to which working pipe lines are exposed, although it was realized that unknown and uncontrolled factors influencing the results of such tests might make the explanation of the causes of the results difficult or impossible.

Materials were, therefore, selected from commercial stock and buried in or near cities at such depths as conformed to the practice of the local public utility organizations. The earth removed from the bottom of the trench was placed in and around the specimens in order to insure uniform conditions for all specimens in the trench.

Originally it was intended to limit the test to uncoated pipe materials but as the news of the proposed tests became generally known numerous supplemental tests were proposed, some of which appeared to promise valuable information and were of such a nature that they did not involve either a change of plans or greatly increased expense. Additional materials were, therefore, added at two subsequent periods and the different treatment required by some of them makes the discussion of the procedure and results of the combined tests somewhat unsystematic. The grouping of the specimens in the following discussion is arbitrary and involves some repetition, but no other proposed order of discussion has appeared better from all points of view.

4. SELECTION OF SOILS FOR THE TESTS

Since the purpose of the investigation was to determine whether corrosion might occur on pipe lines in the absence of stray electric currents, it was desired to make the corrosion tests under soil conditions which would be representative of those encountered by working pipe lines.

Typical soils representing extensive areas in which pipes were or might be buried were desired. Because the Department of Agriculture had been making studies of soil for a number of years it appeared that this organization was best qualified to select the soils for the investigation, and the cooperation of the Bureau of Soils was, therefore, secured. This bureau submitted lists of soils that were considered of importance, and from these lists most of the soils involved in the investigation were selected. In a few cases the selection of the location was determined by some condition in which the research subcommittee or the Bureau of Standards was especially interested, but with the exception of some of the latter locations the soils were selected without knowledge of their properties with respect to corrosion.

To insure that the selected soil was secured, Bureau of Soils field men were sent to nearly all of the proposed test locations to examine and take samples of the soils before the pipe specimens were buried. The selection of the site was governed by the judgment of these men, by its freedom from electrolysis, and by the ground available for test purposes. Occasionally it was necessary to accept locations which were not entirely typical of a certain soil type because no such soil was found in which the tests could be made. Especial attention was paid to securing soils free from foreign matter and from stray electric currents.

Samples of the soils were sent to the chemical laboratory of the Bureau of Soils for identification and study and to the Bureau of Standards for special laboratory tests. Figure 1 shows the locations of the sites finally selected. It will be seen that, in general, they are most numerous in those sections of the country where there are the most pipes. The reason for the absence of test locations in some other regions in which there are extensive pipe networks is that it happened to be more convenient to bury the samples in similar soils elsewhere.

IV. CLASSIFICATION AND DESCRIPTION OF SOILS

As will be shown later, the character and rate of corrosion appears to be closely related to the type of soil in which the metal is buried. For practical application of the results of the investigation, the pipe user must know to which of the soil conditions involved in the investigation his local soils are comparable. Since many pipe users are not familiar with the classification of soils as established by the Bureau of Soils and used in this report, a somewhat detailed discussion of the subjects of soil classification and a description of the soils selected for investigation seems desirable.

Fig. 1.—*Location of soil corrosion tests*

Soil classification like other new sciences, is in the developmental stage, and some of the ideas expressed in the older soil literature and quoted here may be modified in the light of additional information. The press of its own work has prevented the Bureau of Soils from giving the following discussion of soils a thorough revision, and the section will probably be somewhat modified in the final report of the soil corrosion investigation.

Information regarding the soils is so necessary for the application of the data already obtained that it is felt that it is better to publish such information as is available at this time rather than to omit the discussion of soils or to delay the preliminary report.

1. METHOD OF CLASSIFYING SOILS

The earth's crust is broken up into great blocks which in past ages have shifted in their positions with respect to each other and formed the continents and larger mountain ranges. The surface portions of these blocks are all subject to weathering agencies, and the rocks of which they are composed are modified in many ways by these agencies. Where the surface of a block is above sea level, such weathering agencies as wind, frost, and precipitation gradually disintegrate the rock and transport the fragments to other places. In general, rocks in elevated regions are being disintegrated and carried to the ocean floor where the material is again consolidated into rocks. The upper part of this disintegrating rock material that has been modified by soil-making processes is called the soil. Compared with the rocks themselves it is more stable, especially after it has attained approximately a stage of maturity.

Since it was organized, the soil-survey division of the Bureau of Soils has been engaged in mapping and classifying the soils of the United States. After some preliminary work a system of classification was evolved which seemed to be the most practicable and at the same time as detailed and elastic as possible.

The most casual observation is enough to convince anyone that all soils are not alike. Some soils with a high content of organic matter are almost black; others which lack both organic and inorganic coloring matter are almost white. Some soils that have a comparatively large content of the larger-sized soil particles are called sandy or light-textured soils, while the heavy-textured or clay soils are composed largely of smaller sized particles. There are many other characteristics which might be used to differentiate and classify soils. The following, taken from Bureau of Soils Bulletin No. 96, describes the general method used by that bureau in classifying the soils of the United States (1):[1]

> The soils are brought together into groups on the basis of certain characteristics of the soils themselves, each group constituting a series. A soil series may be defined, therefore, as a group of soils having the same range in color; the same character of subsoil, particularly as regards color and structure; broadly, the same type of relief and drainage; and a common or similar origin.
>
> Soils may be grouped on the basis of soil texture also, and a group of soils all having the same texture belong to the same soil class. A soil class, therefore, includes all soils having the same texture, such as sands, clays, loams, etc.

An experienced soil man can usually tell without a laboratory analysis in which class a soil belongs, but in making the soil maps he

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[1] The figures given in parentheses here and throughout the text relate to the reference numbers in the bibliography given at the end of this paper.

is always checked by mechanical analyses. In making a mechanical analysis the soil is separated by means of sieves and decantation (4) into the several soil separates listed in Table 1.

TABLE 1.—*Size of particles in soil separates*

Separate	Diameter[1] (in millimeters)
Fine gravel	2–1.
Coarse sand	1–0.5.
Sand	0.5–0.25.
Fine sand	0.25–0.1.
Very fine sand	0.1–0.05.
Silt	0.05–0.005.
Clay	(Below) 0.005.

[1] The diameter refers to the diameter of the circular perforations in sieves that are used to separate the soil particles. For silt the diameter refers to the diameter of a spherical particle, which settles at the same rate as the soil particles.

From this analysis, by the use of the classification given below and the chart shown in Figure 2, the soil texture can be determined.

The soils are classified as to texture as follows:

1. Soils containing from 0 to 20 per cent silt and clay:
   (*a*) Sands—
      Coarse sand (35 per cent or more of fine gravel and coarse sand and less than 50 per cent fine or very fine sand).
      Sand (35 per cent or more of fine gravel, coarse and medium sand, and less than 50 per cent of fine or very fine sand).
      Fine sand (50 per cent or more of fine and very fine sand).
      Very fine sand (50 per cent or more of very fine sand).
      Soils containing 15 to 20 per cent silt and clay.
   (*b*) Loamy sands—
      Loamy coarse sand (35 per cent or more of fine gravel and coarse sand, and less than 35 per cent fine and very fine sand).
      Loamy sand (35 per cent or more of fine gravel, coarse and medium sand, and less than 35 per cent of fine and very fine sand).
      Loamy fine sand (35 per cent or more of fine and very fine sand).
      Loamy very fine sand (35 per cent or more of very fine sand).
2. Soils containing 20 to 50 per cent of silt and clay:
   (*a*) Sandy loams—
      Coarse sandy loam (45 per cent or more of fine gravel and coarse sand).
      Sandy loam (25 per cent or more of fine gravel, coarse and medium sand, and less than 35 per cent of very fine sand.
      Fine sandy loam (50 per cent or more of fine sand, or less than 25 per cent of fine gravel, coarse and medium sand).
      Very fine sandy loam (35 per cent or more of very fine sand).
3. Soils containing 50 per cent or more of silt and clay:
   (*a*) Loam (less than 20 per cent of clay, from 30 to 50 per cent of silt, and from 30 to 50 per cent of sand).
   (*b*) Silt loam (less than 20 per cent of clay, 50 per cent or more of silt, and less than 50 per cent of sand).

(c) Clay loams (soils containing 20 to 30 per cent of clay).
  Sandy clay loam (less than 30 per cent of silt and from 50 to 80 per cent of sand).
  Clay loam (from 20 to 50 per cent of silt and from 20 to 50 per cent of sand).
  Silty clay loam (from 50 to 80 per cent of silt and less than 30 per cent of sand).

(*d*) Clays (soils containing 30 per cent or more of clay)—
  Sandy clay (from 30 to 50 per cent of clay, less than 20 per cent of silt, and from 50 to 70 per cent of sand).
  Clay (30 per cent or more of clay, less than 50 per cent of silt, and less than 50 per cent of sand).
  Silty clay (from 30 to 50 per cent of clay, from 30 to 70 per cent of silt, and less than 20 per cent of sand).

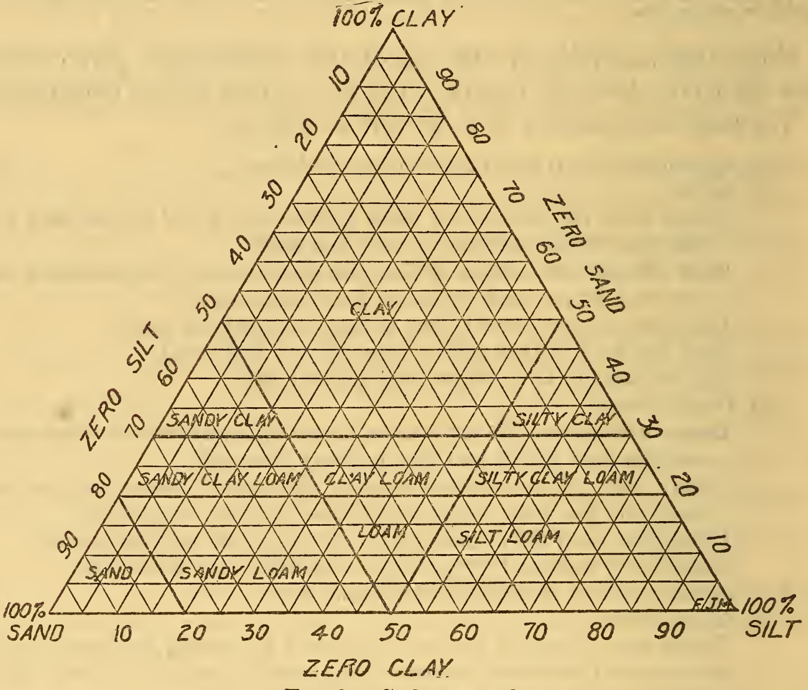

FIG. 2.—*Soil texture chart*

The soil unit or the soil individual is the soil type. It connotes all the features named above and is limited to a single class, a single series, and a limited region in which it occurs (1).

A soil type, therefore, is a soil which throughout the area of its occurrence has the same texture, color, structure, character of subsoil, general topography, process of derivation, and, usually, derivation from the same material.

The broad soil grouping (5), such as the separation of the groups I to VII in this discussion, is based wholly on soil character without reference to the geology of the soil materials, but the smaller differentiations, such as the series differentiations, are based in part on geology. This is an inheritance from a former practice when geology entered as a factor in all categories of soil classification. It may possibly be entirely abandoned in the future as our knowledge in increased.

The same soil type (3) can be developed from widely different parent rocks. On that account we must take into consideration a complex series of factors, which have acted together to produce the soils of the earth, yet for most soils at least the climate factor is the most important of the group.

As the soils of a section of a State are identified their locations are plotted on a map. A scale of 1 inch equals 1 mile is usually used in making the detailed soil maps. This permits mapping an area as small as about 5 acres. Each map is accompanied by a report describing the soil within the area, which consists usually of one county. Up to January 1, 1922, the total area which had been mapped in detail was about 570,000 square miles. This is 19.2 per cent of the total land area of the United States. The total area covered by the soil series in which specimens are buried is 191,841 square miles, or 33.6 per cent of the total area surveyed.

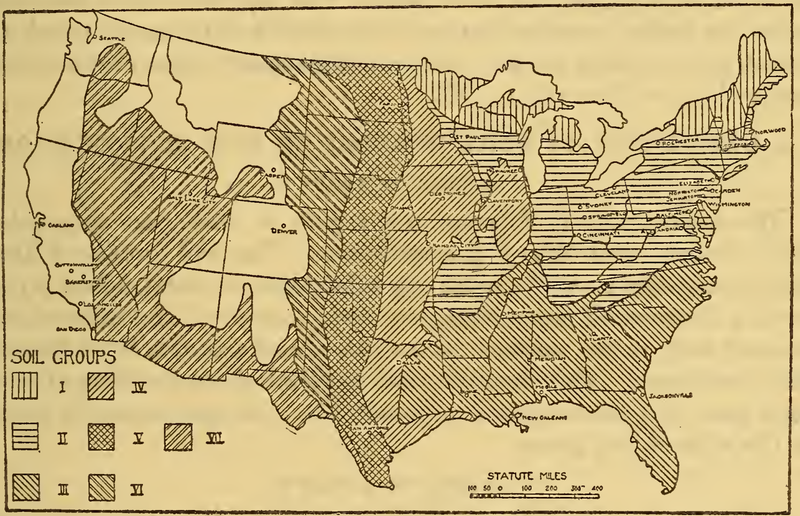

FIG. 3.—*Soil groups of the United States*

The outline map (fig. 3) shows the boundary lines of the areas in the United States in which the soils of the great soil groups of the United States predominate. This method of grouping is a distinct step forward in soil classification; the old method of classification by provinces, based on the origin and mode of formation of the soils, being changed to a method based on the characteristics of the soils themselves. Too much weight should not be placed on the positions of these boundaries, for they are drawn with only a limited amount of information. They can not be sharply defined because the soils of one group gradually merge into the soils of another group. For this reason the soils in which specimens are buried do not all fall in the group which is predominant in the region where the specimens are located.

In the following sections descriptions are given of the various soils in which specimens are placed. The descriptions of soil types are taken from the various publications of the Bureau of Soils. They are to be considered only as general descriptions of average conditions. Local variations within the types are given in the Soil Survey Reports of the areas where the soils are found. Detailed descriptions of some of the locations where specimens were buried were written by field men of the Bureau of Soils. Where they are available these are included with the general description. The depths at which the specimens are buried are the depths of the trench bottoms on which the 6-inch pipe sections are set. The areas given are those that had been mapped up to January 1, 1922.

2. DESCRIPTION OF SOILS INCLUDED IN THIS INVESTIGATION

(a) SOILS OF GROUP I

The soils of Group I occur in a region of coniferous vegetation, cold winters, and heavy precipitation: "The soil profile of these soils is characterized by a relatively thick layer of forest débris on the surface in forested areas, the gray surface layer of the mineral soil, stained dark in the surface, inch or two, and a brown layer beneath the gray layer. The chemical and physical characteristics of these soils have not been studied in detail" (5). No specimens are buried in the soils of this group.

(b) SOILS OF GROUP II

The soils of Group II are developed under conditions of heavy rainfall, rather cold winters and moderately warm summers, and a deciduous forest growth. "They consist, where normally or maturely developed, of a thin layer of leaf mold covering the surface of the forested soil, a dark brown surface layer of mineral soil, ranging from 3 to 4 inches in thickness, with a rather coarse granular structure, a yellowish brown third layer or horizon, often showing a definite horizontal breakage characteristic of soils without well-defined granulation. The plates are often grayish or coated with a grayish layer on the upper side. These two layers of mineral soil are lighter in texture than the underlying or fourth layer. This layer consists of a strong brown, yellowish brown, or faint reddish brown, heavier material, with a definite breakage, except in the sandy members, into angular particles ranging from one-quarter inch to 1 inch or more in diameter. The bottom of this layer extends generally to about 30 inches and is underlain by material whose character is determined by the character of the parent rock. Except where the parent material consists of heavy clay, this material is looser and lighter in texture than the fourth layer. The soils of this group cover a wide range of topographic and geological conditions, but in all of these, whatever may have been the character or source of the geological material or the process by which it has accumulated, the well-developed soils have general features in common, though in minor details they vary rather widely from place to place" (5). The soils types of this group in which specimens are buried are Allis silt loam, Chester loam, Fairmount silt loam, Genesee silt loam, Gloucester sandy loam, Hagerstown loam, Keyport loam, Knox silt loam, Lindley silt loam, Mahoning silt loam, Merrimac gravelly sandy loam, Miami silt loam, Miami clay loam, Ontario loam, Penn silt loam, Sassafras silt loam, and Sassafras gravelly sandy loam. The Genesee, Mahoning, and Keyport are rather poorly drained soils, and for that reason their profiles are not fully developed as are the other soils of this group.

(1) ALLIS SILT LOAM (SOIL NO. 1 IN TABLES).—The area of this series that had been mapped up to January 1, 1922, is 87 square miles in the State of New York, of which 17 square miles is silt loam.

Typically the soils of this series are "from brownish to drab or gray and are about 8 inches deep. The subsoil is usually light gray, but is in places mottled red and gray. The soils occupy steep slopes or elevated positions, and the topography is so rolling that the surface drainage is good. On account of the heavy character of the subsoil, however, artificial drainage is frequently necessary. The soils are derived through weathering of light-colored, soft shales, the structure of which is often preserved in the deep subsoil" (1).

The specimens are buried in a parkway area on the west side of East One hundred and fifty-second Street opposite the Torbensen Axle Factory at Cleveland, Ohio. The following is a description of the location, by A. E. Taylor, of the Bureau of Soils.

> Allis silt loam to a depth of about 8 inches is a grayish yellow or yellowish gray silt loam mottled with yellow and yellowish brown. This is underlain by a mottled yellow and gray silty clay loam which contains small fragments of shale. In this layer, which extends to a depth of 23 inches, the bedding of the shale is noticeable. Underlying this layer to a depth of 30 inches is a bluish gray silty clay loam which has bands of yellow indicating the bedding planes of the shale. From 31 to 70 inches the material is a silty clay or silty clay loam layer of shale which has a bluish gray color and is streaked along bedding planes with yellow. Underlying this is a layer of reddish brown shale streaked with gray, passing at about 76 inches into a rather compact bluish gray shale with yellowish brown and reddish brown streaks. Between 90 and 100 inches the yellowish brown and reddish brown streaks become less conspicuous.
>
> The pipes extended a little above the 90 to 100 inch layer. This shale runs high in aluminum sulphate $Al_2(SO_4)_3$ which with water breaks down into aluminum hydroxide $2Al(OH)_3$ and sulphuric acid. The sulphuric acid would probably attack the pipes directly. Both Eastern Ohio Gas Co. and the Cleveland City

Waterworks Commission report pipes to corrode especially fast in this shale while in the glacial clays they corrode slowly.

The soil was called Allis silt loam, although it occurs in a glaciated region, because the soil is derived from shale and is not a glacial drift soil. The topography is undulating to gently rolling and the natural drainage is poor.

This soil has previously been called Allis loam.

(2) Chester Loam (Soil No. 4).—The Chester series is limited in its occurrence to the northern Piedmont region, where it is the predominant soil. The area of this series mapped up to January 1, 1922, is 2,564 square miles, of which 1,947 is the loam type. The States where it occurs are Pennsylvania, Maryland, Virginia, New Jersey, and Delaware.

The Chester soils (1) (2) and especially the Chester loam are characterized by brown surface soils having a relatively high percentage of silt and a mellow loamy structure. The next horizon, which begins at about 3 inches and extends to 10 inches, is a brownish yellow loam being mellow, smooth, and friable and containing from 40 to 45 per cent of silt. It has a single grain structure. This is underlain by a layer which extends to about 40 inches where the soil is typically developed, consisting of a yellowish brown or reddish yellow silty clay loam to clay loam of a friable, crumbly structure. Below this is a layer about 8 inches in thickness of brownish yellow micaceous material having a soft, greasy feel which grades into schist or gneiss rock. This soil differs from the associated Manor soils in that the second horizon is heavier, thicker, and of more uniform color.

The topography of the stony types is often decidedly rough, but the loam, silt loam, and clay types usually occur on gently to moderately rolling areas where the regional drainage is good.

The specimens are buried near the brow of a small rounded hill on the west side of Moreland Road at the intersection of Gilpin Road, Willow Grove, near Jenkintown, Pa. The surface drainage is good. The surface soil to a depth of 8 to 10 inches is a grayish brown loam. This is underlain by a layer of dull red loam or silt loam which extends to about 20 inches. Below this to a depth of 3 feet is a yellowish or yellowish brown loam, containing fragments of quartz and cherty material. It is in this layer that the specimens are placed, the trench being 3 feet deep.

(3) Fairmount Silt Loam (Soil No. 7).—No soils of the Fairmount series were encountered previous to 1922. Since then they have been mapped in several areas in Ohio.

"These soils are imperfectly developed upland soils occurring on valley slopes where erosion has almost kept pace with weathering. In such positions the unleached parent formation, which is generally a limestone formation, is usually within 2 or 3 feet of the surface and in many places it outcrops. A generalized profile of the soil consists of two horizons, the upper being a brown, friable, silty clay loam, underlain at 1 or 2 feet by a yellowish brown calcareous silty clay" (15).

The specimens are buried at Price Hill Substation, of the Union Gas & Electric Co. in Cincinnati, Ohio. The following is a description of the location by A. E. Taylor, of the Bureau of Soils:

> The Fairmount silt loam, brownish gray phase, is a brownish gray silty clay loam or silt loam, passing at about 8 inches into a mottled gray, brownish gray, grayish brown, brownish yellow, yellowish brown, and yellow silty clay loam. This at about 14 inches grades into a brownish yellow silty clay loam mottled with gray and bearing iron concretions. Underlying this at about 24 inches and extending to a depth of 36 inches is a layer of light brown silty clay, mottled with gray and carrying numerous iron concretions. From 36 to 40 inches the material is a residual product from the underlying limestone, and consists of a yellow, plastic clay with many iron concretions. At 41 inches is a mottled gray and yellow, calcareous clay, which continues downward to the limestone. Bedrock (limestone) is encountered at from 4 to 6 feet.
>
> This soil is not typical of any established type, but the lower section, in which the pipes are set at a depth of 40 inches, is Fairmount. The upper part of the section is Illinoian drift. A large amount of pipe in Cincinnati is reported to be set in this kind of material and seems to last very well. The topography is gently rolling, the drainage is fair.

This soil has previously been called Fairmount loam.

(4) GENESEE SILT LOAM. (SOIL No. 9).—The soils of the Genesee series "consist of alluvial sediments deposited along the major streams and their tributaries, throughout the northeastern glaciated region, particularly where the Dunkirk, Volusia, Miami, and Ontario series constitute the principal upland soils. The soils of this series also occur for a short distance south of the glaciated area, where main streams have their headwaters in areas covered by these soil series" (1). The area of the Genesee series is 1,430 square miles in the States of Michigan, Wisconsin, Indiana, Pennsylvania, Missouri, New York, Iowa, Ohio, New Jersey, Illinois, and Nebraska. Of this area 735 square miles is silt loam.

"The sandy members of this series are prevailingly light brown to grayish brown and the loam and silt loam members darker brown. The subsoil is usually of somewhat lighter color, but about the same texture as the soil. These soils are subject to either annual or frequent overflow." The specimens are buried in this soil one-half mile south of Shelby County Infirmary, near Sidney, Ohio.

The following is a description, by A. E. Taylor, of the location where specimens are buried:

> The soil here to a depth of about 10 inches is a brownish gray silt loam, slightly streaked with reddish brown. Underlying this is gray loam streaked reddish brown and mottled yellowish brown and brownish yellow. At about 16 inches it passes from a gray loam to a fine, sandy loam mottled reddish brown. This is underlain with gray gravel at about 22 inches. The pipes are set on the gravel and extend up through the 16 to 22 inch layer into the layer occurring between

10 and 16 inches. Although the fall has been unusually dry the ground-water level was encountered at 24 inches. This soil might be called a poorly drained phase of the Genesee. The pipes are in saturated soil for long periods. The Tidewater Pipe Line Co. have had great difficulty with the pipe rusting in Genesee and similar soils when they are unusually wet, but little difficulty has been encountered by them in the better drained soils, such as Miami and Bellefontaine.

(5) GLOUCESTER SANDY LOAM (SOIL NO. 10).—The Gloucester soils are found in the New England States south as far as New Jersey. The area of this series is 4,283 square miles, of which 685 square miles is sandy loam.

The soils of the Gloucester series are distinguished from the Mahoning and Ontario series in that the Gloucester is derived from granite and metamorphic rock material, the Mahoning from shale and sandstone material, and the Ontario mainly from shale and limestone material.

Typically Gloucester sandy loam "is brown sandy loam about 8 inches deep, overlying a yellowish brown, slightly less coherent sandy loam to a depth of 30 inches, where a light yellowish gray sandy loam or loamy sand is encountered. Stones and small bowlders, chiefly of granite and gneiss, are usually present. Small subangular gravel is often found throughout the soil mass. The topography varies from gently undulating to somewhat hilly, the type for the most part occupying the low rounded hills and ridges. Drainage is good" (1).

The soil where specimens are buried consists of a light brown sandy loam which is underlain by a light grayish brown fine sandy loam containing some gravel in which horizon the specimens are placed at a depth of 3 feet. The location is in the town barn lot at Park and Frank Streets, Middleboro, Mass.

(6) HAGERSTOWN LOAM (SOIL NO. 11).—"It is most extensive and agriculturally the most important of the valley limestone soils. It occurs from southeastern Pennsylvania through Maryland, the Great Valley of Virginia, and associated minor valleys of West Virginia and Tennessee. It also occupies a considerable part of the Blue Grass Region of Kentucky and the Basin Region of central Tennessee" (10). The area occupied by this series is 6,187 square miles, of which 1,977 square miles is loam.

It consists of a brown to dark brown loam to heavy fine sandy loam surface soil 2 or 3 inches deep, underlain by a reddish brown to brown loam ranging in depth from 5 to 8 inches. The subsoil is a reddish brown or brown clay or silty clay loam which extends to 40 or 50 inches. While firm and slightly stiff, it readily breaks down into a granular mass. The subsoil grades into a dull red, yellow, and whitish material, the white portion being soft disintegrated chert, while the redder portion appears to be a completely weathered portion of this rock. Fragments of chert and limestone are sometimes found mixed with the soil, but where the limestone is pure the soil is practically free of rock fragments.

These soils generally occupy a gently undulating to rolling valley floor that has a pitted, sink-hole topography which is characteristic of regions underlain by pure limestone. The surface drainage is always adequate, and in many areas an intricate system of underground caverns produces excellent interior drainage.

The specimens are buried on a moderate slope adjacent to a rather steep hill at the Lock Raven Reservoir, of Baltimore water department. The soil consists of a brown loam to a depth of about 9 inches, underlain by a reddish brown clay which extends below 60 inches, in which layer the specimens are placed at a depth of 60 inches. This soil has previously been called Hagerstown sandy loam.

(7) KEYPORT LOAM (2) (SOIL NO. 17).—The soils of the Keyport series are similar to the Sassafras soils in origin and distribution. They are limited to comparatively small, flat, poorly to fairly well-drained areas in close association with the soils of the Sassafras and Elkton series. The area of this series is 251 square miles in the States of Virginia, Maryland, New Jersey, and Delaware. Of this area, 15 square miles is Keyport loam.

The Keyport soils are distinguished from the Sassafras soils in that the soil is often of grayish-brown color and the subsoil is a stiff to moderately friable, mottled yellow and rusty brown and gray clay. They differ from the Portsmouth in that the latter have almost black surface soils. These soils occupy an intermediate position between the Sassafras and Elkton.

The specimens are buried on the high-school grounds at Alexandria, Va. The soil consists of a light brown loam which extends to a depth of about 8 inches and is underlain by a yellowish, mottled with brown clay. It is in this horizon that the specimens are placed at a depth of 3 feet. The topography is flat and the regional drainage is rather poor.

(8) KNOX SILT LOAM (SOIL NO. 18).—The area of this series mapped up to January 1, 1922, is 5,488 square miles, of which 5,253 square miles is silt loam. It occurs in Indiana, Illinois, Wisconsin, Iowa, Missouri, and Nebraska.

"The surface soil to an average depth of 10 to 12 inches is a light brown, ashy gray, or nearly white silt loam. In the better drained areas, where erosion has not been excessive, this surface material may have a depth of 14 to 16 inches, and the typical color is then brown or yellow. On the other hand, in areas which are to the least degree deficient in drainage, and also in areas where the organic matter of the surface soil has been largely exhausted, the color is more nearly gray. The subsoil is compact light brown or pale yellow silt loam, sometimes becoming more stiff and clayey at greater depths. Both soil and subsoil are normally stone free, and very little sand is found in any except local areas, where other materials have been mingled through erosion processes with the materials of the Knox silt loam. The fine silt or silty clay, known as loess, has given rise to both the soil and subsoil of this type. The depth of this material varies from 40 to 50 feet along the bluffs of such rivers as the Mississippi, the Illinois, and the Missouri to layers of only 5 or 6 feet thick along the Ohio River and its northern tributaries.

"The Knox silt loam differs from the soils of the Marshall series in two essential respects. In the first instance its surface soil is a much lighter brown or even a pale gray, sharply contrasted with the deep brown or black surface soil of the members of the Marshall series, particularly the silt loam. In the second case, the Knox silt loam is distinctly a timbered region soil throughout the entire extent of its occurrence, as contrasted with the Marshall silt loam, which occupies only the prairie areas of the same general region" (14).

Specimens were buried on the property of the Omaha & Council Bluffs Railway Co., in the rear of the lot occupied by the South Omaha substation at Omaha, Nebr.

At this place there is no important change in the soil profile down below a depth of 4 feet, at which depth the specimens were placed, the soil being a light grayish brown or light brown silt loam.

(9) LINDLEY SILT LOAM (SOIL NO. 19).—The soils of the Lindley series occur principally in Iowa and Missouri with a few small areas in Nebraska and Kansas. The total area of the series mapped up to January 1, 1922, is 1,100 square miles, of which 519 square miles is silt loam.

"These soils are typically yellowish brown, ranging from gray on the one hand to brown on the other. They are usually shallow, the dark soil layer being rarely more than 8 inches thick. The subsoil is yellowish to yellowish brown or in rare cases reddish brown, usually free from mottling or faintly mottled with gray. It is usually heavier than the soil, though it contains in many cases a considerable percentage of sand and gravel. Lime concretions are almost always present in the lower subsoil. The topography is usually rather rough, and the soil was originally covered with oak and hazel brush, especially the medium-textured members. This series of soils is derived by weathering from the Kansas drift and occurs in association with the Shelby soils" (6). It is also similar to the Miami, but differs from it in that the two soils do not occur in the same region. The specimens are buried near the lake in Greenwood Park at Des Moines, Iowa. The subsoil in which the specimens are placed is a light brown heavy silt loam slightly mottled with brown and containing a little fine gravel and sand. They are at a depth of about 3 feet. This soil has previously been called Lindley clay loam.

(10) MAHONING SILT LOAM (SOIL NO. 20).—The Mahoning series up to 1922 had been mapped in only two surveys, in Ohio and in New York, the total area of which is 118 square miles, of which 103 square miles is silt loam.

"The soils of this series are gray with a slightly brownish or yellowish tinge, the upper subsoils are gray and yellowish brown mottled and not so much heavier than the surface soils in texture, while the lower subsoils are dull brownish drab to greenish olive drab in color and very heavy in texture, consisting of a smooth, brittle, heavy clay. Generally, the mottling of the subsurface layer extends a few inches into the heavy clay subsoils, then there is a rapid change to a dull brownish color which extends to depths of 15 to 24 inches, and below this the olive drab color is developed. The subsoils are moderately calcareous below 24 to 36 inches. The surface features are nearly level to gently rolling. The drainage is deficient, but not as poor as in the associated Trumbull soils. These soils are residual on glacial till, derived principally from calcareous shales and sandstones" (6).

The specimens are buried in the rear of the Kinsman Reservoir at Kinsman Road and One hundred and eighth Street SE., Cleveland, Ohio. The following is a description of this location by A. E. Taylor:

> The Mahoning silt loam is a brownish gray, heavy silt loam or light silty clay loam with a depth of about 4 inches. Immediately below this is a pinkish red clay, mottled brownish yellow, yellow, yellowish brown, and gray, and extending to a depth of about 8 inches. From 8 to 24 inches is a mottled drabbish gray, yellow, brownish yellow, and yellowish brown clay. (To a depth of about 15 inches there has been more or less disturbance of the material, but below this it is in place.) This is underlain by a drabbish-gray clay, mottled with brownish yellow, yellowish brown, and pinkish red, and extends to a depth of about 46 inches, where a mottled gray, brownish yellow, and yellowish brown calcareous clay is encountered. This continues below 50 inches.
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> The specimens were set in the lower part of the section extending from 38 to 50 inches. The topography is gently undulating, and the natural drainage is poor.

(11) MERRIMAC GRAVELLY SANDY LOAM (SOIL NO. 24).—The area of the Merrimac series is 2,644 square miles in the States of New York, Massachusetts, New Hampshire, Maine, Connecticut, Vermont, New Jersey, Wisconsin, and Minnesota. Of this area 554 square miles is gravelly sandy loam.

"Merrimac soils are brown to light brown in color, overlying yellowish brown to brown subsoils. The latter are usually as light or lighter in texture than the soils, often consisting of sands and gravels, though in some cases the lighter textured material is not reached in the 3-foot section. The soils are derived from water-laid material, usually of glacial age, consisting of outwash plains and old river terraces, and the source is mainly crystalline rocks. The topography is smooth and constructional" (1).

The specimens are buried near the Ellis Street pumping station near Norwood, Mass. The surface soil at this location is a brown loam containing considerable sand and coarse sand which extends to a depth of 4 inches. Below this and extending below the depth at which the specimens are placed is a grayish coarse sand or fine gravel. The specimens are at a depth of 33 inches.

(12) MIAMI CLAY LOAM (SOIL NO. 25) AND MIAMI SILT LOAM (11) (SOIL NO. 26).—The soils of the Miami series occur in the northeastern part of the great central plain, which extends from the region of the Great Lakes southward beyond the Ohio River and westward beyond the Mississippi. In the regions in which these soils occur they are of great importance. The area of this series is 11,341 square miles, of which 3,737 is clay loam and 4,075 is silt loam. The principal States in which it occurs are Michigan, Wisconsin, Indiana, Ohio, and Minnesota.

"The soils are brown or grayish brown and are underlain by yellowish brown heavier textured subsoils. The surface drainage is usually good, but artificial drainage is advisable in some of the heavier types. The soils are in the main derived, through weathering, from calcareous glacial till" (1).

The Miami soils can be distinguished from the Broaketon series with which they are closely associated by the high organic matter content and poor drainage of the latter. The Miami is also closely associated in places with the Coloma series, which latter always contains more gravel and sand than the Miami.

The specimens are buried in the clay loam just east of the toboggan slide and opposite the refreshment pavilion in Washington Park at Milwaukee, Wis. The following is a description of this location by W. J. Geib:

> Miami clay loam consists of 6 inches of grayish brown silt loam, and in a few places this extends to 8 inches. From 6 to 30 inches is a yellowish brown, stiff, heavy clay loam to clay containing a small amount of gritty material. Underlying this and extending to a depth of 48 inches is a slightly calcareous brownish yellow heavy clay loam which is somewhat lighter in color than the second section and also contains some gritty material. This section is somewhat more crumbly in structure, which may be due in part to the fact that when the sample was taken there was less moisture than in the sections above.

The specimens are placed at a depth of 3 feet in this material.

The specimens are buried in the silt loam near the southern corner of the fair grounds, about 300 feet west of Yellow Spring Street, Springfield, Ohio. The following is a description of the location by A. E. Taylor:

> The soil here, which might be termed a mottled phase of Miami silt loam, consists of a grayish brown silt loam to a depth of about 2 inches, where it passes into a brownish gray to yellowish gray silt loam. Underlying this at about 7 inches is a gray silt loam mottled faintly with yellow. At about 10 inches is a

mottled yellow and gray silt loam, which grades into a brown clay loam to clay mottled brownish yellow and yellowish brown at about 16 inches. This extends to a depth of about 24 inches, where a reddish brown stiff clay is encountered. From 36 to 48 inches is a yellowish brown, gravelly friable clay, which is somewhat calcareous in the lower part of the layer. It was in this layer that the pipe were set. Pipes corrode slowly in this layer, according to the experience of pipemen.

(13) ONTARIO LOAM (SOIL NO. 32).—The soils of the Ontario series are found only in the State of New York, in which State 1,340 square miles have been mapped, of which 935 square miles is loam.

"The soils of this series are brown to grayish brown in color, the subsoils being lighter colored and in many cases grading into yellow. Both soil and subsoil usually contain scattered fragments of limestone. They are derived from the weathering of the glacial till of the drumlin region of New York.

"The topography is undulating to moderately hilly, depending upon the number and shape of the drumlins within a given area. Some of the areas intervening between the drumliodal hills are rather flat. The series includes all soils of this color and character, whether the topography is that of typical drumlins or not. The most important features are the color and calcareous nature of the soil, the thickness of the glacial deposits, and the undulating to rolling topography" (1).

The specimens are buried on the east side of South Avenue extended about 3½ miles south of Rochester, N. Y. The following is a description by H. G. Lewis, of the location in which the specimens are buried:

> The surface soil to a depth of 6 to 10 inches is a brown, to grayish brown when dry, mellow and friable, fine sandy loam to fine loam. The subsoil to a depth of 15 to 20 inches is a slightly more compact, though crumbly loam to fine sandy loam, light brown to yellowish brown in color. The lower subsoil to a depth of 30 to 36 inches is a grayish brown to brownish gray compact loam in place, though friable when bored out. The lower portion, or substratum, represents partially weathered till material, and it is in it that the specimens are placed at a depth of 4 feet.
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> The topography is gently sloping to undulating. Surface and internal drainage is good. The parent material from which the soil is derived is largely limestone with some sandstone, shale, and igneous rocks. Gravels and small stones are common on the surface and in the section, but more abundant in lower portions. The soil is calcareous at from 15 to 24 inches.

(14) PENN SILT LOAM (7) (SOIL NO. 34).—These soils are limited in their occurrence to the northern Piedmont. Practically all classes of this series have been mapped, the areas of the series being 1,579 square miles, of which 477 square miles is silt loam. The States where it occurs are Pennsylvania, Maryland, Virginia, and New Jersey.

The Penn silt loam consists of brown or reddish brown silt loam surface soil and a reddish, Indian red or reddish brown subsoil which grades into a silty clay with increasing depth. It is residual on sandstone and shale of Triassic age, which is encoutered at depths of from 18 to 40 inches; the color of the soil varies somewhat with the rock from which it is derived, which is typically of an Indian red color but sometimes has a yellowish cast. Varying amounts of shale and sandstone fragments are found throughout the soil profile.

The topography is smooth to gently rolling, and the internal drainage is good except on a few rather steep slopes where there is considerable seepage.

The specimens are buried in an almost level area alongside the Germantown Pike northwest of Morristown, Pa. The surface soil is a dull red, or Indian red, silt loam which extends to about 12 inches. Below this is a light reddish brown silt loam which extends below 3 feet. The specimens are at a depth of 30 inches. Since this soil is deeper than the average type, it would probably be classed as a colluvial or deep phase.

(15) SASSAFRAS SILT LOAM (SOIL NO. 39) AND SASSAFRAS GRAVELLY SANDY LOAM (SOIL NO. 38).—Two soils, the Sassafras and Keyport, are derived from Glacial, Piedmont, and Appalachial material which has been mixed and carried down by the rivers to the coastal plain. The soils of the Sassafras series are, therefore, confined entirely to that part of the coastal plain where glacial material has been added to the Piedmont-Appalachian material. It is probable that this series does not occur farther north than Brunswick, N. J., nor farther south than Norfolk, Va. The area of this series in the States of Maryland, New Jersey, Delaware, and Virginia is 6,071 square miles, of which 861 square miles is silt loam and 259 square miles is gravelly sandy loam.

"The soils of this series are distinguished by their yellowish brown to brown color and their mellow structure. The subsoils are reddish brown and friable in structure, resting upon coarser material or beds of gravel and sand at depths varying from 2½ to 5 feet. The substratum of gravel makes drainage good. The series is developed along flat marine or estuarine terraces standing from 10 to 250 feet above sea level" (1).

"The Sassafras is easily distinguished from the soils of the Elkton series, which occur in the same region, since the latter possess gray to whitish surface soils and mottled yellow and gray heavy subsoils. It is best distinguished from the soils of the Norfolk series by the brown color of the surface and reddish brown cast of its subsoil. It does not possess the black surface soil of the Portsmouth series of soils, which is sometimes found in the same localities" (17).

The specimens are buried in Sassafras silt loam in the north side of Lake Street, between Summit Street and Elmhurst Place at Wilmington, Del. The soil profile in this location consists of a brown silt loam to a depth of about 14 inches. This rests upon a reddish yellow silty clay which changes at about 32 inches into a yellowish red sandy silty clay which extends below 4 feet. The specimens are in this layer at a depth of 36 inches. Gravel is found throughout the profile but gets more abundant with increasing depth. The topography is almost flat. The drainage is fair.

The specimens are buried in Sassafras gravelly sandy loam on the Delair Pumping Station grounds of the Camden Water Department at Morgan and Adams Avenues, Camden, N. J. The soil profile in this location consists of a very loose, friable, very light brown sandy loam or coarse sandy loam to a depth of about 18 inches. The soil underlying this is of practically the same texture but a lighter color, in which layer the specimens are placed at a depth of 30 inches. Considerable water-worn gravel is found throughout the soil section. The vegetation is sparse owing to the excessive drainage. The surface is gently sloping toward the Delaware River.

(c) SOILS OF GROUP III

"The soils of Group III consist of two kinds of subgroups—a yellow and a red. These soils are in some respects like those of Group II. They are developed under a heavy rainfall and a subtropical climate. The dark-colored surface layer in the natural forest-covered soil is usually somewhat thinner and grayer than in Group II, and the next layer is yellow, often pale yellow, rather than yellowish brown as in Group II. The layer below this is yellow in the one subgroup, red in the other. In both cases there is a wider difference in texture between this layer and the one above it than there is in Group II. The true soil layer, including both the above-described layers, is thicker than in the soils of Group II and the percentages of lime, magnesia, potash, and soda are, in general, less than in the soils of Group II. This is especially true of the lower horizon" (5).

Specimens are buried in the following soil types, which are members of this group: Cecil clay loam, Kalmia fine sandy loam, Memphis silt loam, Miller clay, Norfolk sand, Ruston fine sandy loam, Sharkey clay, St. Johns fine sand, and Susquehanna clay. Some of these soils, such as the St. Johns and Susquehanna and especially the Miller and Sharkey, are poorly drained and have not developed the characteristic profile of the soils of this group. The following is a description of these soil types and the locations where specimens are buried.

(1) CECIL CLAY LOAM (8) (SOIL NO. 3).—This soil is most prevalent in the southern Piedmont, where it is the most important soil. This series occupies about one-third of the entire Piedmont Province. The area of this series is 22,239 square miles, of which 4,473 square miles is clay loam. It is found principally in Georgia and the Carolinas. The soils of the Cecil series have grayish brown surface soils in the sandy types to reddish brown and even red surface soils in the heavier types, and a red, stiff, but brittle, clay subsoil. The

parent rock, which is of igneous origin, predominantly granite or gneiss, is found at depths ranging from 3 to perhaps as great as 30 feet. Rock fragments are often found in the soil. Quartz sand is nearly always present in the subsoil and is often on the surface, especially in the sandy types.

The clay loam type, locally known as "red land" in virgin areas, consists of a mere film of vegetable matter overlying a reddish brown clay loam which ranges from 5 to 7 inches in depth. This layer normally contains enough sand to render it friable. The subsoil is a red clay, heavy, stiff, but brittle, hard when dry, sticky when wet, breaks into irregular shaped lumps with no definite cleavage lines or markings of stain along breakage lines. This layer grades into a yellowish red, friable micaceous clay at depths of from 3 to 10 feet which is soft and crumbly. Below this is found the yellow and gray soft disintegrated rock. The color of cultivated fields depends somewhat on the content of organic matter and the quantity of red clay turned up. The topography of this series is a little more hilly than the Penn or Chester series and the drainage is excellent.

The specimens are buried near the top of a knoll about 250 feet northeast of Blandtown Road gate to water reservation, 200 feet south of new reservoir, and 1,000 feet west of Howell Mill Road at Atlanta, Ga. The surface soil to a depth of 8 inches consists of a grayish brown rather compact very fine sandy loam. A few fragments of granite and quartz were found on the surface. Between 8 and 10 inches is a transition layer below which and extending to 32 inches is a compact brittle red clay containing very few mica flakes and practically no sand or stones. The specimens are placed in the lower part of this horizon. This is underlain by a micaceous more friable red clay loam which extends to a depth of 70 inches and rests upon a red moderately friable very fine sandy loam, full of mica crystals and having a few brownish and yellowish mottlings. This material becomes less compact and slightly lighter in texture, and the extent of the mottling increases with depth to about 9 feet.

The surface has a moderate slope and the drainage is a little excessive. The land was probably cultivated at some time in the past. It now supports a moderate growth of grass, which is mowed occasionally, and a few small oak trees.

(2) KALMIA FINE SANDY LOAM (SOIL NO. 16).—"The soils of the Kalmia series are typically and most extensively developed along streams in the Gulf Coastal Plain region of Mississippi and Alabama, as terraces lying largely above overflow" (1). The total area of this series mapped to January 1, 1922, is 2,582 square miles, and it is found in practically all the Southern States except Florida. Of this area 1,209 square miles consists of fine sandy loam.

"The surface soil of the Kalmia fine sandy loam in virgin or old field areas is a grayish brown to light brown fine sandy loam or loamy fine sand 2 to 4 inches deep. Below this top layer is a pale yellow loamy sand which extends to depths of 14 to 18 inches. The subsoil to depths of 40 to 60 inches is a yellow sandy clay of a crummy structure. Below this subsoil is a friable sandy clay, which is mottled with purplish red, or brown, yellow, and whitish colors, and contains a few soft iron accretions. Where cultivated the top layer has been mixed with some of the second layer, producing a light gray color.

"In the better drained situations the subsoil color is yellow, causing such areas to resemble the corresponding members of the Norfolk series very closely. These soils are closely related to the Cahaba series, differing, essentially, in their poorer drainage and consequent less oxidized condition of their subsoils. The component material of the Kalmia series is derived largely from the coastal plain soils, although on the larger streams issuing from the Appalachian Mountains and Piedmont Plateau there is present more or less of the soil from this region. The surface is usually flat, and the drainage on this account is inadequate in most cases" (6).

The specimens were buried at the Fair Grounds in Mobile, Ala. The soil to a depth of 8 inches is a grayish brown fine sandy loam which appears to have been disturbed. This is underain by yellowish brown or dingy yellow very fine sandy loam. The texture gradually gets finer, and the compaction increases with increasing depth. Some reddish mottling and a few iron concretions about ¼ inch in diameter are most numerous at about 3 feet and disappear entirely at 6 feet. Below 42 inches is a mottled red, gray, and yellow material containing layers of clay and fine sand but with the average texture of a silt loam. Below 72 inches the color is light yellowish brown with light gray mottlings. The specimens are at a depth of 30 inches. The surface of the ground has a gentle slope to a stream channel which is about 10 feet below and 150 feet west of the trench. To the east the surface is almost flat with a very gentle slope to the west. The water table is approximately 10 feet below the surface. This soil has previously been called Norfolk fine sandy loam.

(3) MEMPHIS SILT LOAM (SOIL No. 22).—"This soil, unlike other soil types derived from loess, is derived from those deposits that extend southward from the confluence of the Missouri and the Mississippi Rivers almost to the margin of the Gulf of Mexico. In this respect it is unique among loess-derived soils. It comprises a long, narrow belt along both sides of the Mississippi River in southern Illinois and eastern Missouri, covering a considerable proportion of the upland in western Kentucky, a belt 50 to 70 miles broad in western Tennessee, a continuous belt, varying from 50 miles in width in

northern Mississippi to a narrow strip, 15 to 20 miles broad, where it passes across the southern line of Mississippi into eastern Louisiana and terminates between Baton Rouge and New Orleans. It also occurs covering a considerable territory on the west side of the Mississippi in northeastern Arkansas" (13). The area of this series is 6,407 square miles, of which 6,340 square miles is silt loam.

"It covers the various coastal-plain formations and in its more northern portion even the consolidated rocks of the outward edge of the Ozark uplift. The surface soil of the Memphis silt loam in its characteristic development is a brown or brownish yellow silt loam, containing nearly 80 per cent of silt and 15 to 20 per cent of clay, with very small amounts of coarser material, although a little very fine sand is not infrequently present. The depth of the surface soil varies materially in the different parts of any area where it may be developed. Upon the steeper and more hilly portions of the type the surface covering is from 2 to 5 inches thick, while upon the more level areas, where erosion has not been so active, the surface brown loam may attain a depth of 8 to 15 inches. It grades downward into a chocolate-brown to yellow silt loam, which is a little more stiff and compact than the surface soil through the presence of a slightly higher content of clay.

"This material usually extends to a depth of 3 feet or more, and in the majority of cases rests directly upon the soft but compact yellow silt, sometimes mottled with gray, which constitutes the characteristic section of the loess wherever it is fully developed. In other instances, and particularly near the eastern margins where the total thickness of the loess dwindles to 3 or 4 feet, the deep subsoil may be somewhat modified by the presence of small amounts of medium to coarse sand, with occasional pebbles and noncontinuous bands of gravel. In such instances the entire section is liable to be distinguished by brown or chocolate color. In the less eroded areas, where weathering has proceeded uninterruptedly to greater depths, the subsoil is reddish yellow to deep chocolate brown and is also somewhat more stiff and clayey through the breaking down of the silt particles.

"The Memphis silt loam is sharply contrasted with all of the soils in the region where it occurs, for it is the one great silty soil which extends from southern Illinois to the region of the Gulf of Mexico, being contrasted with the more sandy and clayey soils derived from other formations. The less eroded, deeper, darker, loamy phase has in recent surveys been mapped as Richland silt loam.

"The usual topography of the Memphis silt loam is rolling to hilly. At places more remote from the bluff line of the rivers along which it occurs the surface becomes slightly rolling to undulating, and in the more remote uplands there are considerable areas of practically flat land which will probably be classified with Richland silt loam because of this topographic difference.

"The natural drainage of the type is quite complete along the bluff lines and in close proximity to the larger drainage ways. In the smoother country, somewhat remote from the streams latterly mapped as Richland, there are level areas and even minor depressions where the natural drainage of the Memphis silt loam is deficient. Such areas are always marked by a light gray to ashy-white surface soil, except where the drainage is so obstructed that local swampy areas have been formed and the shallow mucky accumulation over the silty material gives a darker color to the surface soil" (13).

The specimens were buried in the south end of the Tri-State Fair Grounds at Memphis, Tenn. Except for the admixture of organic matter to the surface 4 inches, the entire soil profile at this place consists of a light brown smooth silt loam with the characteristic loess texture and with no important change above a depth of 96 inches. The specimens are placed at a depth of 33 inches. The land surface is very gently undulating.

(4) MILLER CLAY (SOIL NO. 27).—"The soils of this series are typically developed in the first overflow bottoms of streams, usually from the Permian red bed region. They are found along the Brazos and Red Rivers in Texas and Louisiana. Considerable areas are but rarely overflowed" (1). The area of Miller soils mapped up to 1922 is 2,158 square miles in the States of Arkansas, Louisiana, Oklahoma, and Texas. Of this area 1,135 square miles is Miller clay.

"The Miller series includes soils of chocolate brown to pinkish red color, with chocolate red or pinkish red subsoils. The soil and subsoil are calcareous. Some of the sandy members are grayish brown in the surface portion" (1).

The specimens are buried in this soil along the Standard Oil Co.'s right of way, 5½ miles south of Bunkie, La. In this location the soil is a dull red, heavy, calcareous clay extending down below the depth at which the specimens are placed which is 30 inches. The topography is flat and the drainage is poor, the specimens being under water a larger part of the year. This soil has not been identified by the Bureau of Soils but the soil map shows Miller clay at this location, and a sample of the soil was identified as typical Miller clay by H. H. Bennett, of the Bureau of Soils. This soil has previously been called Swampland.

(5) NORFOLK SAND (SOIL NO. 31).—The soils of the Norfolk series "are the most extensive and important soils of the coastal-plain region. They occur throughout the region from southern New Jersey to central Texas, but are most extensive in the section above the Atlantic and Gulf flatwoods, between the James River in Virginia and the region of the loessial soils in Mississippi. The sand and sandy loams are important types" (2). The area of this series is 36,708 square miles in the States of New Jersey, Maryland, Delaware, Vir-

ginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas, Olkahoma, and Arkansas. Of this area 9,041 square miles is Norfolk sand.

"These soils are characterized by the grayish to very light brown color and loose nature of the soil and by the yellow color and friable structure of the subsoils. The sandy loams consist of a grayish or very light brown sand or loamy sand to fine sand or loamy fine sand, passing at an average depth of 3 to 5 inches into pale yellow material of about the same texture, underlain usually at about 40 to 50 inches by pale yellow sand with slight mottlings of light gray. Below this is a mottled reddish brown and light gray loamy sand containing lenses of sandy clay. Frequently there is considerable quartz and chert gravel on the slopes and ridges. These sandy soils are characteristically low in humus. Where there is much gray mottling in the lower subsoil the soil is classed as Caddo, and where there is much reddish mottling in the subsoil it is classed as Bowie.

"The Norfolk soils are all thoroughly drained, with the rare exception of a slight excess of moisture in the lower subsoil of a few low-lying areas of the flatwoods country. For the most part this series occupies flat, undulating, and gently rolling country" (2).

The location where specimens are buried in Norfolk sand is west of the west wall of Catholic Cemetery in Katherine Street, between Lane and Union Streets, in the eastern part of the city of Jacksonville, Fla. The surface soil at this location consists of a dark gray sand containing some organic matter and extending to a depth of 4 inches. This is underlain to a depth of 8 inches by a gray sand having a slight yellowish tint. Below this, and extending below 9 feet, the subsoil consists of pale yellow sand. The specimens are at a depth of 24 inches.

(6) Ruston Sandy Loam (Soil No. 36).—"These soils are the most extensive lands over large areas in southern Alabama and Mississippi and are important in Louisiana, Arkansas, and southwestern Georgia. They occur in the rolling country above the flat coastal areas" (2). The area of this series is 13,052 square miles in the States of Alabama, Mississippi, Georgia, Virginia, Louisiana, Arkansas, North Carolina, Texas, South Carolina, Missouri, Tennessee, and Maryland. Of this area 2,515 square miles is sandy loam.

"The surface soil of the Ruston sandy loam in virgin areas is a loamy sand 2 to 4 inches deep grading into a brownish yellow loamy sand or light sandy loam which extends to a depth of 10 to 18 inches. The subsoil is yellowish red or reddish yellow to yellowish brown moderately friable sandy clay having a thickness of 2 to 8 feet. Below this is a mottled red, yellow, and whitish hard, but brittle material; the upper part near the subsoil shows more red, while at 7 or 8 feet the gray and yellow color predominates.

"The series holds an intermediate place between the Orangeburg and Norfolk soils in the color of its subsoils; and a similar place between Orangeburg and Norfolk, on one side, and the Susquehanna, on the other side, in point of subsoil structure. Occasionally the lower subsoils are mottled with gray and shades of yellow" (6). These soils are in close association with the Susquehanna soils. The drainage is well established, and the surface is well suited for cultivation.

The specimens are buried on the Meridian Waterworks Reservation, 2 miles east of Meridian, Miss. The surface soil consists of a light yellowish brown loamy sand or light sandy loam which extends to depth of about 10 inches. This is underlain by a yellowish red or reddish yellow clay which passes into a sandy clay loam or sandy loam at about 20 inches. This layer extends below 3 feet, and the specimens are set in it at this depth. A little mottling appears below 60 inches, but the texture is practically the same to a depth of 96 inches. This soil has previously been called Ruston fine sandy loam.

(7) Sharkey Clay (Soil No. 40).—"The soils of the Sharkey series occur as bottom lands subject to overflow from the Mississippi River" (1). The total area occupied by these soils is 4,698 square miles in Louisiana, Mississippi, Missouri, Tennessee, Indiana, and Arkansas, of which 4,337 square miles is Sharkey clay.

"The soils of the Sharkey series are of yellowish brown to drab color, with mottled rusty brown, bluish, drab, and yellowish subsoils of plastic consistency. In the slight depressions where water stands a good part of the year organic matter accumulations impart a nearly black color to the soil. The series contains a high percentage of clay in both soil and subsoil. The component material was mainly deposited some distance back from the river in quiet water. On drying, the soil cracks readily, forming small aggregates, and this condition gives rise to the name 'buckshot land.' The soils are poorly drained and subject to annual overflow" (1).

The specimens are buried near the roll-of-honor monument at Audubon Park in New Orleans. The soil here consists of 8 inches of dark brown clay loam full of organic matter and grass roots. Below this and extending to a depth of 30 inches is a stiff plastic gray clay mottled with rusty colored material but containing no definite hard iron concretions. The specimens are in the lower part of this layer. The deeper subsoil is a gray silt loam mottled with rusty brown. The rusty colored spots get lighter in color with increasing depth and practically disappear at 60 inches.

The topography is very gently undulating; both surface and internal drainage is poor. The water table is usually at about 6 feet. The soil supports a rather heavy growth of grasses. This soil has previously been called clay.

(8) St. Johns Fine Sand (Soil No. 37).—The soils of the St. Johns series "are extensive in the Florida flatwoods and are found all the way along the coast to east-central New Jersey" (2). The area of this series is 629 square miles in the States of New Jersey, Delaware, Maryland, North Carolina, South Carolina, and Florida. Of this 485 square miles is St. Johns fine sand.

"The soil is black with a high content of organic matter and having a subsurface layer of gray sand. The subsoil is like that of the Leon soils, having a compact layer of brown sand locally called 'hardpan' resembling coffee grounds, this often passing down into lighter colored material. In places this hardpan is consolidated in the first 1 or 2 inches. The St. Johns differs from Leon series in that the latter has light colored surface soils, and from the Portsmouth in that the latter does not have the brown 'hardpan' subsoil layer. These soils occur in wet flats, such as are commonly occupied by the Portsmouth soils" (2).

The specimens are buried in this soil in the southwest corner of the Jacksonville Gas Works property at the foot of Church Street, Jacksonville, Fla. The soil at this location consists of a dark gray or black fine sand which extends to a depth of about 2 inches where it begins to merge into a yellow layer which has a distinct lower boundary at 10 inches. It contains a few very hard round black iron concretions about one-eighth inch in diameter that are surrounded by reddish brown sand. This is underlain by light gray fine sand to a depth of 28 inches. Below this and extending to 36 inches is a dark brown rather compact fine sand or loamy fine sand in which the specimens are placed at a depth of 30 inches. Below this and extending to 60 inches is a pale yellow fine sand which is saturated with water. The topography is flat and drainage is poor. This soil has previously been called St. Johns sand.

(9) Susquehanna Clay (Soil No. 42).—"The soils of the Susquehanna series are developed most extensively in the higher portions of the coastal plain from the vicinity of Chesapeake Bay to central Texas" (1). The area of this series is 11,519 square miles in the States of Maryland, Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Texas, Oklahoma, and Arkansas. Of this area 1,956 square miles is Susquehanna clay.

"The fine sandy loam and clay are the principal types. These are grayish (in the sandy types) to red (in the clay), with stiff, plastic, red heavy clay subsoils, which become mottled in the lower part with gray or bluish gray, red and yellow. Often the mottling begins just beneath the soil. This layer extends to from 60 to 72 inches; the mottling is usually red in the upper and light gray in the lower part. Below this is the parent material which consists of alternating layers of light gray or bluish gray clay and brownish yellow fine sandy material. The Susquehanna soils can easily be distinguished from the Orangeburg and Ruston soils, with which they are closely associated, by the stiff, mottled, impervious clay subsoil of the Susquehanna.

"The surface of these stiff lands is characteristically rolling to hilly, but there are many flat and undulating areas. There are numerous sections where the country is so deeply dissected and rolling that cultivation is impracticable or impossible. West of the Mississippi River the topography is usually more subdued, and much of the land is cultivated. The surface drainage is nearly everywhere good; the stiff clay subsoil is rather impervious to movement of moisture and air" (1).

The specimens are buried near the upper end of the reservoir of the Meridian Water Department, about 2 miles east of Meridian, Miss. In this location the surface soil to a depth of 5 inches consists of a reddish brown clay. From 5 to 84 inches is a mottled red, yellow, and gray, very hard compact clay with a layer of silt loam between 45 and 56 inches. The trench is on a rather steep slope that had been terraced and cultivated. The top soil has been eroded away. The specimens are placed at a depth of 30 inches.

(d) SOILS OF GROUP IV

"The soils of Group IV have been developed under a grass cover while those of the other groups previously described have been developed under a timber cover. There are other differences, but they are relatively unimportant or arise as a natural consequence of the conditions of development. They will not be discussed here.

"These soils have, in general, a profile very much like that of Group II, with the exception that the top horizon is black or very dark in color. In the regions occupied by Groups I, II, and III there are dark-colored soils, but they are all imperfectly developed soils, either because of excessive moisture or because of highly calcareous marls as parent or source materials.

"The fully or maturely developed soils of Group IV are all dark in color. There are dark colored, immature soils associated with them, but there is no such difference in color in such cases as in the other groups so far described" (5).

The soil series of this group in which specimens are buried are Bell clay, Hempstead silt loam, Houston black clay, Marshall silt loam, Muscatine silt loam, Summit silt loam, and Wabash silt loam. Of these soils the Muscatine and Wabash are not fully matured because of their poor drainage.

(1) Bell Clay (Soil No. 2).—The Bell series is of limited extent and distribution, it being found only in rather small areas in close association with the Houston and Sumter.

The soils of the Bell series are black limy soils that occur on second bottoms. They are alluvial soils, the soil material having been carried by streams running through the black prairie limy soils of Texas, southern Oklahoma, Alabama, and Mississippi. Typically the Bell clay has a surface soil 6 to 8 inches in thickness of a dark brown to almost black color and a clay texture. The subsoil is a gray to pale yellow, sticky, plastic clay, mottled with yellow. At depths of from 15 to 18 inches this clay changes in color to a drab, or is mottled with bluish gray, yellow, and brown. The soil is sticky when wet, but crumbly and friable when dry, and is generally calcareous.

The specimens are buried on Sycamore Street near its intersection with Fitzhugh Street in Dallas, Tex. The surface soil to a depth of about 10 inches consists of a black to dark brown silty clay. The subsoil is a black clay and extends below 40 inches at which depth the specimens were placed. No definitely residual material was discovered within 40 inches. Small rounded quartzite gravel and lime concretions was found disseminated through the subsoil. The topography is practically flat, but the place is not subject to overflow.

(2) HEMPSTEAD SILT LOAM (SOIL NO. 14).—"The Hempstead soils are dark brown prairie soils. The subsoils are yellow to reddish yellow in color and are usually somewhat heavier than the soils. The subsoils rest on gravel or sand beds at about 2 to 6 feet from the surface. The gravel and sand is mainly of crystalline rock and sandstone origin. The topography is essentially level, the only relief consisting of dry stream channels which traverse the area of these soils. They are derived from the weathering of glacial outwash material" (1). The natural drainage is fair, and the internal drainage is not excessive on account of the gravel substratum. These soils differ from the Merrimac only in their darker color. The specimens are buried on the University farm just north of Larpenter Avenue, approximately ⅛ mile west of Snelling Avenue at St. Paul, Minn. At this place the surface soil to a depth of about 10 inches is a dark brown silt loam. This is underlain by a layer of gray sand. The specimens are in a light brown sandy loam at a depth of 5 feet.

(3) HOUSTON BLACK CLAY (SOIL NO. 15).—The soils of the Houston series are included in "the ashy brown and black prairie limy lands of the black prairie belt of central Alabama and northeast Mississippi and of the much larger areas constituting the black waxy belt of Texas. Small detached bodies occur in other parts of Texas and in southern Oklahoma, southwestern Arkansas, and central Louisiana. The area of this series is 5,860 square miles in the States of Texas, Alabama, Mississippi, Oklahoma, and Arkansas. Of this area 3,040 square miles is Houston black clay.

"The main types are clay and black clay, with considerable areas ranging to the texture of a loam. The clay is a rather dark-gray to black soil in the surface, passing at depths of about 5 to 15 inches into yellowish brown or greenish yellow plastic heavy clay. At from 3 feet for the clay and deeper depths for the black clay the subsoil contains enough whitish, chalky, limy material to make the clay distinctly friable. On drying, the surface, especially of eroded areas, assumes an ashy gray color that gives rise to the local name 'ash-prairie' and 'gray prairie.' The black clay is black or nearly black at the surface, but usually passes into dark brown or yellowish clay in the lower subsoil, often containing whitish, chalky, lime material. In places, especially in swales along the lower slopes, the black material extends to a depth of 3 feet with very little change. The typical soils are highly calcareous. These soils are derived from the underlying lime beds, consisting mainly of whitish and bluish soft chalky limestone.

"The Houston soils occupy undulating to gently rolling country, have good drainage, and are nearly all in cultivation. In places the virgin soil is characterized by a hummocky surface, referred to as 'hog wallow land.' " (2).

The specimens are buried near the bottom of a broad swale in the alley north of Dewey Place between Gillispie and Kendall Streets in San Antonio, Tex. The soil to a depth of about 36 inches, which is the depth at which the specimens are placed, consists of black clay with no appreciable change. Small fragments of lime are found through the section, and the soil is slightly calcareous.

(4) Marshall Silt Loam (Soil No. 21).—The area mapped up to January 1, 1922, of this series is 14,890 square miles, of which 13,958 square miles is silt loam.

"The surfaces oil of the Marshall silt loam consists of a dark brown, chocolate-brown, or almost black silt loam, which is evidently rich in organic matter. The surface soil varies in depth from 7 to 15 inches where it grades into a lighter colored silty loam or silty clay. This same class of material extends from 6 or 8 to 20 or 30 feet or even more where the deposits are fully developed. Both surface soil and subsoil are unusually free from gravel of any description, and even the coarser grades of sand are almost entirely lacking. Not infrequently, however, there are found within the subsoil concretions and accumulations of lime carbonate, and occasionally the limy remains of shells principally of land forms or oganic life. The Marshall silt loam is one of several important soil types derived directly from the weathering of the loess mantle which was distributed over the central part of the Mississippi drainage system by the wind.

"The Marshall series is distinguished from the Miami series, which is lighter colored and derived from the weathering of glacial till, and also from the black soils of the Carrington series, which resemble it in color, but have also been derived principally from ice-laid materials. It is distinguished from the soils of the Knox series, which also owe their origin to the surface layer of loess in that the latter have light-colored surface soils and are found within the timbered areas as contrasted with the prairie areas in which the darker Marshall soils occur.

"Throughout its entire extent the Marshall silt loam is marked by nearly level, slightly undulating, or gently rolling surface topography" (12).

The specimens are buried alongside of the road one-half mile west of Raytown at a depth of 3 feet. The soil in which the pipes are placed is a light-brown silt loam. Raytown is about 10 miles southeast of Kansas City.

(5) MUSCATINE SILT LOAM (SOIL NO. 30).—The soils of the Muscatine series occur principally in eastern Iowa and western Illinois, with a few areas in Kansas and Missouri. The total area of this series is 951 square miles, of which 945 is silt loam. "The soils of the Muscatine series are dark brown to black, overlying light gray, grayish brown to yellowish brown, and gray mottled friable upper subsoils. The latter have usually more gray than the deeper subsoils and are usually not distinctly mottled. At 18 to 24 inches the subsoil becomes slightly more compact, this compactness increasing gradually downward to 3 feet and deeper in some cases. With increase in compactness, mottling begins to appear, the colors being brown to yellowish brown and gray, though the mottling is strong only in rare cases. The subsoil is moderately friable and is neutral to acid, no effervescence being obtainable. Lime concretions rarely if ever occur.

"The Muscatine soils occupy nearly level to smooth rolling uplands originally in an open prairie condition, and they are derived from the loess. They differ from Marshall soils in that they lack lime which often occurs in the Marshall" (6).

The specimens are buried on the Tri-City Fair Grounds, inside the inclosure formed by the race track at Davenport, Iowa, at a depth of 3 feet.

(6) SUMMIT SILT LOAM (SOIL NO. 41).—The soils of the Summit series are found most extensively in the eastern part of the Great Plains and are valuable agricultural soils. The area of this type is 3,266 square miles in the States of Missouri, Kansas, Nebraska, and Oklahoma, of which 1,633 square miles is silt loam.

The Summit soils are residual on calcareous shales and sandstones or on shale and sandstone interbedded with limestone. The surface soil is typically of a dark gray or black color due to its rather high content of organic matter. It often contains considerable fine quartz sand. The subsoil is a mottled yellow, gray, and brown silty clay. Drainage is usually well established. These soils are found on smooth and nearly flat to sharply rolling prairies, but are usually confined to narrow ridges.

The specimens are buried at the county farm about 14 miles southeast of Kansas City, Mo. The soil in which specimens are placed, at a depth of 3 feet, is a mottled grayish brown and brown heavy silt loam which is noncalcareous.

(7) WABASH SILT LOAM (SOIL NO. 44).—The Wabash soils "are developed typically in the first bottoms of streams of the central prairie States, the material being derived principally from the loessial and associated soils of this region" (1). The area, mapped up to 1922, of this series is 8,468 square miles in the States of North Dakota, Minnesota, Wisconsin, Michigan, Ohio, Indiana, Iowa, Nebraska, Kansas, Missouri, Illinois, Arkansas, and Oklahoma. Of this area 5,465 square miles is silt loam.

"This series includes soils of dark brown to black color and high organic matter content and slightly lighter gray or drab subsoils" (1). In its virgin condition this series is found in river bottoms, and the topography is usually flat. The specimens are buried on the grounds of the Lakoma Country Club near the corner of Lakeview and Seventy-fifth Streets at Omaha, Nebr. The soil here consists of an almost black silt loam containing a large amount of organic matter which extends below 30 inches at which depth the specimens are placed.

(e) SOILS OF GROUP V

The soils of Group V are developed under moderate conditions of temperature and precipitation, the native vegetation being principally grasses.

"These soils are dark in color like those of Group IV, but they differ from the latter mainly in the presence in the lower part of the true soil layer of a layer of lime carbonate accumulation. The parent rock or source material may or may not have a great deal of lime carbonate. There is always, in the mature soil a layer of accumulated lime carbonate, regardless of the character of the parent rock, provided that it is something else than pure quartz sand" (5). The only soil which falls in this group in which specimens are buried is Fargo clay loam.

(1) FARGO CLAY LOAM (SOIL NO. 8).—"The type owes its origin to the extensive deposition of fine-grained lake sediments in the bed of old glacial lakes" (16). The area of this type mapped up to January 1, 1922, is 4,996 square miles, of which 1,396 square miles is clay loam.

"The surface soil of the Fargo clay loam is a dark gray to black clay loam containing a perceptibly large quantity of organic matter. This surface soil has a depth varying from 12 to 24 inches in the various areas where the type is encountered. In the slight depressions found within the type the surface material is often mucky and of an intense black color to a depth of 4 to 8 inches. This is underlain by a heavy dark gray silty clay which not infrequently has a definitely stratified structure and extends to from 16 to 24 inches.

The next lower layer is the zone of lime accumulation. It is an olive gray clay containing streaks and concretions of lime. The entire soil material of this layer is calcareous. Dark streaks and tongues which extend downward into this layer are caused by the filling of cracks by the surface layer. The next lower layer is the parent material, a grayish yellow clay or silty clay loam. This material is calcareous, but the lime is not so highly concentrated as is the layer above.

"The characteristically calcareous subsoil distinguishes the Fargo clay loam from the black soils of the Clyde series, while the Fargo clay loam is distinguished from the dark-colored soils of the Washburn series in that the latter contain considerable quantities of stone, while the soils of the Benoit series are underlain by a substratum of gravel. The Fargo clay loam is distinguishable from the Carrington black clay loam through the fact that it occupies the beds of extinct glacial lakes of some size, while the Carrington black clay loam consists of an accumulation of dark-colored surface material overlying glacial till which frequently constitutes the subsoil of that type. The topography of the Fargo clay loam is uniformly flat with a very gentle slope and the drainage is poor" (16).

The specimens are buried on the grounds of the North Dakota Agricultural College at Fargo, N. Dak. The surface soil at this location is black clay loam containing considerable organic matter and extending to a depth of about 1 foot. Below this and extending below the specimens which are at a depth of 4 feet is grayish, compact, calcareous clay. The topography is flat.

(f) SOILS OF GROUP VI

The soils of this group differ from those of Group V in having a dark brown surface layer rather than a black or very dark brown surface. In other respects they are much alike. The layer of accumulated lime carbonate lies a little nearer the surface as a rule than in the soils of Group V.

The soils at Casper and Denver probably are in this group, although the soils at neither of these places are typical of this group.

(1) Soil at Casper, Wyo. (No. 45).—Since no detailed maps have been made anywhere in the vicinity of Casper, Wyo., it is questionable whether this soil will fit in any previously recognized soil series. At this stage it therefore seems best to describe the soil where the samples were buried and wait until more information is obtained of this region before a classification is attempted. The following is a description of the soil in which the specimens were buried, written by F. A. Hayes, of the Bureau of Soils.

> The surface soil varies greatly in texture, ranging from almost pure sand to heavy silt loam. It has an average depth of about 6 inches. The color is prevailingly light, ranging from gray to light grayish brown. The soil contains only a small percentage of organic matter.

The upper subsoil to an average depth of 20 inches is a heavy, compact gritty clay. It is slightly darker than the surface horizon, ranging in color from brown to grayish brown. The material is plastic and waxy when wet but becomes hard and tough upon drying.

Below 20 inches the subsoil changes abruptly to a light gray sandy clay. This horizon ranges in thickness from 7 to 10 inches. It is slightly more friable than the upper subsoil, probably due to its higher sand content. Below an average depth of 30 inches the sand content decreases, the color becomes slightly darker, and the material is more compact than in the intermediate horizon. It does not, however, attain the extremely compact structure of the upper subsoil. This layer extends to below 4 feet.

The type is highly alkaline, and white streaks and splotches of concentrated salts occur abundantly throughout the soil profile except in the immediate surface soil of the more sandy portions. The greatest concentration is in the intermediate subsoil horizon. The organic matter content gradually decreases with depth and is seldom noticeable below 20 inches.

The type has weathered under conditions of restricted drainage from the disintegrated limy sandstones and shales of late cretaceous or early Tertiary age, chiefly from the Teapot sandstone. The heavy compact nature of the subsoil is probably due to a downward leaching of the finer surface particles and their concentration in the lower strata. Surface wash from the surrounding higher levels had also contributed to its formation.

The topography is flat. The type occupies a depressional basin-like area in the surrounding plain. It has no surface drainage, and the compact subsoil prevents free underdrainage. In the lower portions of the type water stands on the surface the greater part of the year.

Owing to the high alkali content, poor drainage, and to the hardpan-like structure of its upper subsoil, the type is of little agricultural importance and is all included in pasture land. The native vegetation consists of sagebrush, salt grasses, and small amounts of grama grass. There are numerous small patches with little or no vegetation.

The test plot in which the specimens are buried is about 9 miles north of Casper, Wyo. It lies in the SW. ¼ of the SE. ¼ of sec. 33, T. 35 N., R. 79 W.

The specimens are at a depth of about 30 inches.

(2) SOIL AT DENVER (No. 46).—A detailed soil map has not been made of this region, and so little is known about the soils that it is impossible at this time to identify them as members of established series.

The specimens are buried near the intersection of California and Twenty-fourth Streets in Denver. The soil profile to a depth of 5 feet, at which depth the specimens are placed, consists of a brown or grayish brown sandy loam, which grows a little lighter in color with increasing depth. Fragments of rounded quartz, quartzite, and other rocks show that the parent material is derived from a wide variety of sources. It has no doubt been carried to its present position by streams from the Rocky Mountains. Both soil and subsoil are noncalcareous.

(g) SOILS OF GROUP VII

The soils of Group VII are developed in desert regions which are characterized by wide temperature ranges, low humidity, and little precipitation. These soils are, in general, light colored, low in humus, and are calcareous throughout the entire profile. The lower horizon often contains an accumulation of lime. The soil profile has a typical structure, which consists usually of horizontal layers or plates below the surface mulch, then a layer having a nut or pea structure, and below this a columnar horizon which often extends to depths of 10 or 15 feet.

The only soil which falls in this group is the soil at Salt Lake City (No. 47), and this is not a typical desert soil for it is now being irrigated.

In Salt Lake City the specimens are buried near the southeast corner of Nibley Park, on the west side of East Seventh Street, between South Twenty-seventh and South Twenty-eighth Streets. The surface soil is a grayish brown heavy silt loam on clay loam without important change to a depth of about 2 feet. Here a light gray compact clay or clay loam was encountered. This extends below the depth at which the specimens are placed, which is about 3 feet. Both soil and subsoil are highly calcareous. The topography is almost flat. The soil supports a heavy growth of weeds and grasses.

(h) THE SOILS OF THE PACIFIC COAST

The large area along the Pacific coast and in the intermountain region has not been placed in any of the great soil groups. This region is mountainous and rough, and big changes in climate occur between points not far removed from each other. For this reason this region is made up of small intermingled areas which fall in all of the previously considered groups, and a separation of these areas into their respective groups is not attempted. The soils of the Pacific coast in which specimens are buried are Dublin clay adobe, Everett gravelly sandy loam, Hanford fine sandy loam, Hanford very fine sandy loam, Merced silt loam, Montezuma clay adobe and Ramona loam. Of these the soils of the Hanford and Merced series are rather poorly drained and have not yet reached a stage of maturity.

(1) DUBLIN CLAY ADOBE (SOIL NO. 5).—The soils of the Dublin series are found only in the State of California, the total area that has been mapped being 96 square miles, of which 29 square miles is of the clay adobe class.

The following is taken from a memorandum of M. H. Lapham, of the Bureau of Soils, concerning the locality in which the specimens are buried.

> The Dublin soils consist in their typical development of recent alluvial soils in which the surface soils are very dark dull brownish gray or dark gray to black color, usually black under moist field conditions; of moderately high organic content, and underlain by upper subsoils of similar color, or which are somewhat feebly mottled with brown and drab and with occasional yellowish or reddish iron stains, resting upon a deeper subsoil or substratum of dull brown or yellowish brown color in which occasionally occur yellowish brown or reddish

iron stains or specks of iron oxides. The surface and upper subsoil materials are usually well leached of lime and rarely effervesce with dilute hydrochloric acid. The deeper lighter colored subsoil, however, frequently contains grayish mottlings and soft nodular or concretionary accumulations of lime which effervesce strongly. These soils are derived mainly from the shale and sandstone formations of the region, the materials having been disturbed and transported by streams, usually of variable flow or intermittent character.

These soils (1) occupy level to gently rolling alluvial slopes, fans, and alluvial valleys traversed by minor streams. There is nearly always a perceptible slope, and drainage is in most cases well established, although some flat areas would be improved by the use of tile. Alkali salts are occasionally noted over small areas. The soils are treeless or support occasional valley oaks, willow, or sycamore.

The site is located in the southwestern part of the city of Richmond, north of and adjoining the A. T. & S. F. R. R. right of way, about ½ mile from tidewater at Richmond Harbor. The surface of the tract is smooth, flat, and only a few feet above tide level.

In the site selected for this study the soil is of silty clay or clay texture, is sticky when wet, and during the dry summer season the typical adobe exhibiting the usual surface checks and cracks is well developed. It is recognized as representing the clay adobe type of the Dublin series of soils, though it is, perhaps, not quite as heavy in texture or as dark in color as is the material of this soil type elsewhere where occurring in its most pronounced and extreme development.

In profile, also, the material appears to have been somewhat modified since deposition, the upper subsoil being slightly compacted, and the deeper subsoil having a rather pronounced development of lime accumulation, occurring as conspicuous nodules and thin horizons, seams or lenses of lime concentration which are partially cemented and which approach in physical character a relatively soft lime cemented hardpan. In this development of the subsoil the material approaches in profile the related and associated soils of the Montezuma series which represent an older and modified development of the Dublin materials.

Like most of the lower flatter areas of the Dublin soils adjacent to tide level, the material also approaches somewhat in character of profile the material of salt water tide marsh deposits, and it is possible that the materials of the lower part of the soil section may have been modified or reworked by tidal currents and by deposition of lime and other soluble minerals occurring in the brackish tidal sloughs and waters.

While, however, the soil type in this locality departs from the typical Dublin soils in these charcteristics, it is believed to be representative of soil conditions occurring extensively in the local alluvial valleys and upon the lower and flatter slopes of the alluvial fans adjacent to San Francisco Bay and its various indentations.

While the past season has been wet and late rains have fallen, so that the water is standing in surface drainage ditches within a few feet of the trenches in which the sections of pipe are buried, the soil removed from the trenches was not saturated and was only in favorably moist condition, and 6-foot borings with soil auger indicated the water table to be below this depth at this date.

In excavating for the trenches a section of old iron pipe, which had been in place many years, was removed and gave evidence of having been badly corroded.

The lower or deeper, lighter colored calcareous subsoil was not encountered in the trenches, this material occurring at a depth of 4 to 6 inches below the bottom of the trenches which were approximately 30 inches in depth.

The soil profile in the trench consists of a surface soil extending to 10 inches of a dark dull gray or drab clay of adobe structure, sticky when wet. It contains numerous plant and grass roots and an appreciable amount of fine gritty material and gravel fragments, apparently of shale or chert. It is without well developed structural horizons.

This is underlain to a depth of 36 inches by a brownish gray or drab friable clay which is sticky when wet. It is slightly more compact than the surface soil, but without development of structural horizons, and it stands up well in the trench sides. It is somewhat mottled irregularly with brown and with dull slaty gray or black streaks, the general color being slightly lighter and more brownish than the surface soil. It contains frequent small spherical shotlike iron concretions of black or bluish black color, ranging in size from that of a small pinhead to small buckshot. When moist, it breaks apart by irregular fracture exposing irregular smooth surfaces of shiny gelatinouslike appearance. It is probably high in colloidal clay.

Beginning at 36 inches the soil grades into a yellowish brown silty clay material, which is strongly yellowish brown or brown below the first 4 inches with slight light grayish mottlings of lime concentration. This horizon is mildly calcareous and is the upper limit of lime accumulation. Below 48 inches is a yellowish brown compact clay containing many light grayish fragments of lime carbonate nodules which are localized in thin seams or layers, the material being partially cemented but can be penetrated with a soil auger. It is said to become very hard in the dry season and appears to approach a development of lime carbonate hardpan. These calcareous fragments effervesce vigorously and entirely disappear in dilute hydrochloric acid. The soil material itself where the nodular lime accumulations are absent is mildly calcareous. Below 60 inches the soil is slightly more compact or cemented, and the small specks and concretions of iron oxides and light-colored lime nodules are somewhat more pronounced.

This soil has previously been called Dublin clay loam.

(2) EVERETT GRAVELLY SANDY LOAM (SOIL NO. 6).—The soils of the Everett series have been mapped only in western Washington, the total area being 4,334 square miles, of which 2,111 square miles consists of gravelly sandy loam.

"The soils of the Everett series range from light brown to light reddish brown in color and are of light texture and porous structure. Large amounts of organic matter often occur in the immediate surface, giving it a dark color and loamy texture. In some members of the series small, spherical, iron-cemented pebbles are conspicuous. The subsoils are light brown to gray and usually gravelly and porous, the parent material consisting mainly of sands and gravel, with compact silts and clays sometimes occurring in the deeper portions of the deposits. The materials are derived both from basaltic and crystalline rocks. The series supports a heavy growth of fir, cedar, spruce, and hemlock and occupies humid to subhumid areas of sloping to undulating, plateau-like surface and hilly to mountainous areas. Morainic ridges, kames, and kettle holes are of frequent occurrence. Erosion is more or less active, and some of the areas are marked by surface or embedded bowlders and occasional gravel outcrops. Drainage is usually excessive, and the soils are subject to drought" (1).

The specimens are buried about one-quarter mile west of the west arm of Swan Lake, which is approximately 16 miles southeast of Seattle, Wash. The surface soil consists of a light brown gravelly sandy loam containing practically no organic matter. The subsoil is a light gray or grayish brown compact sandy loam containing considerable gravel and small fragments of firmly cemented soil material. This is the horizon in which the specimens are placed at a depth of 3 feet. Both soil and subsoil are noncalcareous. The trench is located on a gentle slope.

(3) HANFORD VERY FINE SANDY LOAM (SOIL NO. 13) AND HANFORD FINE SANDY LOAM (SOIL NO. 12).—The soils of the Hanford series are found only in California and Oregon. The total area of this series, which has been mapped in detail, is 1,597 square miles, of which 552 square miles is fine sandy loam.

"The soils of the Hanford series are usually of light grayish brown or buff to light brown color, the heavier members carrying considerable organic matter and becoming dark gray to nearly black when wet. They are micaceous, smooth to the touch, friable, and of porous structure, and generally free from gravel and bowlders. They range in depth to 6 feet or more. They are sometimes underlain by variable interstratified alluvial deposits at less than 6 feet. The soil material represents recent alluvial stream deposits, derived mainly from granitic rocks with a relatively unimportant admixture of other material. The soils occur usually as elongated bodies extending in the direction of stream channels and occupying flood plains, adjacent lower stream terraces and alluvial valley plains. The surface is generally level to gently sloping but is sometimes marked by slight ridges or undulations or cut by sloughs or stream channels often bordered by willows and other trees. Such stream channels often appear as partially filled remnants of older stream courses or as intermittent streams which carry water only in times of flood and merge into sandy washes. The lower lying bodies or those occurring adjacent to stream courses are poorly drained or subject to overflow when not protected by levees. These soils are occasionally subject to accumulations of alkali salts" (1).

The specimens are buried in Hanford very fine sandy loam in the alley west of Oleander Avenue, south of Verdi Street in Bakersfield, Calif. The large sets which were buried in 1924 were placed along the Taft-Bakersfield Highway, 8 miles from Bakersfield. The soil in Bakersfield consists of a light brown very fine sandy loam which extends to a depth of 24 inches. Here a brown or dark brown very fine sandy loam is encountered. This extends below the depth at which the specimens are placed which is about 30 inches. The topography is practically flat. The soil contains sufficient alkali in the carbonate form to give a decidedly alkaline reaction to phenolphthalein. This soil has previously been called black alkali in Hanford.

The specimens are buried in Hanford fine sandy loam on the Fruitvale Road west of Magnolia Avenue in eastern Los Angeles.

The soil here consists of a light brown fine sandy loam with a grayish cast which passes into a very fine sandy loam of the same color at about 28 inches. The specimens are at a depth of 24 inches. The topography is practically flat. This soil differs from the soil at Bakersfield in that it does not contain soluble carbonates or "black alkali" in appreciable amount and it effervesces only very slightly with hydrochloric acid.

(4) MERCED SILT LOAM (SOIL NO. 23).—The soils of the Merced series have been mapped in the Fresno, Modesto, and Merced areas in California. The total area is 182 square miles, of which 80 square miles is silt loam.

"These soils are of dark brown to dark gray or drab color, with light brown, gray, or drab subsoils. Both soil and subsoil are somewhat micaceous. The series is of alluvial origin and derived mainly from granitic or related crystalline rocks. It occupies river flood plains and lower terraces, usually of flat surface. The soils are frequently poorly drained and subject to overflow during times of high water and often contain injurious amounts of alkali salts. Sloughs and remnants of former stream channels are of frequent occurrence" (6).

The specimens are buried at the Midway steam plant of the San Joaquin Light & Power Corporation at Buttonwillow, Calif., which is 24 miles west and 2 miles north of Bakersfield. The soil consists of a black silt loam of 10 inches depth underlain by a gray clay loam which extends to 24 inches. From 24 to 30 inches is a gray sandy loam, and this is the horizon in which the specimens are placed. The topography is flat, the drainage is poor, and the soil conditions indicate a high concentration of alkali. This soil has previously been called White Alkali soil.

(5) MONTEZUMA CLAY ADOBE (SOIL NO. 28).—The soils of the Montezuma series are confined to central and southern California, the total area mapped in detail being 58 square miles, of which 54 square miles is clay adobe.

"The soils of the Montezuma series are gray to black in color, sometimes exhibiting quite uniformly a brownish tint in freshly plowed fields when moist. They are generally of compact structure, and the heavier members are inclined to puddle when wet and to bake and assume an adobe structure on drying, but when in a favorable condition as regards moisture content are friable under cultivation. The organic matter content is generally moderate to high. The subsoils, which generally occur at a depth of about 36 inches, are of yellowish brown to light brown color and of calcareous character and of moderately heavy to heavy texture and compact structure. Calcareous nodules or lenses or intermittent hardpan-like layers and crusts occur frequently in the subsoil material. The members of this series are derived from weathering in place of unconsolidated old coastal plain or valley filling material, consisting mainly of light brown to light gray calcareous clays and other fine sedimentary deposits representing in character of minerals a variety of igneous, metamorphic, and sedimentary rocks. The parent sedimentary deposits giving rise to the soils of this series are in places somewhat indurated and frequently exhibit a joint structure, but at other times are distinctly stratified.

"The surface varies from gently sloping or undulating to rolling and sometimes quite hilly. The contours of the elevations are, however, rounded and only infrequently of sufficient steepness of slope as to interfere seriously with cultivation. Gravel is of infrequent occurrence. Surface drainage is well established to excessive, but the soils are, except for local occurrence of hardpan, deep, retentive of moisture, and productive.

"The soils of the Montezuma series are in features of origin, mode of formation, general character, and topography related to those of the Antioch series from which they are distinguished by their darker color.

"The clay adobe is very sticky when wet and checks extensively when exposed to periods of drought. Surface drainage is always good, but subdrainage is restricted and the soil and subsoil are retentive of moisture" (6). The specimens are buried in east San Diego, Calif., in the alley north of El Cajon Boulevard between Copeland and Van Dyke Streets in a brown, heavy clay adobe at a depth of 24 inches.

(6) Ramona Loam (Soil No. 35).—These soils are found only in southern California, the total area that has been mapped being 342 square miles, of which 182 square miles is Ramona loam.

"The Ramona series is characterized by brown to dark brown soils. Phase variations of grayish brown or slightly reddish brown are included. When wet, the soils frequently have a reddish cast in the field. The subsoils are brown, dark brown, and in places reddish brown. They are nearly always compact and are heavier in texture than the surface material. The series is usually low in organic matter and generally contains a small amount of mica. The substratum is usually not quite so heavy in texture nor as red in color as the subsoil, but it is quite compact in most places. The series is derived from weathered and altered waterlaid deposits, which consist principally of granites, gneiss, and quartz-bearing schistose, igneous, and metamorphosed igneous rocks. The material of this series of soils is not quite so highly oxidized nor are the subsoils as heavy generally as those of the Placentia series" (6).

The topography of the Ramona loam is typically gently sloping to undulating, but locally the surface may be steep and eroded or dissected by streams. Drainage is well developed.

The specimens are buried at the intersection of Valencia Street and Gleason Avenue in Los Angeles, Calif. The surface soil to a depth of 8 to 12 inches consists of a reddish brown loam to clay loam. This is underlain by a reddish brown clay loam which extends below 3 feet, which is the depth at which the specimens are placed.

(i) POORLY DRAINED SOILS

Specimens are buried in three soils which do not belong in any of the above-described groups. The ground-water table in two of these soils (tidal, marsh, and muck) is so near the surface that the soils have had no opportunity to develop a structure, and the third (peat) has not weathered sufficiently to be considered as a soil in a state of stability. The following is a description of these soils:

(1) MUCK (SOIL NO. 29).—Areas of muck are found distributed over the entire United States, especially along sluggish streams and in low, swampy places where the remains of growing plants have been partially preserved under water. These areas are small and widely scattered. Areas of either peat or muck or both have been mapped in 28 States. Muck may be defined as "a phase of surface peat material which occurs under topographic conditions permitting extensive weathering and the accumulation of large amounts of silt and clay" (9). It is a soil containing between 25 and 65 per cent of organic matter (4). The specimens are buried in parkway between West End Boulevard and the car track, opposite house No. 6929, which is the first house south of Walker Street, in New Orleans, La. The surface to varying depths consists of dark colored material of variable texture most of which is fill. Below this is a black, semifluid mass of well-decomposed muck which rests upon an almost solid mat of old cypress stumps and roots which are in an excellent state of preservation. The land here was originally a cypress swamp; the old stumps that can still be seen in places show that the growth was very dense and the trees were large. The substratum is a stiff, putty-like gray clay. The vegetation now consists of grasses and "tea weed" and a few ornamental shrubs. The specimens are at a depth of 24 inches, at which depth the soil is always saturated with water.

(2) PEAT (SOIL NO. 33).—Peat, like muck, is widely distributed as small scattered areas over the entire United States. Two large bodies of this material, one in north-central Minnesota and one in the Everglades of Florida, are perhaps the largest continuous bodies of a single soil anywhere in the United States. Peat differs from muck in that it has not reached such an advanced stage of decomposition as the latter. Peat deposits differ widely from each other, their nature being influenced by their method of deposition, the plants from which they are derived, and the climate under which they have weathered. A peat is defined as a soil containing 65 per cent or more

of organic matter (4). Peat beds vary from 8 or 10 inches to several feet in thickness.

The specimens are buried on the south side of Lincoln Avenue, about 700 feet west of Thirty-second Street, Milwaukee, Wis. W. J. Geib, of the Bureau of Soils, describes the soil profile at the location where specimens are buried in this soil as "a black, well-decomposed peat 30 to 36 inches deep where it rests on a drab or bluish plastic clay loam. The specimens are at a depth of 24 inches. The lower part of the section was saturated with water. The peat merges into Clyde loam, the line of separation being rather indefinite." A sample of this soil lost 42 per cent weight on ignition.

(3) TIDAL MARSH (SOIL NO. 43).—Areas of tidal marsh are developed along the Atlantic and Gulf coasts, the total area that has been mapped being 2,246 square miles. Areas of marshy land into which soluble salts from the higher surrounding lands have been carried, and which are of frequent occurrence in regions where alkali soils are found, are called salt marshes, as distinguished from tidal marshes which are found only along the seacoast. The marshy lands in the vicinity of river mouths, which are below high tide but which the salty ocean water does not reach, are called swamps, to distinguish them from tidal marshes.

The soil material of tidal marshes varies from dark, oozy sediments interspersed with coarse marsh grass roots to a yellowish or dark-colored clay, and at depths varying from 2 to 4 feet it rests upon a still darker colored clay. Calcareous nodules are sometimes present. The subsoil and the free water in the soil are charged with hydrogen sulphide. The vegetation consists almost entirely of salt grass in all places except Florida, where mangrove covers these areas. The topography is flat, and the soil is always saturated with water.

The specimens are buried on the grounds of the Bayway Refinery at Elizabeth, N. J., northeast of the salt-water pumping station and north of tanks 305 and 306. The place is surrounded on three sides by a tidal stream. The surface of the ground is always above high tide. The entire soil profile, and especially the surface foot, contains a large percentage of undecayed organic matter and has a black color when wet. The specimens are at a depth of 3 feet. Upon drying, the color changes to grayish brown. The soil contains hydrogen sulphide and a considerable amount of soluble salts, but no lime. The surface portion of the soil lost 20.7 per cent on ignition. This soil has previously been called salt marsh.

3. HYDROGEN ION CONCENTRATION, WATER-SOLUBLE SALT CONTENT, AND RESISTIVITIES OF SOILS UNDER TEST

Samples of the various soils were tested for acidity and soluble salts by J. G. Smith in the division of soil chemistry, Bureau of Soils. The total quantity of soluble salts present in a 1:5 water extract of the soil was determined with an electrical bridge, according to the method developed in the Bureau of Soils (20). The hydrogen ion concentration of the soil suspension was determined electrometrically with a hydrogen electrode, the procedure followed being essentially the same as that described by Gillespie and Hurst (21). These data are given in Table 2.

The hydrogen ion concentrations indicate the acid condition of the soils, and as given in Table 2 are expressed in pH values. The pH value $= \log \frac{1}{(H+)}$ where $(H+)$ = hydrogen ion concentration. Thus the pH value is reduced by 1 unit for every tenfold increase in hydrogen ion concentration. For pure water $(H+) = 10^{-7}$ and the pH value is therefore 7. If $(H+)$ is increased one hundredfold the pH value becomes 5, etc.

The 1926 hydrogen ion values were taken in the field with a colorimetric apparatus.

The soil resistance measurements (Table 3) were made on the soil in place in the trench wall by means of the McCollum earth current meter (19).

The resistance of a soil depends upon its moisture content, and the variations of the resistances of a given soil at different times can be partly accounted for in this way, although measurements taken at the same time in different parts of the same trench sometimes yield values differing by 50 per cent.

TABLE 2.—*pH values and soluble salts of soils*

Soil No.[1]	Upper horizon			Central horizon			Lower horizon		
	Depth	pH	Soluble salts	Depth	pH	Soluble salts	Depth	pH	Soluble salts
	Inches		*Per cent*	*Inches*		*Per cent*	*Inches*		*Per cent*
2	0–10	7.5	0.038	10–30	6.9	0.067	30–40	6.1	0.047
	0–6	7.3	.043	6–20	6.2	.025	20–30	5.7	.056
3	0–4	4.9	.014	4–28	4.9	.009	28–36	4.6	.009
4	0–15	4.6	.032	15–40	4.5	.012	---	---	---
5	0–10	6.0	.039	10–30	5.9	.044	---	---	---
	0–12	5.3	.021	12–24	5.2	.030	24–36	6.9	.052
	36–48	7.7	.150	48–60	8.4	.180	60–72	8.2	.174
6	0–10	5.8	.012	10–30	5.6	.007	30–36	5.8	.011
8	Top.	---	.330	Middle.	---	.350	Bottom.	---	.350
10	0–8	5.1	.027	10–30	4.8	.016	30–36	5.1	.009
11	0–9	5.8	.014	9–36	5.8	.010	---	---	---
12	0–28	7.1	.017	28–36	7.6	.023	---	---	---
13	0–8	10.2	.283	8–24	9.0	.342	24–30	8.2	.038
14	0–12	5.7	.055	12–24	5.5	.039	24–36	5.6	.034
15	0–10	7.8	.069	10–24	7.8	.093	24–36	8.0	.134
16	2–6	5.1	.008	6–12	4.6	.007	22–24	3.9	.007
17	2–8	3.4	.016	20–36	4.3	.016	---	---	---
18	0–12	7.9	.040	12–28	7.4	.043	28–48	7.3	.089
19	0–12	5.4	.008	12–24	4.9	.010	24–36	4.6	.008

[1] Names of soils in Table 3.

TABLE 2.—*pH values and soluble salts of soils*—Continued

Soil No.	Upper horizon			Central horizon			Lower horizon		
	Depth	pH	Soluble salts	Depth	pH	Soluble salts	Depth	pH	Soluble salts
	Inches		*Per cent*	*Inches*		*Per cent*	*Inches*		*Per cent*
21	0–6	7.8	0.056	10–30	5.4	0.014	30–40	5.5	0.013
23	0–10	8.2	1.316	10–24	9.2	2.100	24–30	9.2	1.338
24	2–8	4.6	.015	10–24	5.3	.009	30–36	5.3	.007
25	0–6	7.1	.022	8–30	7.9	.035	30–48	7.3	.036
29	0–10	5.5	.063	10–20	3.5	.073	20–30	4.4	.166
31	0–2	5.8	.016	2–8	6.4	.011	8–24	6.8	.011
33	0–36	7.8	.192	----------	----------	----------	----------	----------	----------
34	0–8	7.4	.032	8–28	7.0	.018	----------	----------	----------
35	0–8	7.4	.064	8–26	7.2	.061	26–36	7.3	.053
36	0–10	6.1	.008	10–20	4.9	.008	20–30	5.3	.007
37	0–6	4.9	.007	6–24	5.5	.007	24–36	5.3	.024
38	0–4	4.4	.007	4–36	4.8	.008	----------	----------	----------
39	0–14	5.4	.014	14–32	5.9	.011	32–36	6.4	.014
40	0–8	5.1	.020	8–20	5.9	.019	20–30	6.1	.016
41	0–6	7.6	.042	10–30	5.2	.020	----------	----------	----------
42	0–5	4.6	.007	5–20	4.5	.007	20–30	4.1	.007
44	0–10	5.5	.016	10–28	6.0	.048	28–40	8.3	.025
45	Top.	----------	.030	Middle.	----------	.140	Bottom.	----------	1.260
46	0–6	7.5	.051	6–18	6.5	.068	18–24	8.1	.088
47	0–6	8.2	.088	10–24	8.1	.197	24–36	8.0	.097

TABLE 3.—*Field measurements of soil resistivity* [1]

Soil No.	Soil	Year		
		1922	1923	1926
1	Allis silt loam	5,180	3,350	----------
2	Bell clay	----------	----------	892
3	Cecil clay loam	57,000	----------	85,300
4	Chester loam	10,700	----------	14,600
5	Dublin clay adobe	1,060	----------	626
6	Everett gravelly sandy loam	534,000	----------	502,000
7	Fairmount silt loam	----------	1,410	1,890
8	Fargo clay loam	316	490	410
9	Genesee silt loam	3,300	2,690	2,500
10	Gloucester sandy loam	99,000	----------	84,600
11	Hagerstown loam	44,500	----------	22,900
12	Hanford fine sandy loam	20,200	----------	5,500
13	Hanford very fine sandy loam	6,020	----------	8,640
14	Hempstead silt loam	----------	24,200	33,000
15	Houston black clay	306	----------	337
16	Kalmia fine sandy loam	20,900	----------	40,300
17	Keyport loam	----------	----------	13,600
18	Knox silt loam	----------	1,990	2,400
19	Lindley silt loam	1,830	2,400	1,840
20	Mahoning silt loam	3,880	3,610	4,800
21	Marshall silt loam	1,840	2,780	2,890
22	Memphis silt loam	----------	----------	7,000
23	Merced silt loam	390	----------	370
24	Merrimac gravelly sandy loam	----------	500,000	792,000
25	Miami clay loam	12,600	3,320	4,690
26	Miami silt loam	16,500	6,880	5,040
27	Miller clay	----------	----------	630
28	Montezuma clay adobe	----------	----------	528
29	Muck	1,900	----------	1,670
30	Muscatine silt loam	860	----------	1,210
31	Norfolk sand	----------	----------	119,000
32	Ontario loam	10,000	8,000	6,000
33	Peat	1,570	----------	----------
34	Penn silt loam	4,970	----------	4,140
35	Ramona loam	2,000	----------	----------

[1] The unit used is the ohm-centimeter.

TABLE 3.—*Field measurements of soil resistivity*—Continued

Soil No.	Soil	Year		
		1922	1923	1926
36	Ruston sandy loam	---------	---------	129,000
37	St. Johns fine sand	---------	---------	27,200
38	Sassafras gravelly sandy loam	266,000	---------	84,300
39	Sassafras silt loam	12,500	---------	4,500
40	Sharkey clay	---------	---------	3,880
41	Summit silt loam	2,400	3,650	2,100
42	Susquehanna clay	---------	---------	24,300
43	Tidal marsh	62	---------	64
44	Wabash silt loam	1,560	1,340	---------
45	Unidentified alkali soil	2,600	251	310
46	Unidentified sandy loam	---------	5,610	4,080
47	Unidentified silt loam	1,400	1,510	1,000

V. TESTS OF UNCOATED IRON AND STEEL PIPE

The pipe materials originally selected are listed under section A of the general list of specimens on page 453. The specimens were 6 inches in length and from 1½ to 6 inches in nominal inside diameter. The 1½-inch pipe represents a size frequently used for gas services, and is one of the larger sizes of butt-welded pipe. The 3-inch pipe represents a size of lap-welded steel pipe frequently used for gas and water mains, while the 6-inch pipe is representative of a frequently used size of cast-iron pipe. On account of the comparatively large surface of the 6-inch pipe, one 6-inch specimen was considered equivalent to two 3-inch specimens.

Since oil was used in the cutting of most of the specimens when they were received from the rolling mill or foundry, they were first brushed to remove dirt, loosely adherent mill scale, molding sand, etc., and then washed with airplane gasoline to remove the grease. The specimens were then numbered on the ends, weighed, and check weighed to 3 parts in 100,000 or better. The ends of the pipes were then coated with asphalt to protect the identification numbers and to prevent galvanic action between the cut and the original pipe surface. Since the protected ends did not corrode, they furnished a base or point of reference from which to measure the depth of the pits caused by corrosion.

In order that the progress of the corrosion could be determined from time to time without affecting the specimens to be examined later, six groups of each material were buried in each test location with the expectation that the groups would be removed at approximately two-year intervals. Two specimens of the 1½-inch and 3-inch specimens were buried in each group while, because of its size, one 6-inch specimen per group was deemed sufficient. The specimens of a group were placed in rows along the sides of the trench, the order of the specimens in one row being reversed from that in the other row in order to minimize any effects due to conditions not being uniform throughout the trench. Before the specimens were buried, tests were made with the earth-current meter (19) to determine whether the earth was free from stray electric currents, and no specimens were buried where appreciable current was found.

In order that use should be made of all available surface, it was decided to put soil inside as well as outside of the pipe, and this necessitated the placing of the specimens on end to subject all sides to similar soil conditions. This deviation from the usual position in which pipes are laid eliminates to a large extent the effects of unequal packing, aeration, and drainage which often causes pipes to corrode worse on the under side, but this effect of position, while a factor in corrosion, is a function of the method of laying pipe rather than of either soil or pipe material.

The pipes were placed 1 foot apart in order that one should not be influenced by another, and laboratory experiments indicate that this distance is ample. Indeed, on the basis of laboratory tests, specimens buried later were separated only 6 inches. Figure 4, previously referred to, shows the relative positions of the specimens in the trench. At the time the specimens were buried, the soil resistivity was measured with an earth-current meter and samples of the soil were taken for laboratory tests. Burial of these specimens was begun in the southern part of the country in the early spring of 1922 and was finished in the Northern States in the fall of that year.

In order to determine whether the rate of corrosion changed with time it was intended to remove the first groups of specimens after they had been in the ground a year. However, other work caused delay, and removal of the specimens was not started until October, 1923. In order to secure weather conditions satisfactory for work the Northern States were visited first, and this resulted in removing specimens in that region after about one year's exposure, while those in the Southern States were exposed approximately two years.

As the specimens were removed from the trench as much of the earth and corrosion products were removed as local facilities permitted, and they were boxed and shipped to the Bureau of Standards, where they were first cleaned mechanically and then by the use of a solution of ammonium citrate and such brushing and scraping as was necessary to remove the corrosion products from the pits. The specimens were then weighed and the losses determined. The depths of the five deepest pits on the outer surface were then determined with a depth gauge.

On account of this difference in time of exposure, and because of variations in amounts of surface exposed by specimens of different materials, the corrosion data have been reduced to rates of corrosion and pitting.

After these data were tabulated a tentative report on the results of the tests was prepared, and representatives of the manufacturers of the materials and of the national associations representing the users of these materials were asked to meet at the Bureau of Standards to examine the specimens and discuss the proposed report. While the Bureau of Standards assumes full responsibility for the report as issued, the suggestions that were offered have received careful consideration, and the Bureau acknowledges its indebetedness for the assistance rendered by those attending the advisory meeting. In most instances the report was revised in accordance with these suggestions and so, in a large measure, represents the consensus of opinion of a considerable number of technical men who have participated in the meeting. Specimens were removed in 1926 and the same procedure as to treatment of specimens and the preparation of the report on them was followed. The organizations participating in the discussion of the section of this report which deals with uncoated pipe specimens are as follows:

American Foundrymen's Association, American Cast Iron Pipe Co., H. Y. Carson.
American Gas Association, J. K. Crowell and D. D. Ransdell.
American Rolling Mill Co., J. R. Cain.
American Water Works Association, Technical Committee No. 3 on Specifications for Cast Iron Pipe, A. E. S. C., L. P. Wood.
Bureau of Soils, H. H. Bennett and P. L. Gile.
A. M. Byers Co., E. B. Story.
Cast Iron Pipe Publicity Bureau, T. F. Wolfe.
Jones & Laughlin Co., A. Milne.
National Tube Co., H. R. Reddington.
Republic Iron & Steel Co., L. B. Grindlay.
United States Cast Iron Pipe & Foundry Co., J. D. Capron.
Wheeling Steel Corporation, B. M. Hazeltine (guest).
Youngstown Sheet & Tube Co., G. A. Reinhardt.
The Bureau of Standards, represented by H. W. Gillett, K. H. Logan, H. S. Rawdon, and T. P. Saeger.

Briefly, the results of the examination of the specimens removed in 1924 showed that the welded iron and steel pipes buried in any one of the test locations differed little in the extent of pitting or in the loss of metal per unit of exposed area, and that severe pitting and serious loss of metal had occurred in several soils.

The corrosion of the cast iron differed somewhat from that of the welded metal, but it also showed serious pitting in a few locations. Where the pitting of the cast iron was severe the corrosion product was always of the type commonly referred to as graphitic. This corrosion product could not be removed by washing and brushing, as most of the corrosion products of steel usually can, but had to be dug out with a knife or sharp tool. The pits' boundaries were frequently indefinite, and the corrosion products became harder on long exposure to the air.

FIG. 4.—*Arrangement of original specimens*

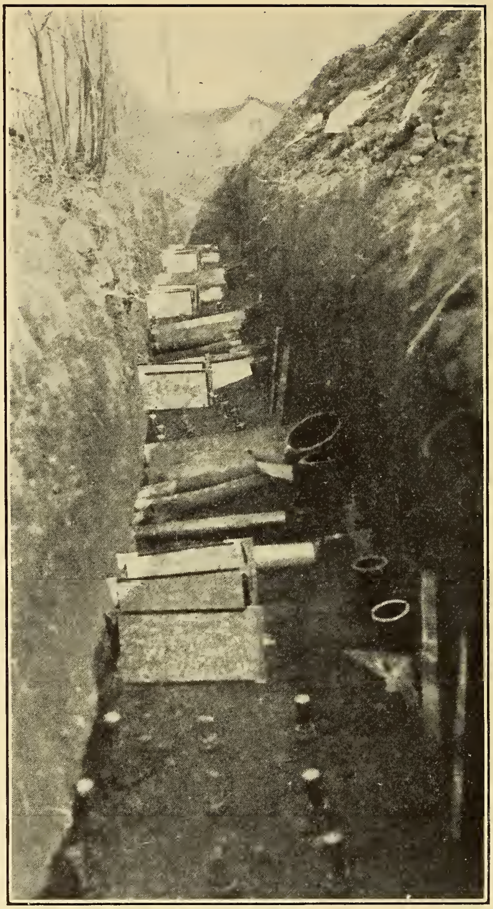

FIG. 5.—*Arrangement of specimens buried in 1923–24*

FIG. 6.—*Exhibit of uncoated pipe specimens*

The type of corrosion differed widely in different soils. In very wet corrosive soils and in the alkali soils the corrosion occurred in patches, sometimes as large as the palm of the hand; in the heavy clay and silty soils the corrosion usually took the form of rather small deep pits; in one sandy soil the specimens appeared as if worm-eaten, while in a single very wet silt loam the oxide was removed as if by acid pickle, but the iron beneath showed little corrosion and no pits. In one well-drained gravelly soil almost no corrosion was found. The data on these specimens are summarized in Tables 4 and 5, which also show similar data for specimens removed later.

The removal of specimens in 1923 and 1924 afforded an opportunity to bury additional specimens not only of pipe materials but of pipe fittings and protective coatings. These were divided into two classes, some to be tested in all soils and others in only a few soils. The materials of the first class are given in sections D and H of the list on page 454. Since the initial corrosion in many soils appeared similar, it was decided that for most purposes it would be sufficient to test most of the additional materials in six widely different soils—soils containing white and black alkali, a tidal marsh, a clay, a muck, and a gravelly soil. The metallic materials buried in these soils in 1922 and 1924 are given in sections B, C, F, G, H, and I on pages 454 and 455. The arrangement of these materials in the trench is shown in Figure 5.

TABLE 4.—*Comparison of rates of corrosion* [1] *at end of first and second periods*

Soil No.[2]	Times of burial		Wrought iron (4 specimens)[3]		Bessemer steel (6 specimens)[4]		Pure open-hearth iron (2 specimens)		Open-hearth steel (2 specimens)		Copper bearing open-hearth steel (2 specimens)		Sand mold cast iron (2 specimens)		De Lavaud cast iron (2 specimens)	
	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d
1	0.98	3.58	1.23	1.16	1.19	1.12	1.08	0.92	1.39	1.17	1.17	0.96	1.45	1.05	0.80	0.96
2	2.09	4.03	.93	.80	1.03	.75	.90	.71	1.05	.68	.88	.62	.93	.97	-----	-----
	1.94	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.43	(3)
3	2.01	4.09	.85	.83	.97	.84	.73	.70	.98	.81	.86	.89	.98	1.03	-----	-----
	2.07	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.58	(3)
4	1.38	4.03	.92	.90	1.04	.87	1.06	.91	1.01	.91	1.12	.92	.99	1.01	.91	.90
5	1.93	4.13	.49	.53	.61	.57	.57	.35	.51	.51	.49	.50	.46	.42	-----	-----
	2.20	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.17	(3)
6	1.93	4.13	.07	.15	.09	.18	.07	.17	.07	.17	.08	.13	.06	.08	-----	-----
	2.20	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.12	(3)
7	1.04	3.50	.62	.73	.61	.70	.46	.70	.51	.83	.59	.72	1.25	.84	.60	.76
8	1.13	3.80	.59	.47	.67	.51	.64	.50	.54	.45	.64	.48	1.24	1.06	.69	.49
9	1.03	3.48	.86	.65	.73	.59	.54	.49	.61	.35	.52	.49	.69	.66	.70	.41
10	1.33	4.01	.89	.45	.98	.49	1.01	.34	.78	.30	.88	.39	.71	.54	.75	.43
11	1.36	3.97	.30	.26	.33	.27	.20	.23	.29	.23	.26	.24	.17	.22	.07	.16
12	1.94	4.14	.11	.41	.17	.39	.13	.34	.11	.37	.13	.39	.13	.38	-----	-----
	2.21	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.03	(3)
13	1.93	4.22	1.76	1.18	2.12	.92	1.28	.64	2.33	.55	2.11	1.11	1.90	1.99	1.41	.68
14	1.13	3.80	.32	.62	.42	.63	.23	.52	.41	.59	.40	.51	.26	.60	.24	.30
15	1.96	4.04	1.10	.75	1.21	.83	1.25	.89	1.15	.83	1.38	.76	.97	.83	-----	-----
	2.08	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.15	(3)
16	1.97	4.04	1.17	.83	1.25	.81	.96	.71	1.14	.74	1.06	.85	1.25	.59	-----	-----
	2.07	(5)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.76	(3)
17	1.21	3.83	1.27	.90	1.23	.90	1.22	.86	1.24	.90	1.21	.95	1.94	.96	1.15	.94

See footnotes at end of table.

TABLE 4.—*Comparison of rates of corrosion at end of first and second periods*—Continued

Soil No.	Times of burial		Wrought iron (4 specimens)		Bessemer steel (6 specimens)		Pure open-hearth iron (2 specimens)		Open-hearth steel (2 specimens)		Copper bearing open-hearth steel (2 specimens)		Sand mold cast iron (2 specimens)		De Lavaud cast iron (2 specimens)	
	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d
18	1.19	3.74	0.47	0.42	0.42	0.42	0.35	0.32	0.27	0.30	0.40	0.44	(6)	0.27	0.21	0.16
19	1.12	3.66	.65	.51	.63	.57	.56	.54	.56	.62	.75	.55	.49	.35	.34	.37
20	.98	3.57	.90	.64	1.05	.58	.95	.60	1.05	.60	.95	.56	1.11	.67	.75	.51
21	1.47	4.02	1.45	.67	1.43	.68	1.37	.63	1.35	.73	1.44	.62	1.53	.79	1.09	.62
22	1.72	3.68	.88	1.01	1.03	.96	.82	.87	.89	1.00	1.03	.94	.91	1.11	.62	.67
23	1.93	4.27	3.48	2.95	3.85	2.82	2.80	2.62	3.38	2.79	4.06	2.26	7.11	6.74	2.96	2.89
24	1.32	4.01	.17	.12	.21	.11	.15	.11	.20	.09	.15	.08	.11	.09	.13	.05
25	1.03	3.71	.45	.28	.42	.28	.43	.19	.36	.23	.40	.28	.48	.45	.47	.30
26	1.04	3.49	.84	.60	.81	.56	.76	.45	.73	.55	.87	.54	1.04	.95	.76	.56
27	1.95	4.05	.31	.82	.26	.89	.20	.80	.29	.86	.24	.66	.24	.73	------	------
	2.11	(5)	------	------	------	------	------	------	------	------	------	------	------	------	1.10	(3)
28	1.64	(3)	1.76	(3)	1.92	(3)	2.04	(3)	1.94	(3)	2.15	(3)	2.86	(3)	2.76	(3)
29	1.96	4.07	1.74	1.84	2.09	1.73	2.03	1.78	2.16	1.79	2.13	1.94	1.99	2.05	(4)	(3)
30	1.11	3.65	.81	.36	.94	.35	.81	.30	.96	.35	.91	.34	1.12	.51	1.04	.45
31	2.01	4.07	.51	.46	.68	.53	.34	.50	.62	.62	.52	.56	.37	.45	------	------
	2.07	(5)	------	------	------	------	------	------	------	------	------	------	------	------	1.09	(3)
32	.94	3.73	.42	.42	.40	.39	.27	.31	.42	.35	.34	.38	.40	.53	.52	.42
33	1.03	3.71	.39	.95	.41	.94	.42	.94	.44	.93	.35	1.02	.35	.88	.42	.92
34	1.38	4.03	.96	.45	.89	.45	.95	.40	.98	.46	.86	.44	.95	.45	.91	.43
35	1.93	4.14	.43	.50	.44	.41	.42	.41	.47	.47	.48	.43	.60	.70	------	------
	2.20	(5)	------	------	------	------	------	------	------	------	------	------	------	------	.51	(3)
36	1.99	4.07	.52	.45	.58	.49	.58	.35	.42	.42	.47	.37	.47	.32	------	------
	2.08	(5)	------	------	------	------	------	------	------	------	------	------	------	------	.36	(3)
37	2.00	4.07	1.17	1.09	1.21	1.08	1.15	1.03	1.20	1.09	1.21	1.21	.83	1.00	------	------
	2.07	(5)	------	------	------	------	------	------	------	------	------	------	------	------	1.95	(3)
38	1.40	4.04	.13	.15	.19	.15	.11	.11	.18	.10	.20	.13	.06	.09	.03	.07
39	1.38	4.02	.85	.80	.87	.74	.75	.78	.99	.76	.90	.73	1.02	.74	.86	.71
40	1.96	4.06	1.12	1.04	1.07	1.00	1.09	.97	1.28	1.05	1.45	1.02	1.17	1.42	------	------
	2.10	(5)	------	------	------	------	------	------	------	------	------	------	------	------	1.12	(3)
41	1.47	4.02	.40	.77	.44	.70	.51	.68	.43	.73	.27	.62	.82	.65	.26	.46
42	1.98	4.07	1.64	1.49	1.57	1.36	1.51	1.09	1.20	.83	.97	.84	2.45	2.28	(4)	(3)
43	1.29	4.06	1.44	1.48	1.80	1.34	1.05	.90	1.70	1.28	1.87	1.58	.91	.93	.78	.77
44	1.09	3.63	.47	.45	.38	.47	.30	.38	.32	.38	.38	.35	.59	.32	.15	.27
45	1.18	3.78	1.05	.78	1.22	.79	1.00	.96	.81	.85	1.16	.86	1.36	1.11	1.14	2.06
46	1.46	4.05	.80	.69	.76	.67	.53	.68	.76	.63	.78	.79	1.47	1.17	.35	.55
47	1.48	4.08	.27	.39	.30	.41	.35	.31	.39	.32	.25	.50	.38	.59	.40	.46

[1] The unit used is ounces per square foot per year.
[2] Names of soils given in Table 3.
[3] These specimens buried when first sets were removed.
[4] These specimens are included with extra specimens.
[5] Time of burial of De Lavaud cast iron. It was buried in these locations when first specimens were removed.
[6] Specimens damaged before weighing.

TABLE 5.—*Comparison of rates of penetration[1] at end of first and second periods*

Soil No.	Wrought iron		Bessemer steel		Pure open-hearth iron		Open-hearth steel		Copper-bearing open-hearth steel		Sand mold cast iron		De Lavaud cast iron	
	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d
1	------	10	------	11	------	13	------	10	------	13	45	29	------	17
2	------	11	------	11	------	13	------	11	------	11	19	10	------	(2)
3	25	16	25	18	31	18	26	13	30	22	32	16	------	(2)
4	------	6	------	7	------	8	------	8	------	10	24	12	------	8
5	------	7	------	8	------	7	------	7	------	8	------	9	19	(2)
6	------	------	------	------	------	------	------	------	------	------	------	------	------	(2)
7	------	------	------	------	------	8	------	9	------	------	------	------	------	------
8	30	10	34	11	38	12	38	13	54	15	59	18	------	15
9	38	15	24	17	44	13	31	17	32	18	------	10	------	------
10	16	6	14	3	19	3	15	3	19	5	------	------	------	------

[1] In thousandths of inches per year—deepest pit. [2] Specimens buried when first sets were removed.

TABLE 5.—*Comparison of rates of penetration at end of first and second periods*—Continued

Soil No.	Wrought iron		Bessemer steel		Pure open-hearth iron		Open-hearth steel		Copper-bearing open-hearth steel		Sand mold cast iron		De Lavaud cast iron	
	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d	1st	2d
11	27	17	24	16	36	16	24	13	31	15	------	9	26	6
12	------	10	------	11	------	10	------	9	------	13	------	11	------	(2)
13	20	11	25	11	18	6	33	13	37	15	------	35	16	13
14	31	16	28	14	29	14	28	15	57	19	24	------	------	------
15	19	7	20	9	15	11	17	8	22	12	40	12	14	(2)
16	19	12	20	14	21	11	17	11	22	17	23	14	15	(2)
17	------	6	------	6	------	5	------	6	------	------	39	6	------	------
18	18	10	14	11	22	10	24	14	23	9	------	25	------	10
19	23	11	24	13	30	10	22	12	34	13	------	21	------	9
20	------	------	------	------	------	------	------	------	------	------	------	------	------	------
21	------	12	------	13	------	15	------	9	------	11	------	15	------	10
22	21	14	27	14	25	12	22	16	27	14	32	25	18	13
23	25	23	26	24	28	21	45	31	34	22	60	60	18	33
24	------	------	------	------	------	------	------	------	------	------	------	------	------	------
25	20	8	23	10	23	9	26	8	24	9	------	10	------	10
26	------	11	------	14	------	11	------	13	------	14	------	11	------	9
27	------	9	------	9	------	------	------	9	------	10	------	15	13	(2)
28	16	(2)	19	(2)	12	(2)	24	(2)	22	(2)	31	(2)	19	(2)
29	20	14	26	15	24	16	35	19	19	22	21	12	(3)	(2)
30	------	5	13	3	21	4	15	4	16	5	------	------	------	------
31	17	9	26	7	15	------	23	11	27	8	------	9	20	(2)
32	29	11	25	8	43	12	24	9	29	11	36	10	------	12
33	------	------	------	9	------	10	------	8	------	10	------	11	------	12
34	16	5	15	4	14	6	20	4	21	6	------	7	------	7
35	------	------	------	------	------	------	------	------	------	------	------	8	------	(2)
36	19	9	19	9	14	9	24	12	19	10	24	12	15	(2)
37	19	12	25	15	18	11	21	14	45	23	------	------	------	(2)
38	------	------	------	------	------	------	------	------	------	------	------	------	------	------
39	------	------	------	8	------	10	------	6	------	11	------	9	------	8
40	15	11	17	10	23	15	20	11	22	11	16	13	18	(2)
41	28	10	26	11	13	8	21	9	21	9	18	10	------	------
42	28	19	31	19	27	15	31	20	28	18	50	38	(3)	(2)
43	31	18	30	13	14	9	35	19	29	14	------	24	------	14
44	29	12	28	14	34	21	36	12	35	14	------	19	------	12
45	------	8	19	7	------	9	14	9	23	12	38	14	------	12
46	35	16	38	22	39	20	26	14	54	27	24	13	------	------
47	------	------	------	------	------	------	------	------	------	------	------	------	------	------

[2] Specimens buried when first sets were removed

[3] These specimens are included with extra specimens.

Names of soils given in Table 3. Blanks indicate pits were less than 0.02 inch total depth. Times of burial are given in Table 4.

In 1926 sets of specimens were removed from all locations. An idea of the number of specimens involved may be gained from Figure 6, which shows the unprotected pipe specimens arranged for inspection. About an equal number of other specimens were removed at the same time. In general, the 1926 uncoated specimens appear similar to those removed in 1924. While radically different materials were not affected similarly, there was a striking similarity in the appearance of the rolled materials in almost any of the soils under investigation. This is illustrated in Figure 7, which shows specimens of pure open-hearth iron, wrought iron, Bessemer steel, open-hearth steel and copper-bearing open-hearth steel buried in Cecil clay loam at Atlanta, Ga. (soil No. 3) for approximately four years. The similarity in the appearance of these specimens was duplicated in other localities and was an evidence of the controlling influence of the soil on the character of corrosion.

While all of the rolled specimens in a given soil showed similar corrosion patterns, the types of corrosion varied widely in different soils, as is illustrated in Figure 8, which shows the corrosion patterns on Bessemer steel in eight soils.

The specimens in Everett gravelly sandy loam (soil No. 6), a well-drained soil, showed almost no corrosion after four years. Those in the unidentified silt loam at Salt Lake City (soil No. 47) lost their oxide coatings as if they had been pickled in dilute acid, but the surfaces were smooth and free from pits, and the losses very small. The surfaces of the specimens in Keyport loam (soil No. 17) were roughened but showed few distinct pits. Those in Memphis silt loam (soil No. 22) showed patches of rather severe corrosion, although the original oxide coating remained on most of the surface. In Hagerstown loam (soil No. 11) most of the original surface was intact, but there were a few deep pits. Marshall silt loam (soil No. 21) specimens showed numerous deep pits. Most of the specimens from the unidentified sandy loam in Denver (soil No. 46) showed grooves as if they were worm-eaten. Large patches of deep corrosion appear on the specimens in Merced silt loam (soil No. 23) containing white alkali in California, and the thinner walled specimens have failed. In this soil there is especially severe corrosion along the butt welds.

Tables have been prepared showing the rates of corrosion and pitting and the pitting factor for each bare pipe specimen removed. Because of the number of specimens involved and the variations between specimens nominally the same, these tables are difficult to interpret, and for most purposes the summary of the results as given in Tables 4 and 5 is of greater interest. In these tables similar materials have been grouped together. The number of specimens in the group ranges between two and six. Not all the specimens in the larger groups are from the same manufacturer or made in exactly the same way, but examination of the detailed data will show that the variations between the specimens of different materials grouped together is of the same order of magnitude as that between specimens of the same material. The tables are intended to bring out the progress of the investigation, and for this reason show both 1924 and 1926 data. For reasons discussed elsewhere the data should not be used for determining the relative merits of materials.

The specimens buried in 1922 were exposed to the soil on both surfaces. For the wrought specimens this is proper, since the two surfaces are similar. This is not strictly true for the De Lavaud cast iron, and for this reason the specimens of this material buried in 1924 had the inner surfaces protected. This change should be kept in mind when comparing data involving these specimens.

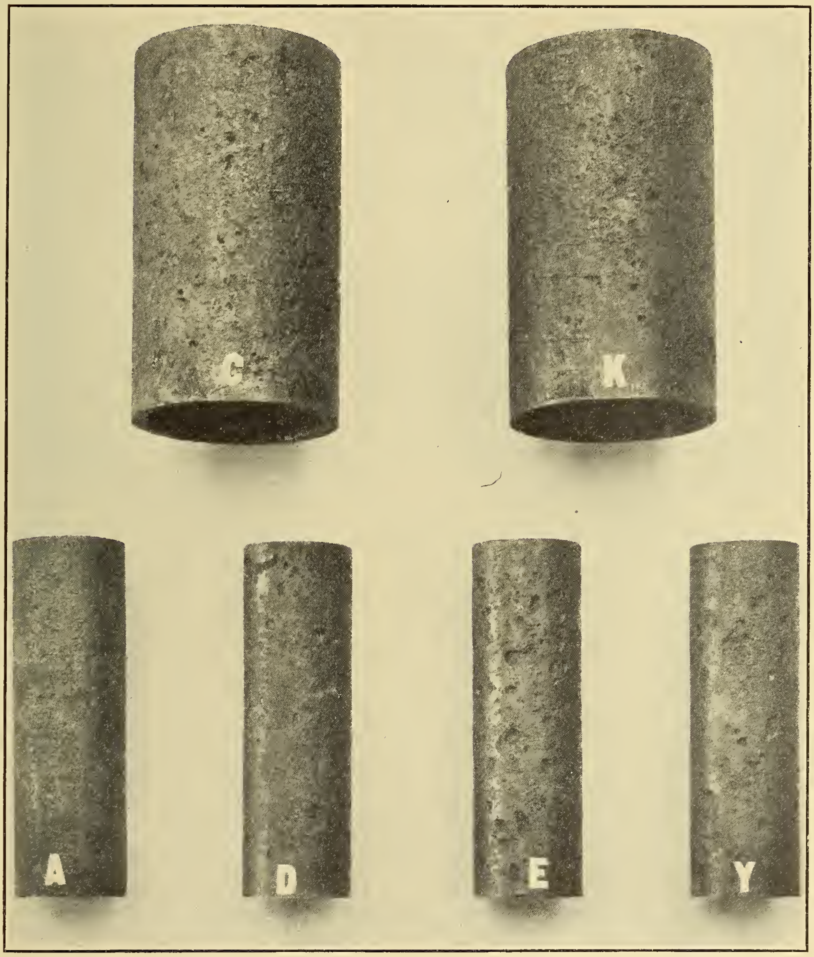

FIG. 7.—*Pipes of six materials buried in the same soil*

Note similarity of types of corrosion on all specimens

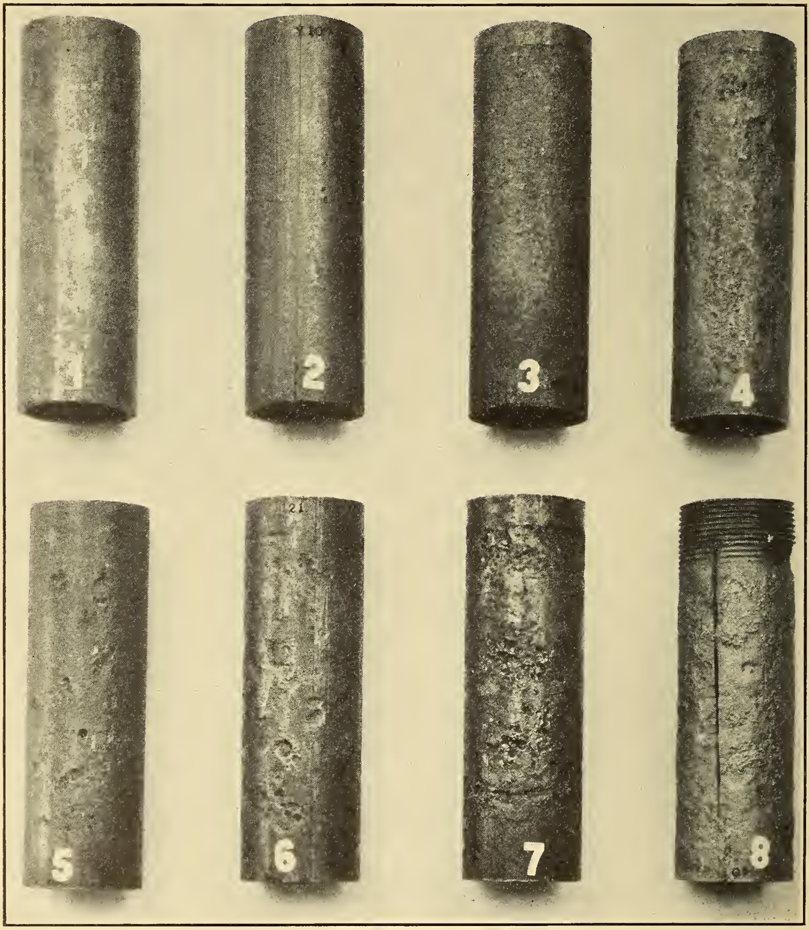

Fig. 8.—*Types of corrosion specimens of the same material for eight soils*

Table 4 shows the rates of corrosion for each kind of material tested at the first and second examination (1924 and 1926). Since the irregularities in all soils and of different materials were not the same, a basis for computing the probable error in the data is lacking. If we assume that a difference of 0.05 ounce per square foot per year is not significant, we find that out of 306 cases in Table 4 in which we may compare the losses at the end of the two periods, in 170, or 56 per cent, there is a decrease in the rate of corrosion, while in 73, or 24 per cent, there is an increase in the rate.

From the standpoint of soils we find that in 25 soils 4 or more materials showed a decreased rate of corrosion with not more than one material showing accelerated corrosion, while in 10 soils 4 or more materials showed accelerated corrosion, with not more than 1 material showing a decreased rate. The cast iron deviates from the general trend of the specimens more often than any other material.

Table 5 shows the rates of pitting for each material in each soil under investigation. The figures are the average of the maxima for the specimens of their class. When these data were collected, it did not seem desirable to measure pits less than 0.02 inch in depth. This results in a large number of blank spaces in Table 5, and makes comparisons of soils or materials difficult. Only one case is shown where there is an increased rate of pitting, although more might appear if we had the data on the rates of pitting which the table does not show. Nevertheless, it seems reasonably safe to conclude that in most cases there is a decreased rate of pitting, and that in many instances the decrease in rate of pitting is greater than the decrease in the rate of general corrosion.

The uniformity of the corrosion over the surface of the pipe is often a matter of considerable importance, and this is indicated in a general way by the pitting factor which is the ratio of the maximum to the average penetration of the corrosion. The larger this ratio the less uniform is the corrosion. While the pitting factor furnishes a rough picture of the distribution of corrosion it in no way indicates the extent of the deterioration.

The average pitting factor for all the materials removed in 1923 and 1924 is 25.5, while that for the specimens removed in 1926 is 12.2. This is a definite indication that, on the average, corrosion tends to become more uniform, and since Table 4 indicates that the average rate of corrosion decreases one must conclude that if there is a tendency toward accelerated corrosion on account of the difference of potential between iron and its oxides there is also some protective effect, perhaps, on account of the partial shielding of the metal by the corrosion products. Such a shielding is indicated by the fact that the rate of pitting decreases more rapidly than the rate of corrosion as pointed out above.

The data on the cast iron and steel specimens buried in 1923 and 1924, sections B and C of the list on page 454, are summarized in Table 6.

It may be well to call attention to the fact that in obtaining the losses and depth of pits on cast iron all of the so-called graphitic corrosion products were removed by means of a scraper or sharp tool, whereas they would not have been removed by such washing and brushing as pipes are usually subjected to in a field examination. This graphitic corrosion product becomes harder with age or on exposure to the air and may have some value as a pipe material which is not taken account of in the tables.

TABLE 6.—*Summary of rates of corrosion and pitting of cast iron and steel specimens buried in 1923–24*

Material [1]	Alkali soil, Casper, Wyo., 2.60 years		Hanford very fine sandy loam, Bakersfield, 2.29 years		Merrimac gravelly sandy loam, Norwood, 2.69 years		Muck, New Orleans, 2.11 years		Tidal marsh, Elizabeth, 2.78 years		Susquehanna clay, Meridian, 2.08 years	
	Loss [2]	*Pit* [3]	*Loss*	*Pit*	*Loss*	*Pit*	*Loss*	*Pit*	*Loss*	*Pit*	*Loss*	*Pit*
A	1.67	12	0.49	-------	0.16	-------	2.45	20	0.78	31	1.82	31
CC	.85	-------	.29	-------	.15	-------	3.24	17	1.27	63	1.14	23
MC	.45	-------	1.60	22	.18	-------	1.99	20	1.17	10	1.68	30
M	1.12	-------	1.47	33	.23	24	1.89	34	1.44	10	-------	-------
S	.36	-------	1.10	-------	.36	-------	2.30	17	1.22	17	1.99	29
E	.43	12	1.21	37	.35	-------	2.07	18	.92	23	1.41	36
V	.63	-------	1.30	-------	.20	-------	1.68	21	1.00	9	1.84	32

[1] Materials:
A, 6-inch southern cast iron.
CC, 6-inch De Lavaud cast iron.
MC, 6-inch De Lavaud cast iron, machined.
M, 4-inch cast iron, machined.
S, 2-inch malleable-iron ells.
E, 2-inch cast-steel ells.
V, 2-inch high-tensile cast iron.

[2] Loss in ounces per square foot per year.

[3] Rate of penetration of pits in thousandths of an inch per year; average of maximum pits on specimens, usually 2.

The data on the high-silicon cast iron have not been included in the table. This material in all locations showed very little corrosion. In a few places it was darkened and showed rusted areas, but in no location was there a commercially important loss of weight or pitting.

In attempting to interpret the results of the examination of the specimens as described above several things must be kept in mind. The results concern the initial corrosion of the materials, and the initial rate of corrosion may be affected by conditions which later become unimportant; for example, the initial corrosion occurred soon after the trench had been filled, and the soil contained more air and in some cases at least was less compact than it was later. This initial corrosion may also affect subsequent corrosion either by setting up galvanic action or by forming a protective coating. The effects of the surface condition of the specimens and the character of the surface layer, such as the amount and distribution of oxide or mill scale, the extent of the so-called silica skin on cast iron, etc., are most important during the earlier stages of corrosion.

Then, too, neither the soils nor the materials used are entirely uniform, and only a few specimens of each material from each locality have been examined. On account of these variations some specimens which at first appear better or worse than others may ultimately occupy a quite different position.

For these and other reasons it is inadvisable to draw conclusions at this time concerning the life or relative merits of any of the materials under test. There are, however, several conclusions which can be drawn, although some of them may have to be modified somewhat in the light of additional data.

The data now available indicate that, so far as corrosion during the first four years is concerned, no one of the commonly used pipe materials is superior under all soil conditions.

The number of locations in which rather severe corrosion and pitting has been observed warrant the statement that serious deterioration of pipes may occur in soils free from foreign matter and stray electric currents. The distribution and extent of corrosive soils has not been determined, but a study of this question has been begun. Because the extent of corrosive soils is unknown at present it is not possible to estimate the importance or soil corrosion, but the results of the investigations now under way indicate that soil corrosion is a problem which fully justifies extensive study.

It has already been noted that whenever the corrosion of the cast iron was serious the products took the form of so-called graphitic corrosion. The amount of graphite in this material is usually only a small portion of the total corrosion products, the greater part being iron oxide. Whatever graphite is found existed in the iron before corrosion occurred, and any increase in the percentage of graphite results from the removal of iron.

The presence of graphitic corrosion and the wide variation in distribution of corrosion over the surface of specimens not subjected to stray currents, as illustrated in Figures 7 and 8, leads to the conclusion that it is impossible to distinguish between corrosion due to stray electric currents and that due to the soil either by the appearance of the corrosion or the character of the corrosion products.

Since the method of mitigating corrosion should depend on its cause, the conclusion that the appearance of the corrosion does not indicate the cause is important and suggests that other means for identifying the corrosive agent must be sought. Fortunately there are means for detecting stray electric currents. The study of methods of identifying corrosive soils has not reached the same development.

Perhaps the most striking features of the study of soil corrosion are the similarity in the appearance of the pipe specimens from the same location and their difference in different locations. These lead to the conclusion that during the first few years after an iron or steel pipe is buried its rate of corrosion is determined more by the character of the soil in which it is placed than by the kind of material used. There are, however, some differences due apparently to the kind of material, and specimens to be removed later may show for what conditions each of the materials tested is best adapted.

The variation in the types, as well as the amount of corrosion in different soils, indicates the desirability of associating corrosion with soil conditions and of a thorough study of soils for the purpose of developing methods of predetermining its corrosiveness and the best methods of avoiding losses. The data presented above indicate quite definitely that the corrosion of buried metallic structures is largely influenced by the physical or chemical characteristics of the soil or at least by some phenomena associated with the location of the structure. It is natural to expect that the solution of subsurface corrosion problems will be effected at least in part through an understanding of soil characteristics. An attempt has been made, therefore, to associate some of the soil characteristics with the corrosion observed. Since, according to one of the theories of corrosion, iron replaces hydrogen in the soil solution the concentration of hydrogen ions in the soil may be one of the factors affecting corrosion. For this reason the rates of corrosion and pitting for each material observed at the end of the four-year period, as indicated in Tables 4 and 5, have been associated with the hydrogen ion concentrations in the soils in which the specimens were buried. The results are plotted in Figures 10 and 11.

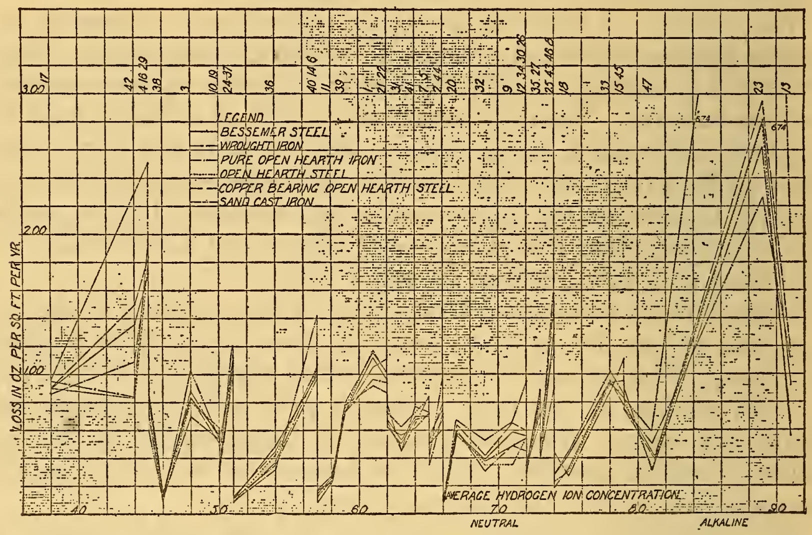

FIG. 10.—*Relation of rate of corrosion to hydrogen ions in the soil*

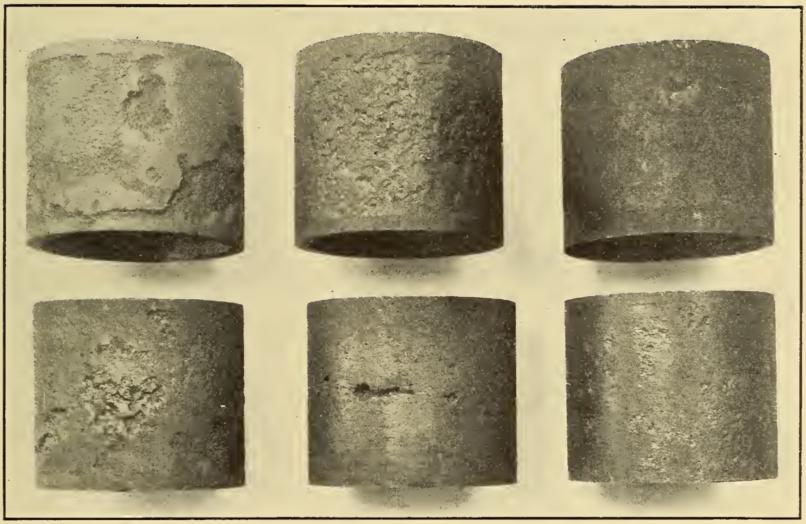

Fig. 9.—*Types of corrosion for cast iron*

The general form of the curves indicate that rapid corrosion is to be expected when the pH values are either very high or very low.

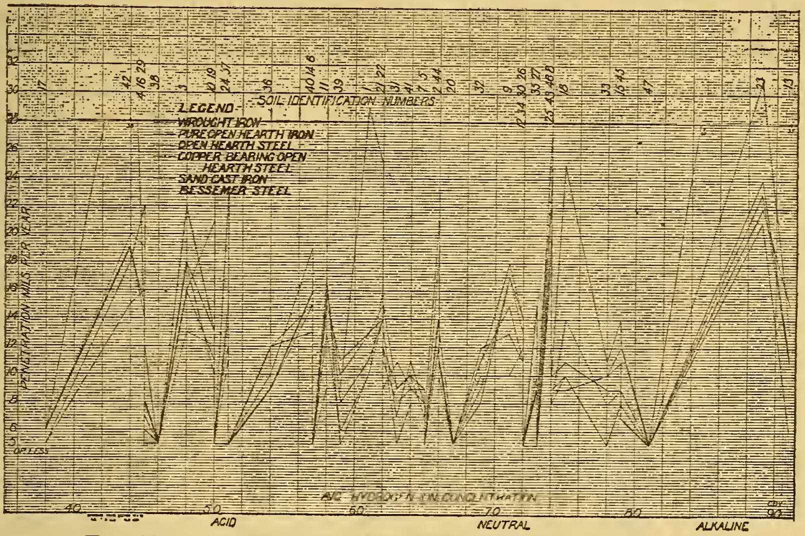

FIG. 11.—*Relation of rate of pitting to hydrogen ions in the soil*

The irregularities in the curves indicate that other factors also influence the rate of corrosion, and that the latter are the more influential when the pH values are nearly neutral.

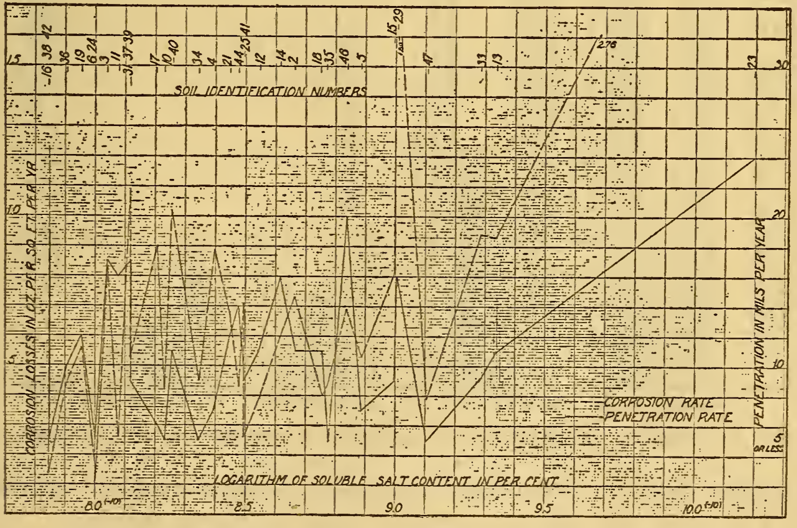

FIG. 12.—*Relation of rates of corrosion and pitting to soluble salt content*

The pH values used for these curves are the averages of all of the values obtained for a given soil by the Bureau of Soils or the 1926 values if no other data were available. When we consider the rather wide range in the pH values found in one soil as indicated in Table 2 and remember that these values may vary somewhat with the season of the year, it is evident that the available corrosion and hydrogen ion data are not closely related. It is quite possible, therefore, that a further study of the subject may show a closer relation between the pH values and rates of corrosion than the curves indicate.

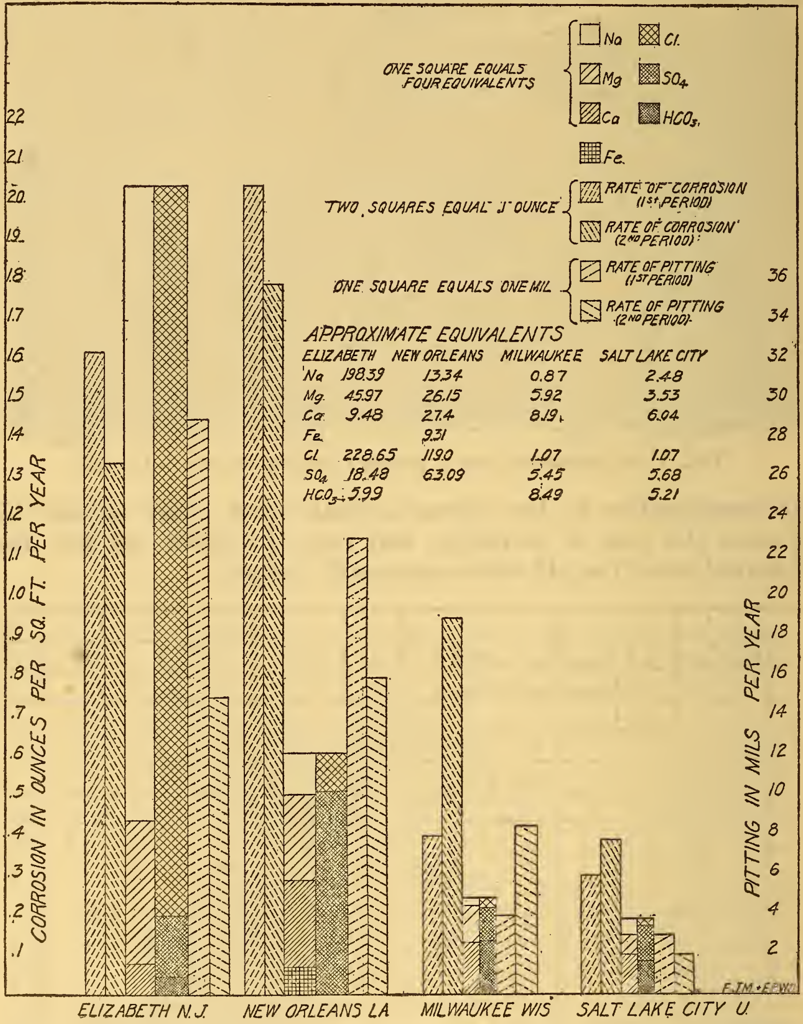

Fig. 13.—*Relation of soluble salts in soil waters to rates of corrosion and pitting*

If the curves are unsatisfactory as an indication of the cause of corrosion, they are useful at least for indicating the similarity of the corrosion of the different materials in the same soil and its variation with the soil type as mentioned in an earlier section of this paper.

Since the electrolytic theory of corrosion is generally accepted, and since the conductivity of a soil is almost entirely due to the salts in solution, it is of interest to associate the data on soluble salts as given in Table 2 with rates of corrosion and pitting, although a distinction should be made between the amount of soluble salts in a soil and the amount of salts actually in solution under normal soil conditions. Perhaps it is on account of this distinction that Figure 12, which shows the relations between soluble salts and rates of corrosion and pitting, is no more satisfactory than those for hydrogen ion values, or the lack of consistency in the data may be because the data available do not show the salts in solution in the soil adjacent to the specimens at the time corrosion was occurring.

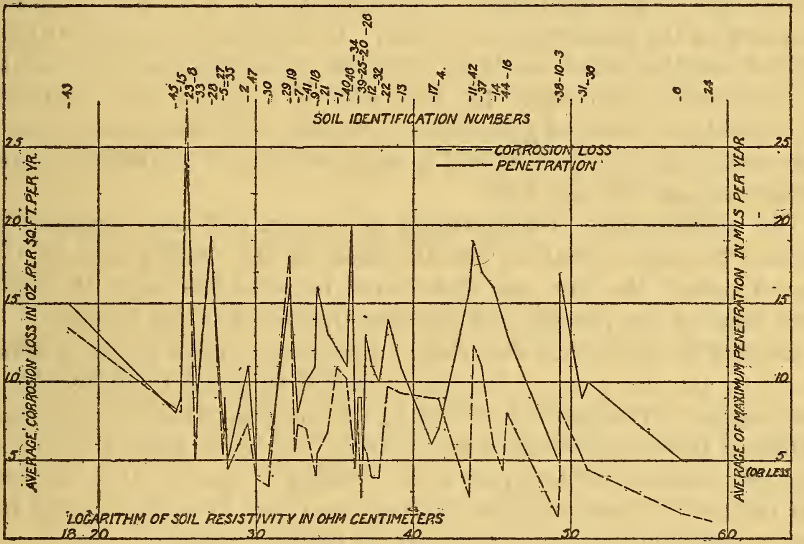

Fig.14.—*Relation of soil resistivity to corrosion loss and penetration*

A further study of the relation of soil waters to corrosion was made with the cooperation of W. D. Collins, of the water-resources branch of the United States Geological Survey, who analyzed waters taken from four soils in which specimens were buried and plotted graphs showing the proportionate parts of the salts found. These have been paralleled with graphs showing rates of pitting and corrosion. The result is given in Figure 13. Total immersion corrosion tests of pure-open-hearth iron in these waters were made by J. R. Cain, of the American Rolling Mill Co., who found substantially the same losses in each of the four waters.

Figure 14 is an attempt to correlate corrosion with the field measurements of soil resistivity given in Table 3. As the conductivity of the soil is almost entirely electrolytic, it was to be anticipated that Figure 14 would be the image of the corrosion curve of Figure 12. That this is only very roughly the case may be because neither the soluble salts nor the soil resistivities as measured are closely associated with the observed corrosion. A more careful and detailed study of the factors related to corrosion is needed for the solution of their relations.

VI. TESTS OF METALLIC PROTECTIVE COATINGS

The discovery of corrosion attributable to soil action at once raises the question of the best method of preventing such action. One way to accomplish this would be to keep the corrodible metal out of contact with the soil by means of a coating which was more resistant. Of the metallic coatings that have been suggested, zinc is the most widely used, and in anticipation of the possibility of finding some corrosive soils, a few specimens of galvanized pipe were buried in the majority of the test locations in 1922. It later became apparent that the information which could be obtained from these samples would be inadequate, and when the first sets of the pipe were removed additional specimens of galvanized materials and other metallic coatings were buried, as is indicated in sections H and I of the list of materials on page 454 and 455.

The effectiveness of galvanizing in a given soil was supposed to depend to some extent on the thickness of the coating and on the way in which the zinc was distributed between the layer of nearly pure zinc on the outside and the zinc-iron alloy layers beneath. It is claimed by some that the relative thickness of these layers is influenced by the character of the base material to which the galvanizing was applied. The method of coating the material with zinc may also influence the effectiveness of the coating, but while there are several practical methods of applying a zinc coating to iron or steel, the hot-dip method of galvanizing is the only one now extensively used for applying a zinc coating to material for underground use.

The scope of the test was, therefore, limited to a study of the effects of the weight of coating and the base metal on the durability of galvanized sheet and pipe. In order not to increase the cost of the original soil corrosion tests unduly, it seemed necessary to use the same test methods and locations selected for studying corrosion of uncoated pipe. The specimens, therefore, were completely buried at depths varying from 2 to 5 feet, and the conditions to which the galvanized material is exposed correspond to those of completely buried material and not to those to which culverts are subjected. This is important, since a very considerable amount of galvanized sheet is used for culvert construction. In this use the metal is exposed to soil on one side and to air, water, sediment, and abrasion on the other—conditions quite different from those of the tests under discussion.

One weight of coating applied to three base-sheet materials was buried in 47 soils. This was thought sufficient to determine soil effects and the relative merits of the base materials. Inadvertently, another variable—galvanizing-plant practice—was introduced. It is assumed that the galvanizing method best suited to each base material has been used. To generalize from the data on the materials tested it is also necessary to assume that other reputable galvanizing plants would produce similar coatings. Whether these assumptions are justified is beyond the scope of this investigation.

The weight of coating on a galvanized sheet varies considerably from point to point on the sheet, and different sheets with the same nominal weight of coating also show variations in weight. In order that the effect of the base material could be determined it was desirable that each should have the same weight of coating or, if this is not practicable, to have data whereby the effect of the variations in weight could be ascertained. For this reason, as well as to study the effect of different weights of galvanizing, several weights of zinc were applied to several base materials buried in seven widely different soils

While pipe and sheet material were of equal interest, it was found impracticable to control the coatings on pipe closely enough to get the weights desired, and the study of the effect of coating weights was limited to sheet material. Two pipe materials were buried, one in 30 and the other in 47 soils, while two other pipe materials also were buried in 7 of these soils.

One kind of galvanized pipe was buried in 1922, the other galvanized specimens were buried in 1923 and 1924. The first specimens of all materials were removed in 1926.

Before shipment, the specimens were cleaned in gasoline, numbered, weighed, the cut edges covered with asphalt, and wrapped in paper to avoid abrasion. When the specimens were removed from the soil, the dirt was scraped off and they were again wrapped separately for shipment. Four sets of each kind of specimen were buried in each location in order that a set could be removed from time to time without disturbing the others and thus affecting their rates of corrosion.

Upon receipt by the Bureau of Standards laboratory the corroded specimens were washed with water and brushed with a fiber brush. While a few of the specimens presented a nearly uniform condition, most of them showed that the corrosion was not uniform. In a number of cases rusted spots or bare iron areas were found on specimens, portions of which were still in good condition, so that the loss of weight of the specimen would not be a satisfactory criterion of the effectiveness of the coating. In some cases at least, the zinc continues to protect the base metal even when the latter is exposed in places. Even the presence of light rust-colored areas may not indicate the complete failure of the coating, since the rust may be derived from the zinc-iron alloy. These considerations indicate that an exact determination of the condition of the specimens is difficult, and since the specimens now available are but a part of those involved in the test and the final conclusions must await the examination of the other specimens, it was decided that the first report on this work should be based only on a visual examination of the specimens. Five conditions were deemed sufficient for the classification of the specimens as follows:

E. Excellent. Little indication of exposed alloy layer.
G. Good. Surface showing dark blue spots or patches of alloy layer, but no rust spots due to corrosion of the metal.
F. Fair. Small rusted areas indicating first attack of base metal.
R. Rusted. Generally rusted, or showing bright areas of exposed base metal.
P. Pitted. Distinct indication of corrosion of base metal, such as heavy rust layer, pitting, or depressions.

Figures 15 and 16 illustrate some of these conditions.

No sharp lines can be drawn between these grades and there will be considerable variation within each. The fact that the coatings on the different base materials are somewhat different in weight must be kept in mind. No attempt to give the ratings numerical values which would indicate the probable remaining life of the coating should be made.

In order that the grading or rating of the specimens should be as instructive as possible, those who furnished material and the national societies whose members are concerned with galvanizing were asked to send representatives to examine the specimens and to advise the Bureau of Standards engineers as to their conditions.

The following organizations responded, sending the representatives indicated. Those marked with a star (*) graded the specimens.

American Rolling Mill Co., H. E. Brooks,* J. R. Cain,* and A. J. Sheldon.*
American Sheet & Tin Plate Co., E. S. Taylerson.*
American Zinc Institute, S. S. Tuthill.
Armco Culvert & Flume Co., C. M. Colvin * (guest).
J. B. Colt Co., H. F. Reinhard.*
New Jersey Zinc Co., R. M. Curts,* William H. Finkeldey* (guests).
Technical committee No. 2, Committee on Specifications for Zinc Coatings, A. E. S. C., J. T. Hay.*
Youngstown Sheet & Tube Co., G. A. Reinhardt.*

The Bureau of Standards was represented at the advisory meeting by H. W. Gillett, H. S. Rawdon, and K. H. Logan.

At the advisory meeting the proposed report was discussed, the rating sheets of the advisers compared, and a composite or adjusted rating for each specimen agreed upon. As is to be expected where there is no definite guide and one condition merges into another, the individual ratings differed somewhat for some of the specimens. The adjusted rating was arrived at by selecting such a rating as represented the opinion of the majority of the inspectors, balancing higher against lower ratings and finally adding a plus or minus sign to indicate that the consensus of opinion seemed to be that the condition of the speci-

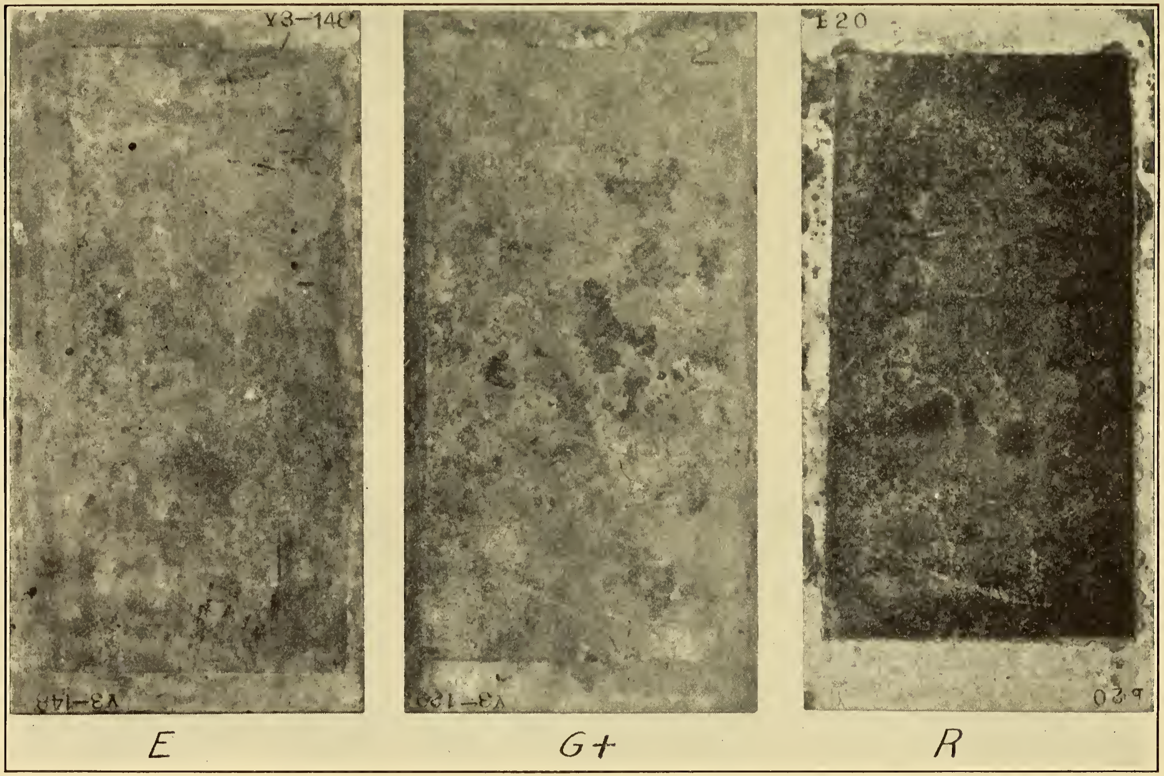

FIG. 15.—*Corrosion condition of galvanized sheet rating E, G+, R*

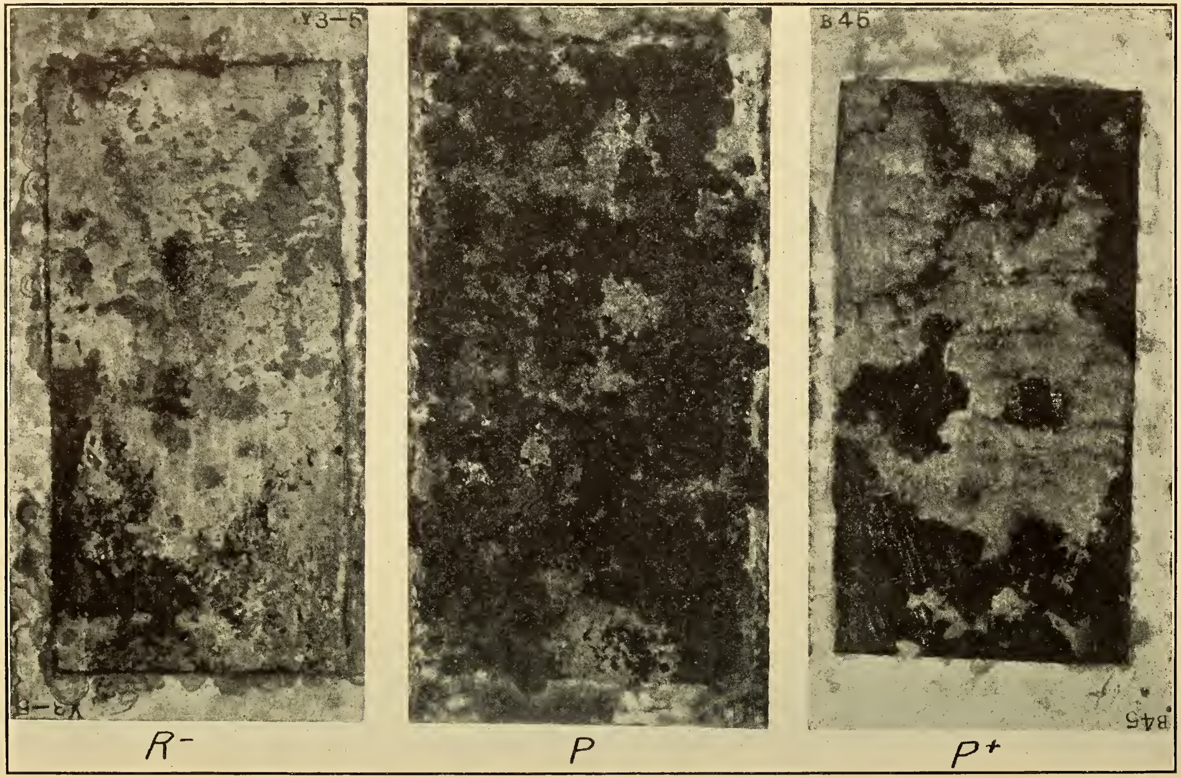

Fig. 16.—*Corrosion condition of galvanized sheet rating R−, P, P+*

men was somewhat better or worse than that indicated by the rating letter alone.

This is, of course, a very rough method of grading materials, but in the absence of something better it may give some idea of the appearance of the specimens. Table 7 gives the kind of material to which the ratings on Table 8 apply, the average weight of coating, and an analysis of a sample of the base metal. Table 8 gives the weight of coating on the specimens rated as determined from strips cut from the ends of the specimens. These strips were cut from sheet specimens marked B, CA, and CY before they were buried. Strips one-half inch wide were cut from the ends of the other specimens after they returned from the test. This portion of each sheet was protected from the soil by a heavy coating of asphalt. In some instances moisture got beneath the asphalt and caused corrosion. In such cases the weight of coating of the specimens could not be determined, and it is necessary to assume that it was the average weight for the class represented. The average weight of the coating on the A3 and Y3 specimens, obtained by averaging the separate weights of coating from specimens that had been buried, was slightly greater than the average weight of coating obtained from samples of the same materials that had not been buried. This indicates that the buried specimens had not lost an appreciable amount of zinc under the asphalt coating which was used to protect the edges. Table 8 also gives the adjusted ratings for the samples buried in most of the soils. Table 9 gives the ratings of those materials buried in seven soils only.

TABLE 7.—*Galvanized materials and weights of coatings per square foot*

Symbol	Material	Average weight of coating	Analysis of base metal [1]					
			C	Mn	P	S	Si	Cu
		Ounces						
B	2-inch Bessemer steel pipe, 24 inches long	[2] 1.81	0.11	0.48	0.008	0.050	0.04	0.018
A	2-inch pure open-hearth iron pipe, 17 inches long	[2] 2.82	.02	.010	.002	.025	.002	.043
D	Wrought-iron pipe, 17 inches long:							
	3-inch	[2] 3.48	.04	.001	.230	.017	.15	.027
	1½-inch	[2] 4.99						
Y	3-inch copper-bearing open-hearth steel pipe	[2] 3.47	.04	.19	.005	.038	.005	.23
A2	16-gauge pure open-hearth iron sheet	[2] 1.79	.01	.02	.002	.022	.001	.032
A3	do	[3] 1.98						
A4	do	[2] 2.65						
Y2	16-gauge copper-bearing sheet steel	[4] 1.57	.02	.03	.008	.034	.005	.20
Y3	do	2.15						
Y4	do	[4] 2.76						
Y5	do	[4] 2.92						
B	16-gauge Bessemer sheet steel	1.62	.07	.37	.097	.067	.01	.008
CA	18-gauge pure open-hearth iron sheet	1.87	.02	.01	.002	.039	.001	.054
CB	18-gauge Bessemer sheet steel	1.66	.09	.39	.028	.040	.01	.24
CY	18-gauge copper-bearing sheet steel	2.12	.09	.42	.006	.046	.01	.23

[1] Analyses by H. A. Bright, chemistry division, Bureau of Standards.

[2] Average of only a few specimens.

[3] Unless otherwise indicated, weights of coating were determined in the soil-corrosion laboratory.

[4] Manufacturers statement of weight of coating. On the pipe specimens the thickness of the coating refers to the outside of the pipe wall.

TABLE 8.—*Composite rating of galvanized specimens removed in 1926 (47 soils)*

Soil No.	Years buried		Pipe		Rating and weight of coating on the sheet[1]					
	24-inch B	Others	24-inch B	A	A3	Zn	Y3	Zn	B	Zn
1	3.58	2.59	G[2]	R+	P+	1.97	R−	--------	R−	1.63
2	--------	1.94	--------	G+	G+	2.23	G+	2.01	G	1.82
3	4.09	2.07	G+	E−	G	1.64	G	2.30	G	1.59
4	4.03	2.65	G	--------	R−	1.52	R+	2.00	R+	1.98
5	4.13	2.20	G−	G−	G	1.84	F+	2.13	F	1.57
6	--------	2.20	--------	E−	E−	2.18	E−	2.05	E−	1.61
7	--------	2.46	--------	E−	R−	2.01	R−	2.11	R−	1.44
8	3.80	2.67	G−	G+	G+	--------	G+	--------	G+	1.63
9	3.48	2.45	E−	G	G	1.96	G−	2.17	F+	1.40
10	4.01	2.68	G+	G+	G	2.08	G	2.11	G	1.78
11	3.97	2.60	E−	E−	G	1.91	G−	1.97	R	1.38
12	--------	2.21	--------	G+	E−	1.95	--------	--------	--------	1.80
13	4.22	2.29	G	E−	F	--------	F	--------	F−	1.71
14	3.80	2.67	G	E−	E−	2.21	E−	2.27	E−	1.36
15	--------	2.08	--------	G−	F	2.00	F−	--------	F	1.60
16	4.04	2.07	G+	E−	G+	2.15	G−	1.95	G+	1.65
17	3.83	2.62	G+	E−	R	2.17	R	1.95	R	1.44
18	3.74	2.55	G+	G	G+	2.06	G+	2.13	G−	1.67
19	3.66	2.54	E−	G	G	1.93	G	2.26	G	1.84
20	3.57	2.59	G+	G−	R	2.04	F	2.11	F−	1.90
21	4.02	2.55	G	G	G	--------	G	2.24	G	1.93
22	3.68	1.95	G	G	G	2.09	G−	2.03	R	1.40
23	4.27	2.28	P	R	P	--------	P	--------	P	1.54
24	4.01	2.69	E	E	E−	1.98	E−	--------	G−	1.47
25	3.71	2.68	G	G	G	1.91	G	2.11	G	1.60
26	3.49	2.46	G+	G−	R−	2.01	R−	2.05	R−	1.71
27	--------	2.11	--------	G−	G	2.16	G	2.09	G	1.67
28	--------	1.64	--------	G	G	--------	G	--------	R−	1.64
29	4.07	2.11	P+	R	P+	--------	P+	--------	P+	1.69
30	3.65	2.54	G+	--------	F+	2.05	F+	2.44	F+	1.50
31	--------	2.07	--------	E−	E	1.82	E−	2.25	E−	1.49
32	--------	2.78	--------	G+	E−	1.94	E	2.11	E−	1.59
33	3.71	2.68	G	G+	F	2.12	R+	2.09	R	1.80
34	4.03	2.66	G	G	G	2.08	G−	2.15	G	1.95
35	4.14	2.20	G	G+	G	1.98	G	2.39	G	1.67
36	--------	2.08	--------	E−	G+	1.95	G+	2.15	G+	1.64
37	--------	2.07	--------	G	G−	--------	G−	--------	P+	1.50
38	4.04	2.64	E	E	E−	1.80	E−	2.16	F−	1.87
39	4.02	2.64	R−	F+	G−	1.96	G	2.01	F+	1.32
40	--------	2.10	--------	G−	G	1.73	G	1.97	G	1.41
41	4.02	2.55	E−	F+	P+	--------	P+	2.30	P+	1.72
42	--------	2.08	--------	G−	--------	--------	--------	--------	G	1.41
43	4.06	2.78	R+	G	R−	--------	F	--------	F−	1.70
44	--------	2.55	--------	G	G+	2.01	G+	1.96	G+	1.73
45	--------	2.60	--------	F−	R−	1.97	F+	2.39	P+	1.65
46	4.05	2.59	E−	E	G+	1.88	G+	2.38	G+	1.51
47	4.08	2.60	G	G	G	1.89	G	2.26	G	1.42
Average weight of coating	--------	--------	--------	--------	--------	1.98	--------	2.15	--------	1.62

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[1] Weight of coating in ounces per square foot (on both sides of sheet).

[2] Rating symbols explained on p. 514.

TABLE 9.—*Composite rating of galvanized specimens removed in 1926 from seven soils*

Soil No.[1]	Years buried	Pipe		Rating and weight of coating on the sheet [2]																	
		D	Y	A2	Zn	A4	Zn	Y2	Zn	Y4	Zn	Y5	Zn	CA	Zn	CB	Zn	CY	Zn
13	2.29	E−[4]	E−	R	----	G	----	R−	----	F−	----	F−	----	G−	2.02	F	1.81	F	2.16
24	2.69	E	E	G+	1.57	E−	2.61	G−	----	E−	----	E−	----	E−	1.82	E−	1.57	E−	2.01
28	1.64	FG−	F+	-----	----	G	----	G	----	G	----	-----	----	G−	-----	F	-----	F−	-----
29	2.11	F	G	P+	----	R	----	P+	----	P+	----	R−	----	R−	1.63	P+	1.52	R−	2.34
42	2.08	-----	F+	-----	----	-----	----	-----	----	-----	----	-----	----	F	[3] 1.90	G	[3] 1.60	F+	[3] 2.25
														R−	-----	G−	-----	G	-----
43	2.78	G	G	R−	----	F+	----	-----	----	F+	----	P+	----	F+	1.67	F−	1.64	F	2.36
45	2.60	F+	F−	P+	1.62	F+	2.50	F+	1.59	F−	2.34	G−	2.74	G−	2.13	F+	1.54	G−	2.25

[1] For soil names see table 3.
[2] Weight of coating in ounces per square foot on both sides of sheet determined by S. Ewing.
[3] Average of 2 specimens.
[4] Rating symbols explained on p. 514.

The galvanized-sheet specimens were all 6 inches wide and 12 inches long and were placed on edge in the trench in order to expose both sides to similar conditions. All cut edges were protected by asphalt. The weight of coating is the total amount of zinc on a sheet 1 foot square—that is, on 2 square feet of surface. The weight of coating on the pipe is the weight of zinc per square foot of outside surface. The tables indicate that there is a wide variation in the rate of deterioration of the coating in different soils. In a few soils a year's burial produces very little change in the coating. In most of the soils under consideration the specimens showed dark-blue discolorations indicative of the alloy layer.[2] Light rusting of the specimens was observed in a few soils, while in a few other soils the bare metal was evidently exposed.

The most corrosive soil appears to be that containing a rather high percentage of white alkali (sulphates), but some soils containing sulphates attacked the sheets less than did some other soils. Serious corrosion occurred in the muck, a soil of New Orleans, and other soils containing rather high amounts of vegetable matter also appeared to be corrosive, though to a somewhat less extent. Allis silt loam (soil No. 1), Fairmount silt loam (soil No. 7), and Summit silt loam (soil No. 41) showed serious corrosive properties. These are all rather heavy soils, slightly acid in character. The first two are usually rather moist. These soils are among the more corrosive with respect to uncoated iron and steel.

The discussion above indicates that soil corrosion is a complicated phenomenon involving several factors, none of which is in all cases predominant.

While the present data do not justify final conclusions, there appear to be a few deductions which may safely be drawn from the data at this time.

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[2] The relative protective values of the several parts of a zinc coating are discussed in Bureau of Standards Cir. No. 80, p. 18.

Galvanized material appears to resist the action of most soils under test, but there are a few soils in which the useful life of the coating is comparatively short. In general, the soils which are most corrosive to bare steel and iron are also the most corrosive with respect to galvanized steel, but this is not universally true. Some of the specimens seem to indicate that in some soils the corrosion of the zinc results in the formation of a protective coating which retards the corrosion of the base metal even after the zinc and the zinc-iron alloys have partially or perhaps entirely disappeared.

A knowledge of the action of the soil involved is necessary before a safe decision can be rendered as to the desirability of using galvanized material in it.

This is illustrated in Figure 17. The three specimens at the top of the figure are galvanized sheets while those below are ungalvanized sheets of the same base metal. It will be noticed that both of the specimens on the left which were buried in a tidal marsh show a moderate amount of corrosion.

The specimens in the center were buried in a muck soil for a somewhat shorter period. Both specimens are corroded more than those on the left, and rust spots appear on the galvanized sheet. The specimens on the right were buried in a heavy clay with a low pH value. The galvanized specimen is in a better condition than the others of the same kind, while the ungalvanized sheet is the worst of its kind. Thus, in such a clay soil one would expect galvanizing to add materially to the life of buried pipes while it would have less relative value in the other soils mentioned. The value of selecting the material with respect to the soil in which it is to be used is further illustrated in Figure 18, which shows specimens of lead, steel, and galvanized iron from two soils in the Middle West. The steel corrodes at about the same rate in both soils. In one the lead corrodes rather badly and the galvanized material shows little corrosion, while in the other the galvanized sheet is corroded and the lead almost uncorroded.

The first examination of specimens does not indicate any marked differences in the corrosion resisting properties of galvanizing due to the base material to which it is applied.

There seems to be a rather close relation between the weight of coating and the apparent condition of the specimens. In a given soil the specimen having the heaviest coating usually appears best. While the specimens removed do not show the relative merits of the zinc and alloy layers or the life of the coatings, the examination of later specimens may throw some light on these questions. The soil corrosion tests have only begun, and it is to be expected that the indications of the data will become more definite as the work progresses and more specimens are examined. The removal of additional specimens at two-year intervals should in time furnish general

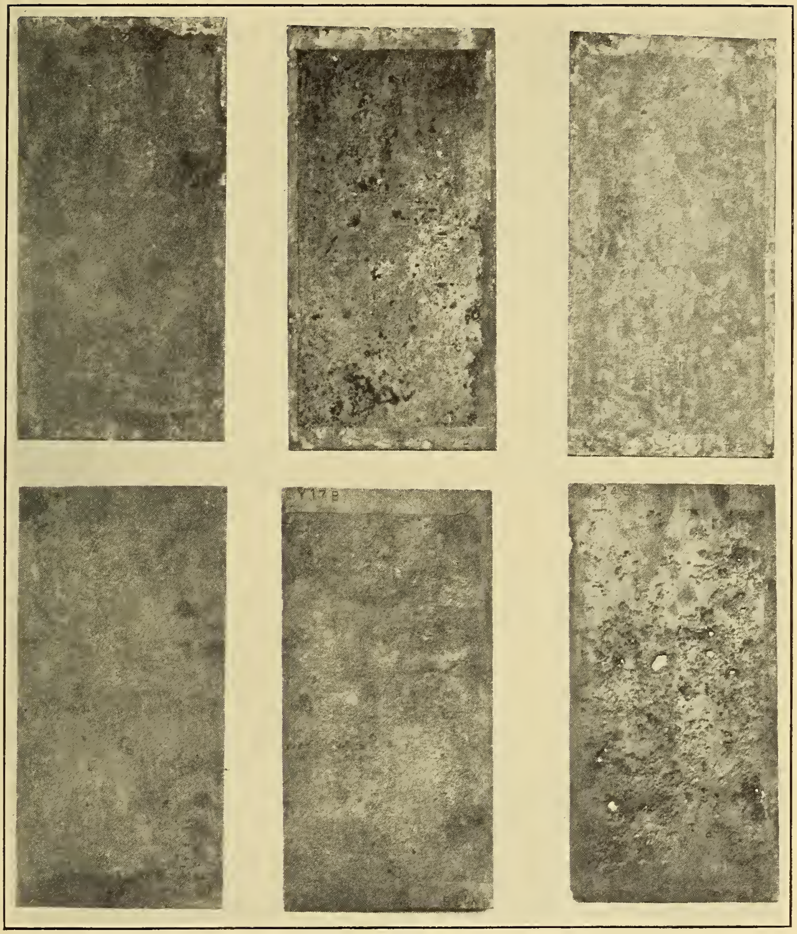

FIG. 17.—*Galvanized and bare sheet steel in three soils*

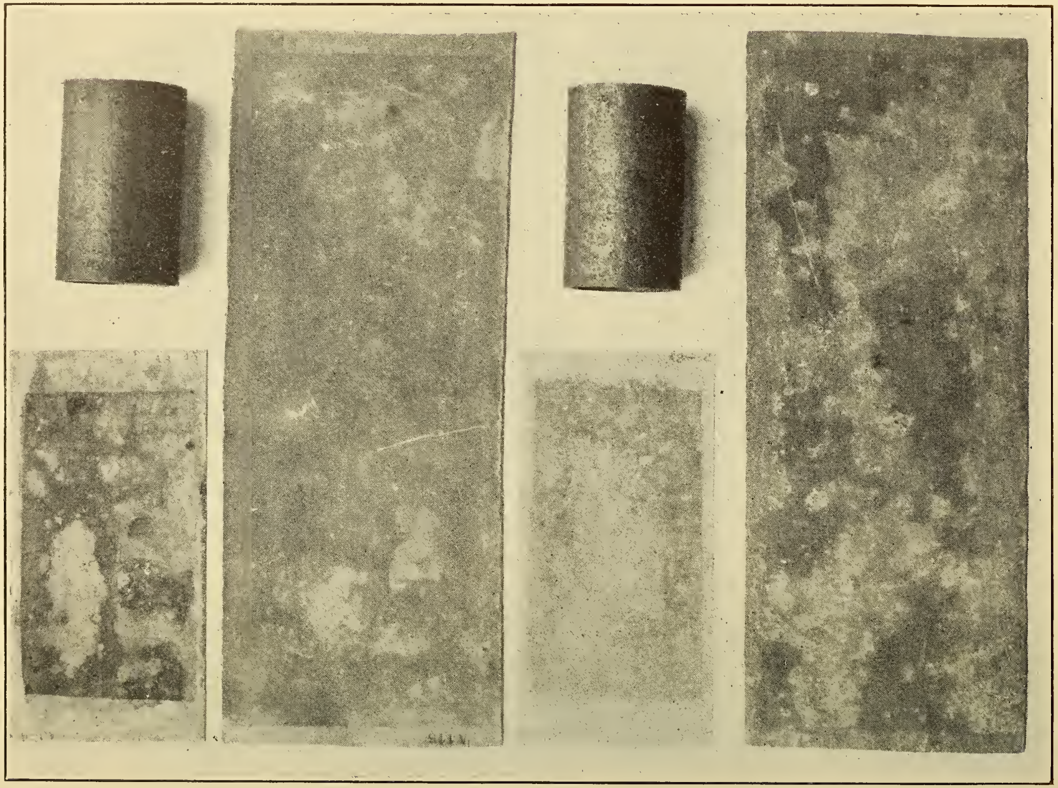

FIG. 18.—*Galvanized iron sheet, steel pipe, and lead cable sheath from Summit silt loam (above) and Marshall silt loam*

information as to the rate of corrosion and probable life of galvanized coatings under a considerable number of diverse soil conditions.

In addition to the galvanized materials, steel pipes coated with two other metals, lead and aluminum, are being tested. The lead-coated pipes are covered with a coating of practically pure lead approximately 0.002 inch thick. The process of applying the coating has been somewhat modified since the specimens were submitted. These specimens were 6 inches long and 1½ inches in diameter.

Two specimens were removed from each location where they had been buried about two years. Table 10 shows the average rate of loss of weight and the average of the deepest pits for the two specimens which were removed in 1926. Pits less than 0.02 inch deep were not measured. Usually the two specimens from the same locality are quite similar, but in a few soils one specimen was found to be in a considerably worse condition than the other. This may be on account of imperfections in the specimens or to irregularities in soil conditions.

TABLE 10.—*Rates of corrosion and pitting of lead-coated pipe*

Soil No.[1]	Years buried	Corrosion rate in ounces per square foot per year	Penetration in mils per year	Soil No.[1]	Years buried	Corrosion rate in ounces per square foot per year	Penetration in mils per year
1	2.59	0.51	21	25	2.68	0.08	19
2	1.94	.11	13	26	2.46	.26	16
3	2.07	.08	(2)	27	2.11	.11	13
4	2.65	.16	15	28	1.64	.34	26
5	2.20	.15	12	29	2.11	.88	18
6	2.20	.05		30	2.54	.05	19
7		(3)		31	2.07	.07	
8	2.67	.14	20	32	2.78	.11	22
9		(3)		33	2.68	.24	15
10	2.68	.06	12	34	2.66	.19	16
11	2.60	.08		35	2.20	.04	
12	2.21	.01		36	2.08	.11	
13	2.29	.05		37	2.07	[4].90	15
14	2.67	.05	8	38	2.64	.09	
15	2.08	.07	10	39	2.64	.19	13
16	2.07	[4].20		40	2.10	.18	15
17	2.62	.32		41	2.55	[4].39	19
18	2.55	.07	9	42	2.08	.14	15
19	2.54	.13	14	43	2.78	.41	Holes.
20		(3)		44	2.55	.04	16
21	2.55	.11	14	45	2.60	.09	12
22	1.95	.44	15	46	2.59	.09	9
23	2.28	.20	21	47	2.60	[4].24	13
24	2.69	.07					

[1] For soil names see Table 3.
[2] Blanks indicate depth of pits less than 0.02 inch.
[3] No specimen.
[4] Specimens cleaned in ammonium citrate. Some of the lead was probably taken off. They are not included in averages.

Figure 19 illustrates a case in which the lead-coated specimen L failed in a soil where an uncoated steel specimen showed only a moderate amount of corrosion. Most of the surface of the coated specimen is in good condition, and the failure may have been caused by galvanic action between the lead and the steel at a point where the coating was injured or imperfect.

It is interesting to compare the condition of these specimens with those of steel pipe (Table 5). Comparing the average rates of loss of two lead-coated specimens with the average rates of loss of six Bessemer steel specimens removed from the same locations in 1924, we find that the lead-coated specimens corroded at a slower rate in all soils. The rate of pitting of the lead-coated pipe was greater in 14 soils and less in 24. Such a comparison may be somewhat misleading as to the ultimate value of the coating, since Table 5 indicates a decrease in the rate of pitting for the uncoated steel, while later the rate for the coated material may be accelerated on account of galvanic action between the coating and the base metal, the latter being electronegative, anodic, to the coating under many soil conditions.

A comparison between the lead-coated pipe and the lead cable sheath H specimens (see Table 14) may also be made, although the depths of pits on the lead sheath have not been measured and are only indicated as slight or bad pits, and the slight pits may be less than the minimum depth measured on the lead-coated pipe. In such cases the lead would be recorded as pitted and the lead coating as unpitted. With this explanation in mind, we may say that in 16 soils both materials showed pits—the lead sheaths showed pits in 10 soils where the depth of pits on the coated pipes were less than 0.02 inch and was unpitted in 11 soils in which the coated pipes were pitted to a greater depth than 0.02 inch. The character of the pitting on the two materials was not the same; that on the coated specimens taking in most cases the form of fine pits while the corroded areas on the lead sheath were usually much larger. On account of the differences in appearance of the pitting and the lack of consistency in the locations where it occurred it is impossible to decide whether the pitting originated in soil action or in imperfections in the coating.

The aluminum coatings were applied to 2-inch steel pipes 6 inches long by two processes and were exposed to six soils. The inside of each pipe was filled with asphalt to confine the corrosion to the outer surface. Table 11 gives the results of the examination of two specimens of each kind from each soil after approximately two years' exposure. While considerable corrosion was found on several of the specimens, the pitting was rather shallow, and the specimens appear to be in better condition than the corresponding specimens of untreated steel. Specimens removed later should afford a better basis for deciding the value of this process as a means of preventing soil corrosion.

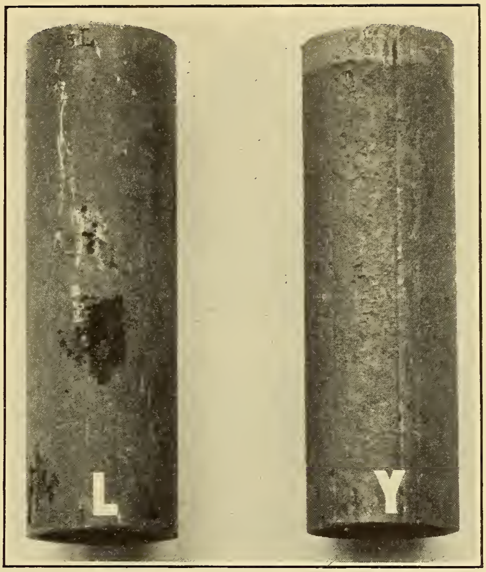

Fig. 19.—*Accelerated corrosion caused by galvanic action. L, lead coated; Y, uncoated steel*

Fig. 20.—*Bituminous coated materials arranged for rating*

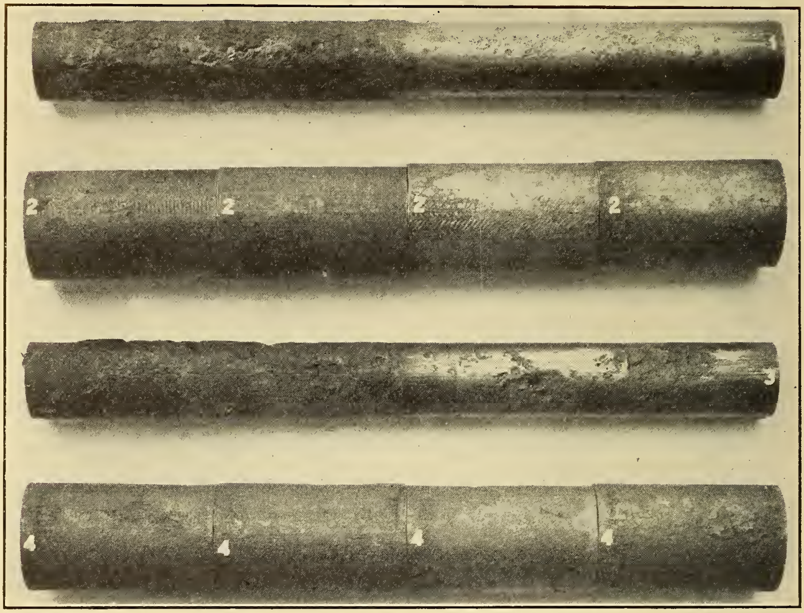

Fig. 21.—*Accelerated corrosion caused by failure of protective coating*

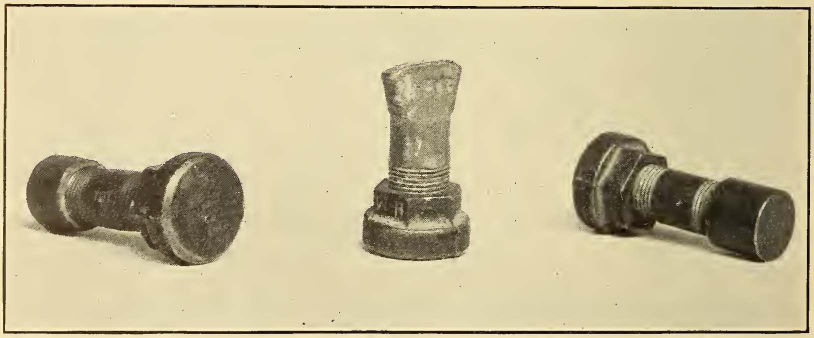

Fig. 22.—*Brass fittings attached to iron, lead, and brass*

TABLE 11.—*Rate of corrosion and condition of calorized pipe*

Soil No.[1]	Years buried	Dry calorized		Wet calorized	
		Loss [2]	Condition	Loss [2]	Condition
13	2.29	0.21	Pitted	0.06	Pitted.
24	2.69	.03	Pitted slightly	.03	Pitted slightly.
28	1.64	.65	Pitted		
29	2.11	.55	do	.34	Pitted.
42	2.08	.35	do	.12	Do.
43	2.78	.59	do	.16	Do.
45	2.60	.18	Pitted slightly	.02	Rusted.

[1] For soil names see Table 3.

[2] Loss in ounces per square foot per year.

VII. TESTS OF BITUMINOUS COATING MATERIALS

At the time the first specimens of uncoated pipe were buried a few specimens of bituminous-coated pipe were also buried, as indicated in section J, page 455. These coatings were selected and prepared by a manufacturer of steel pipe who had been experimenting with protective coatings for a number of years. Later it appeared that a more extensive study of protective coatings should be made, and several large producers of asphalts and tars were consulted as to materials suitable for pipe protection. The selection, preparation, and laboratory testing of the coating materials was done under the supervision of E. H. Berger, then asphalt chemist of the Bureau of Standards, who collaborated in the preparation of this section of this report.

1. COATING MATERIALS USED

As there are numerous varieties of each type it was decided to limit the investigation to a few type materials, which could be applied by the hot dipping processes then commercially used. Coatings and methods in use for the protection of gas and oil lines in the field and already laid were not considered within the scope of this investigation.

Six asphalt coatings and three tar or pitch coatings were considered sufficient for ascertaining the value and usefulness of bituminous dipped pipe coatings. The asphalt coatings were made from the straight residues from Mexican, Texas, and California crude petroleums, and from Mid-Continent asphalt combined with gilsonite, with gilsonite and stearine pitch, and with the residue from Illinois crude oil. The asphalt coatings were all of the blown type and were prepared by blowing the respective crudes with air at elevated temperatures until the required characteristics were obtained.

The tar or pitch coatings were of three different kinds. The first was a low-melting, soft coal-tar pitch produced from high-carbon coal tar, the second was refined low-carbon coal tar from coke ovens, and the third was refined water-gas tar manufactured especially for coating cast-iron pipe.

The materials were furnished by the respective manufacturers, the selection of the proper coating of each type specified being left to the manufacturer. The only conditions which were imposed were that the coating material must be made from raw materials which were then commercially available in such quantities that they should be obtainable at the end of five years. The other requirement was that the coating must be used to a considerable extent commercially.

The following conditions of service were furnished for the manufacturers' information:

(a) The coating material should be impervious to air and moisture.

(b) It should adhere tenaciously to the surface of the pipe.

(c) It should not be brittle at 0° C. (32° F.) or soften to such an extent at 60° C. (140° F.) that it will run or rub off during handling.

(d) It should withstand, without chipping or spalling off, the shocks and abrasion to which the pipe is likely to be subject during transportation and installation.

(e) The coated pipe should not stick together during transportation.

(f) The material should be easily applied by the present approved commercial process of dipping.

(g) The material should be of such a character that any damage occurring in the field can be readily repaired after installation.

2. PREPARATION OF PIPE SPECIMENS

The pipe specimens were butt-welded Bessemer steel pipe 1½ inches in diameter and 17 inches long. Two small holes were drilled in each pipe about ½ inch from the end for inserting the dipping hooks. After cutting and drilling, the pipes were pickled to remove grease, rust, and scale. Immediately before coating they were given a very light pickling to remove grease and rust, passed through a bath of hot dilute alkali, and then thoroughly washed in hot water, after which they were dried on a hot plate and placed in the coating tank.

The apparatus for dipping the pipe consisted of a cylindrical steel tank 30 inches in diameter and of approximately 60 gallons capacity. This tank was provided with a valve near the bottom for emptying and a lid. It was set in a cylindrical furnace of fire brick and was heated indirectly by an oil flame.

3. METHOD OF DIPPING OR COATING

The temperature at which the coating material was applied to the pipes was approximately that recommended by the manufacturer for proper dipping, or when no recommendations were made that decided upon jointly by the representatives of the National Tube Co. which furnished the dipping plant, and by the asphalt chemist of the Bureau of Standards. From 15 to 30 specimens were immersed at one time, and as a specimen was removed from the molten bath another was put in, so that the process was continuous. The pipes were pulled from the bath by means of a windlass at such a rate that there was practically no drip from the lower edge and the coating solidified evenly over the surface. The rate of pulling for the asphalt coatings was from 80 to 90 seconds per 17-inch length of pipe and for the tar-coated specimens from 20 to 30 seconds per 17-inch length of pipe. From 45 minutes to 4½ hours were required for coating the several sets of specimens. Coatings Nos. 1, 2, and 3 required the longest periods of time on account of frothing and other difficulties of handling. In no case, however, were the individual specimens in the bath longer than one-half hour, and this length of time was required only in the case of coatings Nos. 1 and 2. From this standpoint these coatings are somewhat impracticable.

The pipe were dipped twice so as to reduce the tendency to form pinholes. After pulling the first time the pipe were allowed to cool about 1 minute and then were immersed again in the molten bath and allowed to remain from 10 to 30 seconds. They were then again drawn slowly from the bath as before and hung up to cool. The cooled specimens were dusted with Portland cement and wrapped in thin waxed paper, which was followed by ordinary brown wrapping paper.

4. CHARACTERISTICS OF COATING MATERIALS AND RESULTANT COATINGS

No. 1. This material was a mixture of gilsonite and asphalt produced from Mid-Continent petroleum. It had the following characteristics:

Penetration at 32° F., 200 g, 60 sec		21
Penetration at 77° F., 100 g, 5 sec		31
Penetration at 115° F., 50 g, 5 sec		47
Ductility at 77° F.	cm	1. 6
Melting point (ring-and-ball method)	°F	216
Soluble in carbon bisulphide	per cent	99. 9

This material was somewhat "cheesy," and on standing became somewhat sticky on account of the separation of grease. This is characteristic of asphaltic materials made from Mid-Continent crude petroleums. Samples of the coating material both before and after use were tested, and the results were the same on both samples.

For use it was heated to 400° F., the dried pipe were then immersed in it, and this temperature was maintained for one and one-half hours. It was found that at 400° F. considerable frothing occurred, making it rather difficult to get a coating on the pipe free from small bubbles and blisters. After consulting with representatives of the manufacturer of the coating who were present it was decided to allow the material to cool somewhat, and it was found that best results were obtained at a temperature between 365 and 375° F. Four hours were required for dipping this set of pipe on account of difficulties in handling.

Thirty specimens of pipe were weighed before and after coating to determine the average thickness and uniformity of the coating. The weight of coating per 17-inch specimen varied from 31 to 55 grams. The average was 40 grams. The maximum, average, and minimum thicknesses of coating obtained were 0.018, 0.013, and 0.010 inch, respectively.

The coating was quite soft and greasy and smeared over on abrasion. It rubs off and chips on impact, and the adhesion to the pipe is poor.

No. 2. This material consisted of a mixture of Mid-Continent asphalt, gilsonite, and stearine pitch. It had the following characteristics:

Penetration at 32° F., 200 g, 60 sec	14
Penetration at 77° F., 100 g, 5 sec	19
Penetration at 115° F., 50 g, 5 sec	34
Ductility at 77° F cm	2. 0
Melting point (ring-and-ball method) °F	210
Soluble in carbon bisulphide per cent	98. 5
Saponification number	58. 0

This material was glossy, tough, quite rubbery, and was not very much affected by wide variations in temperature. Samples tested before and after the pipes were dipped had the same characteristics.

For use this material was heated to 400° F., but on account of extreme frothing the temperature was reduced, so that the pipe were all drawn between 355 and 380° F. During the dipping considerable scum formed which had to be continually skimmed off during the pulling of the pipe, so that a fairly smooth coating could be obtained. This tendency to froth and to scum over is considered a serious defect in this coating material from a practical standpoint. Four hours were required for dipping this set of pipe on account of this difficulty. No specimen was in the bath longer than 30 minutes.

Thirty specimens of pipe were weighed before and after coating, and from these data the variation in the thickness of the coating was obtained. The maximum weight of coating per specimen was 90 grams, the average 72 grams, and the minimum 60 grams. The maximum, average, and minimum thickness of coating was 0.030, 0.024, and 0.020 inch, respectively.

This material gave a very hard, tough coating which smears on rubbing but which spalls off the pipe on very slight impact and has very poor adhesion to the metal.

No. 3. This material was a mixture of asphalts produced from Illinois and Mid-Continent crude petroleums. It had the following characteristics:

Penetration at 32° F., 200 g, 60 sec	33
Penetration at 77° F., 100 g, 5 sec	49
Penetration at 115° F., 50 g, 5 sec	89
Ductility at 77° F. cm	2. 5
Melting point (ring-and-ball method) °F	181
Soluble in carbon bisulphide per cent	99. 8

This material was soft and somewhat "cheesy" and on standing became sticky on account of the separation of grease. Samples taken before and after the pipes were dipped had the same characteristics.

For application it was heated to 400° F., as recommended, at which temperature it was very fluid and free from froth. Three hours were required for dipping this set of pipe.

Thirty specimens of pipe were weighed before and after coating. The weight of coating per 17-inch length varied between 14 and 27 grams, and the average weight was 20 grams. The maximum, average, and minimum thicknesses were 0.009, 0.007, and 0.005 inch, respectively.

This material gave a very thin, soft, greasy coating which smeared out but did not rub off the pipe on abrasion, and which was pushed off by impact such as would be obtained by knocking the coated pipe together.

No. 4. This material was made from the residuum from heavy Mexican petroleum. It had the following characteristics both before and after the pipes were dipped:

Penetration at 32° F., 200 g, 60 sec	13
Penetration at 77° F., 100 g, 5 sec	20
Penetration at 115° F., 50 g, 5 sec	48
Ductility at 77° F. cm	3. 0
Melting point (ring-and-ball method) ° F	185
Soluble in carbon bisulphide per cent	99. 8

This material was rather hard and tough. The exposed surfaces on standing became somewhat waxy.

A temperature of 350 to 365° F. was found best for application. When heated to 400° F., as recommended by the manufacturer, considerable frothing and foaming occurred, making it difficult to get a smooth coating free from blisters. At a temperature of 365° F. this frothing ceased. This material gave a very smooth, waxy coating which was quite tough and adhesive. It resists abrasion fairly well, but chips when subject to impact. This coating adheres well to metal.

Sixty specimens were weighed before and after coating. The maximum weight of coating was 47 grams, the average 34 grams, and the minimum 24 grams, and the thicknesses of coating were 0.016, 0.011, and 0.008 inch, respectively.

No. 5. This material was made from the residuum from heavy Texas petroleum. It had the following characteristics both before and after the pipes were dipped:

Penetration at 32° F., 200 g, 60 sec		23
Penetration at 77° F., 100 g, 5 sec		33
Penetration at 115° F., 50 g, 5 sec		66
Ductility at 77° F	cm	3
Melting point (ring-and-ball method)	° F	174
Soluble in carbon bisulphide	per cent	99. 9

This material was an air-blown product and was soft and somewhat greasy. For use it was heated to 400° F., at which temperature it gave a very smooth coating free from visible blisters, which smears out on abrasion and spalls slightly when subject to impact.

The amount of material on the specimens was as follows: Maximum 36 grams, average 25 grams, and minimum 19 grams, and the thicknesses were 0.012, 0.008, and 0.007 inch, respectively.

No. 6. This asphalt was made by blowing with air the residue from California crude petroleum. It had the following characteristics both before and after the pipes were dipped:

Penetration at 32° F., 200 g, 60 sec		14
Penetration at 77° F., 100 g, 5 sec		28
Penetration at 115° F., 50 g, 5 sec		80
Ductility at 77° F	cm	5
Melting point (ring-and-ball method)	° F	156
Soluble in carbon bisulphide	per cent	99. 9

This asphalt was a fairly soft rubbery material. For application it was heated to 400° F. A smooth, dull, tough, and somewhat rubbery coating was obtained which spalled when subject to impact and smeared out on abrasion.

The maximum weight of coating was 41 grams and thickness 0.013 inch, the average weight 31 grams and the thickness 0.01 inch, and the minimum weight 24 grams and thickness 0.008 inch.

No. 7. This material was soft coal-tar pitch having a free carbon content of 17 per cent and a melting point of 106° F. On distillation to 355° C. it yielded 24 per cent of distillate and 76 per cent of residue with a melting point of 195° F. Samples tested both before and after the pipes were dipped showed the same characteristics.

The manufacturer recommended that this pitch be heated to 275° F. for application, and that the pipe be preheated and allowed to remain in the hot coating for five minutes. At 275° F. this pitch was very fluid and gave very thin coatings which hardly covered the pipe. After experimenting, it was found that the best results could be obtained with this material between 250 and 260° F. At this temperature a coating was obtained which was heavy enough to cover the steel and which dried hard within 15 minutes after removal from the hot dip. This procedure was approved by the manufacturer's representative who was present.

This material gave a coating that was hard, glossy, and tough, which resists abrasion and adheres well to the metal. It chips, however, when subject to impact. The thickness of the coating was approximately 0.007 inch. This was thicker than any of the other tar coatings.

No. 8. This material was a refined coke-oven tar. It had a free carbon content of 10.5 per cent, a float test at 70° C. of 17 seconds, and on distillation to 355° C. yielded 31 per cent of distillate and a residue melting at 177° F. Samples taken before and after the pipes were dipped on testing showed the same results.

The temperature of dipping was 260° F. At temperatures below this coatings were obtained which required one-half hour and more for drying. A glossy hard, brittle coating was obtained which resists abrasion and chips when subjected to impact. The thickness of the coating was approximately 0.005 inch.

No. 9. This material was a refined water-gas tar prepared for coating cast-iron pipe. It had a specific gravity at 25° C. of 1.12, a free carbon content of 2 per cent, a float test at 70° C. of 8 seconds, and on distillation to 355° C. yielded 55 per cent of distillate and a pitch having a melting point of 320° F. Samples taken before and after the pipes were dipped on testing showed the same results.

The temperature required to give a coating which would dry within 15 minutes was 250° F. At this temperature, however, a very thin, hard, glossy, brittle coat was obtained which chipped on abrasion. The approximate thickness of the coating was 0.004 inch.

In addition to the materials described above, the National Tube Co. prepared a set of samples of pipe wrapped with cloth and impregnated with an asphalt similar to coating No. 1; this is reported on as coating No. 10.

For this report the bituminous specimens buried in 1922 have been assigned numbers as follows:

No. 11. Crude coal tar from a by-product plant boiled down to a melting point of 96° F. and applied at 250° F. The samples were redipped in order to obtain a heavier coating free from porosity.

No. 12. Mid-Continent asphalt and gilsonite applied as a heavy coating.

No. 13. The pipe was single-dipped in the material used for specimen No. 11, over which was applied a wrapping of 6-ounce cotton cloth impregnated with a coal-tar pitch of melting point 150° F., applied at 350° F.

No. 14. Mid-Continent asphalt and gilsonite impregnated fabric.

The characteristics of the bituminous material used on coatings 12 and 14 are as follows:

Penetration at 32° F., 200 g, 60 sec	7–10
Penetration at 77° F., 100 g, 5 sec	25–30
Penetration at 122° F., 50 g, 5 sec	60–70
Melting point (ball-and-ring method) ° F.	215–225
Soluble in carbon bisulphide per cent	99. 30

The fabric used in coating 14 is 3½-ounce cotton applied with lathe type wrapping machine.

Coatings 11 to 14 were applied to 2½-inch boiler tube 24 inches long. The ends of the tube were closed, and insulated leads were brought out by means of which the electrical resistance of the coating could be measured.

It was expected that resistance measurements would indicate the time required for water to penetrate the coating. While tests immediately after the specimens were buried showed high resistance to ground, practically all of the specimens showed very low resistance when tested two years later. Because it was impossible to tell whether this was due to the failure of the coating or to the end insulation, without removing the specimens, half of them were removed for inspection at the end of the four-year period.

In a few localities in California there are also buried sets of specimens of asphalt mastic pipe covering consisting of a mixture of crushed rock, sand, filler, and asphalt. This covering is approximately 1 inch thick and is reported on as coating No. 15. This material consists of 55 to 65 per cent graded sand; 18 to 25 per cent dry limestone dust, rock dust, or cement; and 14 to 18 per cent California asphalt, the latter having a penetration of 25 to 35 at a temperature of 77° F. and a solubility in carbon disulphide of 99.5 per cent.

There were added to these coatings in 1926 samples of machine-wrapped pipe. The covering is an asphalt-impregnated felt applied by a machine built especially for the purpose. In 10 locations specimens of cast-iron pipe coated according to the A. W. W. A. specifications have also been buried. These specimens will not be reported on until 1928 or later.

5. CONDITION OF SPECIMENS REMOVED IN 1926

The 24-inch specimens were shipped in boxes of 10, wooden strip being so nailed across the ends of the boxes that the specimens rested on these strips and could not touch each other. The 17-inch specimens after being wrapped as previously described were also packed in groups of 10, each specimen being separated from the others by a piece of corrugated strawboard. Thus, the chances of injury to the specimens before they reached their destination were reduced to a minimum. The returning specimens were brushed or washed when water was available, wrapped in newspapers, and shipped in boxes especially built for returning these specimens.

Although considerable care was taken in uncovering the specimens, several were injured by the tools of the laborers. These injuries hurt their appearance but do not interfere with determining their condition.

A number of the specimens appear perfect on one side but show deterioration on another side, usually the bottom. In several locations the thick tar coating appears to have flowed, leaving a very thin coat on one side and a thick one on the other. This flow may have taken place before the specimens were buried, but the roughness of the coating suggests that it had taken place after the specimens were buried.

While the majority of specimens appear to be in good condition, a rather surprisingly large number, especially the dipped specimens, show signs of deterioration and several show unmistakable indications of corrosion of the pipe material.

In order to determine the condition of the pipe, the coating was scraped from one-half of the specimen and the pipe washed in gasoline and then oiled to prevent atmospheric corrosion. Thus the effectiveness of the coating could be judged in part by the condition of the pipe surface, allowance being made for isolated corroded spots which might be accounted for by injuries to the coating.

It is rather difficult to present an intelligible description of the individual specimens, and there seems to be no accurate way of expressing the various conditions which they present. On account of these difficulties it was decided to divide the specimens into a number of groups or classes which would show in a general way the results of the exposure to the various soil conditions. The following letters were selected as representing certain distinctions in the appearance of the specimens:

As to condition of coating:
- A. Coating apparently about as when buried.
- B. Coating somewhat deteriorated.
- C. Coating dried out or brittle and porous.

As to condition of pipe:
- a. No indications of corrosion.
- b. Slight general rusting or small shallow pits.
- c. Some pitting or corrosion.

As to adherence of coating to pipe:
- s. Bond good.
- e. Coating does not adhere well.

As to condition of impregnated fabric:
- g. Fabric strong.
- r. Fabric rotted.

The classification of the specimens according to the above designations does not permit sharp distinctions between conditions, and not all who inspect the specimens classify them in the same way. In order to secure as fair a rating of the specimens as possible, the manufacturers of the coatings and the national societies concerned with bituminous materials were invited to send representatives to inspect the specimens and advise the Bureau of Standards concerning the progress report on them. The following organizations responded by sending the representatives indicated:

American Light & Traction Co. (for distribution committee of A. G. A.), D. W. Powell.
American Petroleum Institute, The Asphalt Association, Standard Oil Co. of New Jersey, R. L. Duff.
The Asphalt Association, Prevost Hubbard.
The Johns-Manville Co., E. R. Berger.
The National Tube Co., A. W. Simpson.
Oklahoma Natural Gas Co., E. R. McCarthy.
H. H. Robertson Co., P. D. Gephart.
Standard Oil Co. of California, F. E. Eastman.
Technical Committee No. 3, Sectional Committee on Specifications for Cast-Iron Pipe, A. E. S. C., L. P. Wood.
The Texas Co., F. H. Gilpin.
U. G. I. Constructing Co., W. H. Fulweiler.
United States Cast Iron Pipe & Foundry Co., J. D. Capron.
The Bureau of Standards, represented by P. H. Walker, L. L. Steele, and K. H. Logan.

The specimens were graded by the representatives of the listed organizations in accordance with the plan outlined.

Figure 20 shows the specimens arranged for examination. On account of lack of definiteness in the specifications for the rating symbols, the difficulties in applying a single rating system to materials inherently different, and the lack of familiarity with the properties and characteristics of some of the materials on the part of some of those rating them, there was a wide divergence of views as to the ratings given certain specimens, which reexamination of the specimens in question failed to eliminate. The composite sheets given as Tables 12 and 13 were, therefore, constructed by setting down the rating which represented the ideas of the greatest number and adding plus and minus signs to indicate the tendency of the ratings not agreeing with that recorded. On account of the space required for these tables it is necessary to refer to the soils and the materials by numbers. The soil numbers are the same as in Table 3 and the material numbers those assigned in the earlier part of this section of the report. For convenience, the materials are again listed at the bottom of Table 12. The specimens of asphalt mastic (No. 15) were buried in soils Nos. 5, 12, 13, and 28 in which the makers of the coating were particularly interested. In all locations the rating of the specimens was A a s.

TABLE 12.—*First composite rating of bituminous coatings from seven soils*

Soil No.[1]	Years buried	Coating No.[2]						
		1	2	3	5	6	8	9
13	2.29	C c e	C c+ e	C+ c e	C+ c+e+	C c e	C c s−	C c e+
24	2.69	------	C b e	B+ b s	A− a s	A− b s	B− b− s−	B− b− s−
28	1.64	C c e	C c e	C c e	C c e	C c e	C c+ e+	C c e
29	2.11	C c e	C c+ e	C c e	C c e	C c e	C c e	C c e
42	2.08	B b+ e+	------	------	------	C c e	C c e	C c e
43	2.78	B+ c+ s	A− a s−	C c+ e+	C c+ e	B b s−	C+ c+ e+	C+ c+ s−
45	2.60	B+ a− s	B+ b e+	B c+ e+	B+ b s−	B− b− s−	B a− s−	B− b e+

[1] Soil names given in Table 3.
[2] The properties of these coatings are given on pp. 523 to 528.
1. Mid-Continent asphalt—gilsonite.
2. Mid-Continent asphalt—gilsonite—stearine pitch.
3. Illinois asphalt—Mexican asphalt—gilsonite.
4. Mexican asphalt.
5. Texas asphalt.
6. California asphalt.
7. High-carbon coal tar.
8. Low-carbon coal tar (coke-oven tar).
9. Water-gas tar.
10. Mid-Continent asphalt—gilsonite impregnated fabric.
11. High-carbon coal tar.
12. Mid-Continent asphalt—gilsonite.
13. High-carbon coal tar impregnated fabric.
14. Mid-Continent asphalt—gilsonite impregnated fabric.

The meaning of the rating symbols are given on p. 529.

TABLE 13.—*First composite rating of bituminous coatings from 47 soils*

Soil No.[1]	Years buried	Coating No.[2]			
		13	14	11	12
1	3.58	A a s g	A a−s−g−	C+c e+	B+a s−
2	------	------	------	------	------
3	4.09	A a s g	A−b+s−g−	C c+e+	B+a−s−
4	4.03	A a s g	B+a−e+g−	C+c e+	B+a e+
5	------	------	------	------	------
6	------	------	------	------	------
7	------	------	------	------	------
8	3.80	A a s g	A−a−s−g−	C c e+	B a−s−
9	3.48	A a s g	B+a s−g−	B b+e+	B a−e+
10	4.01	A a s g	A−a−s−r+	B−c+e+	A a−s
11	3.97	A a s g	A−a−s−g	C+c+s−	A−a−e+
12	------	------	------	------	------
13	4.22	A a s g	A−a−s−g	C+c e+	B+b e+
14	3.80	A a s g	A a−s g−	B b s−	B b e
15	------	------	------	------	------
16	4.04	A a s g	A−a−s g−	C+c e+	A−a−s−
17	3.83	A a s g	A−a s g	C c s	B+a−e+
18	3.74	A a s g	A a−s−r+	C+c+e+	A a s−
19	3.66	A a s g	A−a−s−g−	C c s−	B−b+e
20	3.57	A a s g	A−a s g	B c e+	A−a−s
21	4.02	A a s g	B+b+s g−	C c e+	B a−s−
22	3.68	------	A−a s g−	------	B+b+s
23	4.27	A a s g	A−a−s g	C c e+	B+a s−
24	4.01	A a s g	A−b s−r+	B−b s−	A a−s−
25	3.71	A a s g	------	B−c e+	B+a−s
26	3.49	A a s g	A−a−e+g	B−c+e+	A−a−e+
27	------	------	------	------	------
28	------	------	------	------	------
29	4.07	B+a s g	B c+e+r+	C c e+	A−a−s−
30	3.65	A a s g	A−a s g−	C c e+	A−a−e+
31	------	------	------	------	------
32	------	------	------	------	------
33	3.71	A a s g	A a s g	B−c+e+	B+a s
34	4.03	A a s g	A b s g−	C c e+	A a−s−
35	4.14	A−a s g	B+a s g−	C c e+	B+a s

[1] Soil names given in Table 3.
[2] List of coatings given at end of Table 12 and described in pp. 523 to 528.

The meaning of the rating symbols are given on p. 529.

TABLE 13.—*First composite rating of bituminous coatings from 47 soils*—Contd.

Soil No.	Years buried	Coating No.			
		13	14	11	12
36					
37					
38	4.04	A a s g	A—a—s—g	B a s—	A—a s—
39	4.02	A a s g	B+b+e+g—	C c e+	B+b+e+
40					
41	4.02	A a s g	B+a—s r+	C+c e+	B+a—s
42					
43	4.06	A a s g	A—a s g	C c e+	B b—s—
44					
45	3.78	A a s g	A—a s g		
46	4.05	A a s g	A a s g—	C+c+e+	A—a—s—
47	4.08	A a s g	A a s g	B+b+s—	A a e+

Soil No.[1]	Years buried	Coating No.[2]		
		10	4	7
1	2.59		A—a s	B—c e+
2	1.94	B a—e r+	C c+e	C+b—e+
3	2.07	A—a—e+g—	B+a—s	B b+s—
4	2.65		C+c e	B—c s—
5	2.20	A b+e+r+	B c+e+	B b—e+
6	2.20	A a e g	A a—s	B b+s—
7	2.46		B+c+s	B—b—e+
8	2.67	B a—e r+	C c e+	B—b+s—
9	2.45		B b e+	B c s
10	2.68		B b—e+	B b+s—
11	2.60	A—b+e r+	B c+s—	C+b—s—
12	2.21	A a s g	B+a s	C+a—s—
13	2.29	A—b e r	C+c+e+	C c e+
14	2.67		B—b—e+	
15	2.08	A b+e r+	C b—e	C+b—e
16	2.07	A—a—e+r+	B c e+	B—c+s—
17	2.62	A—a—e+g—	B—b e+	B—b s
18	2.55		B+a—s	B—b e+
19	2.54		B+b s	B c+s—
20	2.59		B+a—s—	B—c e+
21	2.55		B—b—e+	B—c+s—
22	1.95		C c+e	B—c+s—
23				
24	2.69		B+c+s	B—b e+
25	2.68		B+b+s—	B a s—
26	2.46		C+b e	B—a—s—
27	2.11	A—a—e r+		
28	1.64	A—b e r+	C c e	C+c e
29	2.11	B b+e r	C c e	C c e+
30	2.54		B+a—s—	B+a s—
31	2.07		C c+e	C b s—
32	2.78		B+b+s—	B b+e+
33	2.68		B—b—s—	C+c+e+
34	2.66	A b+e g—	B c+s—	B b s—
35	2.20	A a e+g	B+a s	B a—s—
36	2.08	B+a—e+g—	B+a s—	B—a—s—
37	2.07		C c+e	C c+e+
38	2.64	A—a—e r+	B—c+e+	B—b e+
39	2.64		B b e+	B—c+s—
40	2.10	A—b+e r+	C+c e+	C c e+
41	2.55		B—b—e+	B—c+s—
42	2.08			C+b—s—
43	2.78		B b s—	B—b—s—
44	2.55		B b e+	B a—s—
45	2.60		A—a—s	C+a—e+
46	2.59		C+c e	C c e+
47	2.60		B+b+s—	B c s—

[1] Soil names given in Table 3.
[2] List of coatings given at end of Table 12 and described in pp. 523 to 528.
The meaning of the rating symbols are given on p. 529.

In comparing the materials it is necessary to keep in mind the fact that some of them have been buried longer than others, as is indicated in the columns showing the time of exposure in each soil. Such tables are probably the best that could be secured under the circumstances and in a way indicate the condition of the specimens. They have the defects of giving equal weights to the qualified and less qualified observers and of making the conditions appear more nearly uniform than they actually appear to any one observer. If it did nothing else, this attempt at rating by a representative group of men specializing in bituminous materials and their application as protective coatings served to bring out the need for a standard method of determining the condition of bituminous coatings applied to pipes.

In applying the data derived from these specimens to practical pipe protection it is well to bear in mind that the tests only show the action of the soil on the coating, and that the specimens were more carefully coated and handled than pipe lines could be. The failure of a coating indicates that probably a similar coating would be unsatisfactory in the soil involved, but a satisfactory specimen coating might give unsatisfactory service if it could not be properly applied to or maintained on a pipe line.

In this connection it should be noted that in these tests there is not the same tendency for the soil to pull the coating from the pipe as is the case of coated pipe lines because the latter move with respect to the soil on account of changes in temperature, vibration, etc.

It appears, therefore, that the specimens represent tests of coating materials rather than protective coatings, and that these tests should be supplemented by others which would take account of the factors involved in pipe-line protection which are not included in the Bureau of Standards tests.

Although the specimens were prepared in accordance with the instructions of the manufacturer as to temperature and time of dipping, it is obvious that these specifications do not conform to ordinary shop practice. Furthermore, these methods are not in accordance with methods regularly followed for coating pipe in the field. A more comprehensive test should include coatings so applied.

On account of the nonhomogeneous nature of soils and unavoidable differences in the thickness of a protective coating the close association of the condition of a given specimen and either the character of the soil or the kind of coating is difficult. Specimens may show differences due to accidental variations in either soil or coating, and a number of tests under the same condition are necessary for reliable conclusions. The specimens which form the basis for this report are but a fourth of those included in the test, and usually but one specimen of a kind has been removed from each soil. Conclusions, therefore, should be regarded as tentative and subject to revision in the light of the data which will be secured from the specimens removed later.

Tables 12 and 13 indicate that a rather surprisingly large percentage of coatings showed signs of deterioration, and that in a number of cases this deterioration resulted in rusting or pitting of the pipe. The character of the deterioration differed with the type of coating and the character of the soil. In some cases the coating becomes brittle and loses its adhesion to the pipe. It is not yet clear whether this loss of adhesion is due to the formation of rust or to changes in the coating. A study of the table will show that, generally speaking, the pitch coating adhered to the pipe better than the asphalt.

The material of the thick pitch coating appears to have undergone little, if any, chemical change, but in a number of cases it has flowed until little or none is left on one side of the pipe. In several cases this apparently resulted in an acceleration of the corrosion of the pipe, since in several soils the pitting on the pitch-coated specimens, No. 11, was greater than on the uncoated steel specimens. This is illustrated in Figure 21. The unsatisfactory results obtained with material No. 11 are largely due to the low melting point of the material and, perhaps, also in part to some foreign material which it contained. The record of the material used is not as complete as in some of the other materials. The results should be applied to this material only and not to coal-tar coatings in general. The pitch-impregnated fabric coating shows little deterioration, but in some cases is dull and in others rather brittle.

In a number of cases the asphalt coating appears to be in at least fairly good condition, but the pipe is found to be coated with a thin layer of rust. Asphalt coatings covering slightly rusted pipe sometimes appear to have dried out, while other asphalt coatings show fine and occasionally rather large irregular cracks. Occasionally a coating is found which appears to have expanded and pulled away from the pipe. The asphalt-impregnated fabric specimens appear slightly better than the dipped specimens, but in a number of cases the bond between the coating and the pipe is poor and the pipe slightly rusted. It appears that moisture enters either through the coating or through pinholes or abrasions and then spreads along the pipe surface. The coating apparently retards corrosion but does not completely prevent it even during the first two to four years in a number of soils.

There does not seem to be a close relation between the action of a soil on bituminous coatings and its action on pipe material. For example, the worst pipe corrosion was found in Buttonwillow, Calif.

(soil No. 23); Elizabeth, N. J. (soil No. 43); and Meridian, Miss. (soil No. 42), while the most deteriorated coatings were found in San Diego (soil No. 28) and New Orleans (soil No. 29). Naturally, however, when the coating fails the deterioration of the pipe is determined by the relation of the soil to pipe corrosion, and, hence, we find in the tables cases of bad coating conditions over a pipe in fair condition, and bad pitting in some localities in which the coating is better.

The following conclusions apply only to the particular materials and methods of application included in these tests and may be noted as a result of the examination of the first sets of specimens.

The thin bituminous coatings add somewhat to the life of a pipe, but in many soils they deteriorate and do not furnish adequate protection against soil corrosion.

The bond between the coating and the pipe seems to hold better in the pitch coatings, but certain of these coatings are friable and easily scraped from the pipe.

The thick pitch coating has a tendency to creep or flow, to leave the upper part exposed, and to allow stones and pebbles to penetrate the coating. It also tends to become brittle, but this may not affect its protective value when the protected pipes are not exposed.

Reinforcing the pitch coating by wrapping the pipe with a loosely woven fabric which can be impregnated with the pitch adds materially to the value of the protection by keeping the coating in place.

There is some evidence of deterioration of the bituminous materials in some soils, and in such soils a bitumen-impregnated fabric coating will not afford permanent protection against soil action.

A coating better than any of the dip coatings under test is needed for a number of soil conditions.

VIII. TESTS OF MISCELLANEOUS MATERIALS

This section of the report deals with a rather wide range of materials grouped together because they are not easily associated with the tests previously described.

The subdivisions of the group are due to the way in which the test is being conducted rather than to any close relation between the specimens in the subdivision. As in the cases of the other groups of materials, the manufacturers who furnished the materials to be discussed and the national societies concerned with them were invited to attend an advisory meeting, the objects of which were to examine the materials and read the proposed report concerning them. The following organizations responded:

American Gas Association, J. K. Crowell and D. D. Ransdell.
American Machine & Foundry Co., W. H. Spowers, jr.
American Petroleum Institute, R. L. Duff.

American Rolling Mill Co., J. R. Cain and A. G. Sheldon.
American Sheet & Tin Plate Co., E. S. Taylerson.
American Water Works Association, Harvey R. Hall.
Bell Telephone Laboratories, R. M. Burns.
Bridgeport Brass Co., Committee B–3, A. S. T. M., J. L. Christie.
Bureau of Mines, A. J. Kraemer.
Copper and Brass Research Association, William G. Schneider.
U. T. Hungerford Brass & Copper Co., Chase Brass & Copper Co., A. Y. Miller.
Mueller Brass Co., C. A. Hill, C. A. Nemo, and F. M. Levy.
Mueller Co., C. T. Ford and W. J. Mix.
National Lead Co., William A. Cowan.
Standard Underground Cable Co., Edward Kerschner.
The Bureau of Standards, represented by S. P. Ewing, K. H. Logan, and H. S. Rawdon.

1. LEAD SHEATH MATERIALS

At the time the first soil-corrosion tests were planned it was decided to include specimens of cable sheath because they were involved in the studies of stray current electrolysis. Two kinds of sheath were secured—lead containing antimony, such as was in use by some telephone companies, and commercial lead, frequently used for power-cable sheaths. The lead was received in the form of sheaths or tubes and cut into 22-inch lengths. To facilitate the test, the tubes were split and the lead flattened to the form of sheets before the specimens were buried. The antimony-lead specimens were 8½ inches wide and the commercial lead specimens 3½ inches in width. Part of these specimens were buried in 1922 and the remainder in 1923 and 1924. They were weighed to 0.1 gram before burial and again upon recovery. The cleaning of the specimens after removal from the soil was accomplished by the use of a solution of oxalic and nitric acid. The losses of weight were determined, and the rate of loss is given in Table 14. The surfaces of the sheets are not sufficiently plane to permit the determination of the depth of the comparatively shallow pits which occurred on some of the specimens.

TABLE 14.—*Corrosion rate and condition of lead sheaths*

Soil No.[1]	First period					Second period				
	Years buried	A[2]		H[2]		Years buried	A[2]		H[2]	
		Condition[3]	Loss[4]	Condition[3]	Loss		Condition	Loss	Condition	Loss
1	0.98	B	0.35	B	0.36	3.58	B	0.14	B	0.19
2	1.94	B	.21	B	.13	-------	-------	-------	-------	-------
3	2.07	S	.14	S	.16	-------	-------	-------	-------	-------
4	1.38	S	.15	N	.16	4.03	-------	-------	B	.10
5	2.20	B	.18	B	.18	-------	-------	-------	-------	-------
6	2.20	S	.06	S	.06	-------	-------	-------	-------	-------
7	1.04	B	.71	B	.77	-------	-------	-------	-------	-------
8	1.13	N	.10	N	.11	3.80	N	.09	N	.05
9	1.03	N	.14	N	.13	3.48	B	.16	S	.08
10	1.33	N	.08	N	.12	4.01	S	.11	N	.09
11	1.36	N	.09	N	.10	-------	-------	-------	-------	-------
12	2.21	N	.03	N	.03	-------	-------	-------	-------	-------
13	1.93	S	.02	S	.03	4.22	N	.03	N	.04
14	1.13	N	.07	S	.12	3.80	B	.18	S	.07
15	2.08	S	.14	S	.14	-------	-------	-------	-------	-------
16	2.07	B	.15	B	.14	-------	-------	-------	-------	-------
17	1.21	S	.45	N	.25	3.83	N	.14	N	.13
18	1.19	B	.11	N	.08	3.74	B	.09	S	.06
19	1.12	-------	.29	-------	.29	3.66	B	.11	B	.09
20	.98	B	.22	S	.20	3.57	B	.22	B	.15
21	1.47	B	.65	B	.44	4.02	B	.26	B	.46
22	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
23	1.93	S	.02	S	.02	4.27	S	.02	N	.03
24	1.32	-------	.05	-------	.08	4.01	N	.04	N	.06
25	1.03	B	.16	B	.16	3.71	S	.05	B	.06
26	1.04	B	.38	B	.21	-------	-------	-------	-------	-------
27	2.11	N	.12	B	.09	-------	-------	-------	-------	-------
28	1.64	S	.27	N	.20	-------	-------	-------	-------	-------
29	2.11	B	.62	B	.51	-------	-------	-------	-------	-------
30	1.11	B	.31	B	.52	3.65	B	.12	B	.13
31	2.07	N	.06	S	.08	-------	-------	-------	-------	-------
32	.94	N	.10	N	.12	3.73	N	.09	N	.06
33	1.03	N	.17	N	.20	3.71	B	.25	S	.20
34	1.38	B	.54	B	.28	4.03	B	.28	B	.17
35	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
36	2.08	N	.14	S	.17	-------	-------	-------	-------	-------
37	2.07	B	.40	B	.36	-------	-------	-------	-------	-------
38	1.40	S	.07	S	.15	4.04	B	.05	B	.05
39	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
40	2.10	B	.27	B	.16	-------	-------	-------	-------	-------
41	1.47	S	.06	-------	.09	4.02	N	.07	B	.07
42	2.08	S	.26	S	.49	-------	-------	-------	-------	-------
43	1.29	B	.06	S	.07	4.06	B	.04	S	.02
44	1.09	N	.22	N	.13	3.63	N	.22	B	.14
45	-------	-------	-------	-------	-------	3.78	N	.03	N	.04
46	1.46	B	.12	B	.07	4.05	B	.11	S	.03
47	1.48	B	.10	N	.13	4.08	B	.07	N	.04

[1] For soil names see table 3.
[2] A, Antimony lead alloy; H, commercial lead.
[3] N, no pits; S, slight pits, less than 0.020 inch; B, badly pitted greater than 0.020 inch.
[4] Loss in ounces per square foot per year.

Specimens of the antimony lead removed in 1926 showed at least slight pits in 30 out of the 47 locations. In 8 of these locations the pitting is slight and in most cases confined to a small portion of the surface. The specimens were placed on edge in the trench in order to expose both sides to the same conditions. Frequently, the lower portion shows the maximum corrosion. In the 24 locations from which specimens were removed in 1924 and 1926, 15 show a decreased rate of corrosion. In a portion of these 15 the decrease in rate is small and may be due to accidental conditions, such as variations in the soil. In a few cases the decrease is 50 per cent or greater, while in two cases there is an increase of over 50 per cent in the rate of corrosion.

In general, the results for the commercial lead sheath are similar to those for antimony lead. Of the 47 specimens removed in 1926, 29 show some pitting. In 8 of these cases the pitting was only slight. In but 2 soils was there any increase in the rate of corrosion, and in each case the increase was too small to be significant. In 14 out of 25 there was a decrease in the rate of corrosion of 40 per cent or more.

Comparing the rates of corrosion of the two kinds of lead, we find that for the first period, about 2 years, out of a total of 43 soils the antimony lead was better in 21 soils and worse in 19 soils, while for the specimens removed after approximately 4 years the antimony lead was better in 6 soils and worse in 16 out of a total of 25 soils having 4-year specimens. The difference in the results for the two periods is accounted for partly by the greater decrease in the rate of corrosion of the commercial lead. The differences between the two leads are not great, and it is too early to draw conclusions as to their relative merits.

2. PARKWAY CABLE

Closely related to the study of corrosion of cable sheaths is the effect of soils on armored cable designed for burial directly in the ground. This material is sometimes known as parkway cable, and consists of a lead-sheath cable protected by layers of impregnated jute and spirally-wound strips of iron covered by a bitumen-impregnated fiber wrapping. The metal wrappings of the specimens removed in 1926 were protected by a very thin coating of zinc. Table 15 shows the results of the inspection of the specimens which in most soils were 22 inches long and about ⅞-inch in diameter. The ends of each specimen were protected by a heavy covering of asphalt. While in a few soils the metal armor shows considerable corrosion, the lead sheath is in good condition in all locations.

3. BRASS FITTINGS

Since brass shut-off cocks are used in connection with water and gas service pipes, it seemed proper to determine whether they would be affected by soil action and whether their use in connection with iron and steel pipes would result in galvanic action.

The study of the relation of soil to the corrosion of brass was approved by the Water Works Standardization Committee of the National Brass Manufacturers Association, and the materials for the test were furnished by them.

TABLE 15.—*Condition of Parkway cable*

[All steel is galvanized]

Soil No.[1]	Years buried	O. F.[2]	I. F.	O. S. C.	I. S. C.	L. S.
1	3.58	G[3]	G	G	G	W
2	1.94	F	G	SR	G	W
3	2.07	F	G	R	SR	W
4	4.03	F	G	SR	G	W
5	2.20	G	G	R	G	TW
6	2.20	G	G	R	G	G
8	3.80	G	G	G	G	TW
9	3.48	G	G	R	R	TW
10	4.01	G	G	G	G	G
12	2.21	G	G	R	SR	TW
13	4.22	B	F	BR	R	G
14	3.80	F	G	G	G	W
15	2.08	G	G	R	R	TW
16	2.07	G	G	R	R	W
17	3.83	G	G	R	SR	G
18	3.74	G	G	VSR	G	W
19	3.66	G	G	VSR	G	W
20	3.57	G	G	G	G	W
21	4.02	G	G	SR	G	W
23	4.27	B	F	BR	BR	W
24	4.01	G	G	G	G	G
25	3.71	G	G	G	G	W
27	2.11	F	F	R	SR	W
28	1.64	G	G	G	G	W
29	2.11	G	G	SR	VSR	TW
30	3.65	G	G	G	G	W
32	3.73	G	G	G	G	W
33	3.71	G	G	G	G	W
34	4.03	G	G	G	G	TW
36	2.08	G	G	G	G	W
37	2.07	G	G	SR	G	TW
38	4.04	G	G	SR	G	TW
40	2.10	G	G	R	R	G
41	4.02	F	G	SR	G	TW
42	2.08	G	G	R	SR	TW
44	3.63	G	G	VSR	G	W
45	3.78	G	G	SR	G	TW
46	4.05	G	G	G	G	W
47	4.08	G	G	G	G	W

[1] For soil names see Table 3.

[2] O. F., outer fabric; I. F., inner fabric; O. S. C., outer steel coating; I. S. C., inner steel coating; L. S., lead sheath.

[3] Rating: G, good; F, fair; B, bad; R, rusted; SR, slightly rusted; VSR, very slightly rusted; BR, badly rusted; TW, thin white corrosion product on lead sheath; W, white corrosion product on lead sheath.

It was the intention of the association to furnish four kinds of brass, each kind being attached to three different metals (lead, iron, and brass), in order that the effect of the galvanic couples so formed might be observed. The cast-brass caps with which the test was primarily concerned are 1½ inches in diameter and 1 inch long. Into these are screwed 2-inch lengths of ½-inch lead pipe closed at the other end by pinching the pipe, or brass or galvanized iron nipples closed at one end by the cast-brass cap and at the other by caps of the same material as the pipe. Figure 22 shows the cast caps attached to galvanized iron (left), lead (center), and brass nipples (right). Bare iron was exposed to the soil at the threaded portions of the iron pipe.

The brass nipples and the small caps used to close their ends have a composition of approximately 60 per cent copper and 40 per cent zinc. The weight of galvanizing on the iron nipples was not determined. The cast caps nominally of the same material were not all cast at the same time, and on this account they differ somewhat in composition. Table 16 gives the analysis of the several compositions as furnished by the manufacturer. The first column of this table indicates the mixture numbers. These consist of two digits, the units column indicating the class to which the caps belong—that is, 1, 2, 3, or 4—while the tens column indicates whether the specimens were selected from the first or second lot of castings. Thus, the caps numbered 23 belong to the third kind of brass and were selected from the second lot, while those numbered 13 are nominally of the same composition but were cast earlier.

An examination of the table will show that some of these alloys contain considerable amounts of tin and might well be called bronze rather than brass. However, as they were all supplied as samples of brass and are considered together it is more convenient to use the term brass to designate the material.

Table 16.—*Composition of cast-brass caps*

Class	Cu	Sn	Pb	Zn	Fe
11	85. 61	3. 45	4. 49	6. 30	----------
21	85. 29	3. 55	5. 11	6. 05	----------
12	86. 91	5. 50	1. 62	5. 97	----------
22	87. 20	6. 23	1. 92	4. 65	----------
13	94. 20	----------	. 51	5. 29	----------
23	89. 38	. 15	. 16	10. 13	----------
33	75. 2	1. 3	2. 2	19. 7	1. 04
14	75. 07	1. 38	1. 89	20. 55	1. 113
24	74. 81	1. 48	3. 24	19. 69	. 77

Analysis furnished by manufacturer.

So far as the corrosion data now available are concerned, the influence of the variations in composition of the alloys can not be detected. On this account all of the cast caps removed from one soil that were attached to the same kind of pipe are averaged together and the results tabulated in Table 17. When additional specimens are removed it may be desirable to distinguish between the alloys. The rates of losses for the cast-brass caps have been divided into groups depending on the materials to which the caps were attached. The losses in column A are for caps attached to lead pipe, those in column B for caps attached to brass nipples, and those in column C for caps attached to galvanized-iron nipples. Following these columns are columns of rates of losses for the nipples to which the cast caps were attached and last are given the rates of corrosion of the small brass and galvanized caps.

Although the number of specimens of one kind is too small to justify final conclusions as to the results of the test, Table 17 indicates several things of interest. It will be noticed that the corrosion losses of the cast-brass caps are small in all soils. No pits of appreciable depth were found on any of them.

TABLE 17.—*Rates of corrosion* [1] *of brass fittings*

Soil No.[2]	Years buried	Cast caps			Nipples			Caps	
		A	B	C	Lead	Brass	Galvanized	Brass	Galvanized
1	2.59	0.00	0.02	0.05	0.28	0.03	2.31	0.02	2.93
2	1.94	.02	.04	.01	.87	.16	.39	.13	.50
3	2.07	.01	.03	.00	.97	.10	.49	.06	.68
4	2.65	.03	.03	.00	1.78	.35	.82	.07	.94
5	2.20	.01	.02	.02	.95	.18	.83	.06	1.64
6	2.20	.01	.02	.01	.28	.02	.24	.03	.16
7	2.46	.00	.02	.00	1.05	.29	.54	.19	.88
8	2.67	.02	.00	.00	.24	.12	1.23	.07	.64
9	2.45	.01	.05	.00	1.03	.23	.63	.29	.59
10	2.68	.01	.03	.00	.53	.14	.31	.09	.48
11	2.60	.02	.03	.00	.92	.11	.28	.08	.44
12	2.21	.04	.03	.00	.12	.01	.20	.01	.18
13	2.29	.01	.02	.02	.52	.02	1.98	.14	2.06
14	2.67	.02	.00	.00	1.40	.12	.29	.02	.67
15	2.08	.02	.02	.01	.61	.13	.62	.06	1.04
16	2.07	.02	.03	.00	1.28	.22	.54	.06	.78
17	2.62	.03	.04	.01	1.22	.25	1.06	.14	1.52
18	2.55	.00	.01	.00	.77	.06	.22	.08	.51
19	2.54	.01	.03	.00	1.28	.23	.44	.14	.70
20	2.59	.01	.01	.01	.71	.09	.60	.04	.97
21	2.55	.00	.02	.00	.80	.08	.24	.05	.43
22	1.95	.05	.03	.01	1.21	.38	.76	.07	1.05
23	2.28	.12	.01	.02	.14	--------	(3)	.20	(3)
24	2.69	.01	.01	.00	.22	.06	.21	.04	.23
25	2.68	.00	.04	.00	1.14	.13	.48	.06	.43
26	2.46	--------	.02	.01	--------	.13	.72	.09	.54
27	2.11	.01	.01	.01	.78	.09	.37	.06	.43
28	1.64	--------	--------	.02	--------	--------	2.84	--------	5.87
29	2.11	.03	.04	.03	3.50	.80	2.63	.33	2.11
30	2.54	.01	.02	.00	.64	.10	.67	.02	.45
31	2.07	.01	.01	.01	1.24	.15	.50	.04	.53
32	2.78	.01	.01	.01	.65	.49	.46	.03	.54
33	2.68	.03	.03	.00	.48	.33	.56	.04	.69
34	2.66	.05	.04	.00	.29	.17	.60	.05	.35
35	2.20	.00	.00	.01	.24	.02	.30	.01	.57
36	2.08	.01	.04	.00	.91	.10	.44	.12	.54
37	2.07	.04	.04	.02	4.06	.35	1.40	.26	1.84
38	2.64	.01	.00	.01	.41	.06	.33	.02	.30
39	2.64	.04	.04	.00	1.59	.39	.94	.06	.76
40	2.10	.02	.03	.01	1.11	.36	.81	.08	.61
41	2.55	.02	.05	.02	2.97	.35	1.87	.20	1.53
42	2.08	.01	.03	.00	2.18	.36	1.23	.13	1.94
43	2.78	.60	.75	.46	.13	.05	.48	.12	.66
44	2.55	.02	.02	.01	.40	.05	.35	.04	.75
45	2.60	.02	.01	.00	.11	.05	.29	.01	.51
46	2.59	.00	.01	.01	.55	.09	1.29	.02	2.34
47	2.60	.02	.01	.00	.25	.03	.19	.03	.53

[1] Corrosion in ounces per square foot per year. [2] For soil names see Table 3. [3] Sample failed.
Blanks indicate missing specimens.

The brass nipples show little loss of weight, but usually they are dark or reddish. The galvanized nipples show greater losses, and in a large number of soils most or all the galvanizing has disappeared. In one soil all of the galvanized nipples were perforated.

The short sections of lead pipe which were connected to the brass caps show pitting in many soils, and in all soils their rate of corrosion is much greater than that of the lead cable sheath. (See Table 14.) This may be on account of the lead being electronegative to the brass to which it was connected. A similar effect appears to be present in the case of the galvanized nipples which corroded much worse than the 17-inch specimens of galvanized pipe buried in the same soils for the same time. If connecting two dissimilar metals causes accelerated corrosion of the one which is electronegative, the corrosion of the electropositive one may be retarded, and there is some evidence of such an effect on the samples under discussion, since the average rate of corrosion of the cast brass connected to galvanized iron nipples is the least and the average rate for the caps connected to brass nipples is the greatest. However, the data on the individual specimens show numerous exceptions to this generalization.

As has been said before, the number of specimens examined is too small and the duration of the test too short to justify conclusions at this time. The study of nonferrous pipe materials was supplemented in 1926 by the burial of several additional kinds of materials. These will not be examined before 1928. These materials are listed in Table 18.

TABLE 18.—*Composition of copper and alloy specimens buried in 1926*

Class	Form	Cu	Pb	Zn	Al	P	Fe	Ni
E	¾-inch tube	99. 97	--------	--------	--------	--------	--------	--------
M	do	99. 93	--------	--------	--------	--------	--------	--------
P	do	99. 94	--------	--------	--------	0. 015	--------	--------
H	do	84. 99	0. 01	14. 97	--------	--------	0. 03	--------
B	½-inch tube	60	--------	40	--------	--------	--------	--------
BC	½-inch caps	64	2. 5	33. 5	--------	--------	--------	--------
L	½-inch ells	59	2. 5	38. 5	--------	--------	--------	--------
N	7/16-inch rod	87	--------	--------	9. 5	--------	3. 5	--------
A	do	47	2. 5	40. 5	--------	--------	--------	10

C, 1-inch tube, chromium, 26 to 28 per cent; Si and Mn, 0.5 per cent; C, 0.2 per cent; Fe, remainder.
These analyses were furnished by the manufacturers of the materials.

4. FERROUS AND NONFERROUS PLATES AND SHEETS

In 1924 the Bureau of Mines was interested in the development of an accelerated corrosion test and desired some field data with which to check their laboratory results, and the Bureau of Standards agreed to bury samples in which the Bureau of Mines was interested along with the other specimens in the soil-corrosion investigation. In order to avoid duplication of work by two bureaus these specimens were later made a part of the soil-corrosion investigation and, although some are not materials usually subjected to soil action, the data on this group are of considerable interest. To simplify the report, we have included with the specimens furnished by the Bureau of Mines a few others. Table 19 shows the general character of the materials in this group. More detailed data on them may be secured before the final report is issued. Table 20 shows the rate of corrosion and pitting of these materials. As, in most cases, there were removed but two specimens of each kind in only five soils, the data are insufficient for many purposes, but the results are interesting.

In order to protect the identification numbers and to avoid galvanic action between the cut edges and other parts of the specimens, all edges of the specimens were protected with a heavy coating of asphalt applied hot. In a few cases moisture got under this asphalt, and greater corrosion resulted at such points than elsewhere on the specimens. The most striking features of this part of the test were the heavy adherent layer of corrosion products on the copper and bronze in the tidal marsh, the deep isolated pits on some of the zinc specimens, and the failure of the aluminum and duralumin by the formation of blisters. These seem to start as a slight elevation of the surface of the metal caused by the formation of corrosion products beneath the surface. The corrosion seems to be going on beneath rather than at the surface of the metal. This apparently continues until the specimen is disintegrated.

TABLE 19.—*Character and dimensions of miscellaneous specimens*

Symbol	Description
A	Pure open-hearth iron, 2 by 6 by 0.125 inch.
S	Copper-bearing steel, 2 by 6 by 0.0625 inch.
CA	Pure open-hearth iron, 6 by 12 by 0.0495 inch.
CB	Bessemer steel, 6 by 12 by 0.0495 inch.
CY	Copper-bearing steel, 6 by 12 by 0.0495 inch.
Z1	Zinc sheet, 99.5 per cent pure, 2 by 6 by 0.0625 inch.
Z2	Zinc plate, 99.5 per cent pure, 2.5 by 6.5 by 0.25 inch.
Z3	Corrugated zinc sheet, 12 by 12 by 0.027 inch.
P	"Standard" zinc sheet, 2 by 6 by 0.0625 inch.
L	Bronze 90–10 Cu-Sn, 2 by 6 by 0.25 inch.
B	Brass 70–30 Cu-Zn, 2 by 6 by 0.050 inch.
H	Copper sheet, 2 by 6 by 0.050 inch.
N	Chemical lead (0.05–0.08 per cent Cu, about 0.005 per cent Ag) 2 by 6 by 0.25 inch.
NN	Hearth refined lead (less than 0.001 per cent each of Cu and Ag), 2 by 6 by 0.25 inch.
C1	Commercial aluminum, 2 by 6 by 0.0625 inch.
C2	Aluminum with 1.5 per cent Mn, 2 by 6 by 0.0625 inch.
C3	Duralumin, 2 by 6 by 0.0625 inch.
AS	Zinc sprayed sheets with pure open-hearth iron base, 3.25 by 3.25 by 0.030 inch.
ES	Zinc-sprayed sheets with sheet steel base, 3.37 by 3.37 by 0.030 inch.
D	Wrought-iron nuts and bolts, 2 by 0.75 inch.
F	Lead-coated nuts and bolts, 2 by 0.75 inch.
G	Sherardized nuts and bolts, 2 by 0.75 inch.

TABLE 20.—*Rates of corrosion and penetration of miscellaneous specimens*

Soil No.[1]	13		24		28	29		42		43		45	
Years buried.	2.29		2.69		1.64	2.11		2.08		2.78		2.60	
Material[2]	Loss	Pits	Loss	Pits	Loss	Loss	Pits	Loss	Pits	Loss	Pits	Loss	Pits
A	1.12	12	------	------	------	2.94	F	2.16	19	2.34	22	0.28	8
S	1.33	16	------	------	------	2.10	17	1.73	F	1.83	------	.27	9
CA	3.20	------	0.91	------	4.30	4.75	------	4.20	2.96	2.59	------	.97	------
CB	2.66	------	.66	------	3.83	4.10	------	3.67	2.95	2.66	------	.55	------
CY	3.06	------	.74	------	3.91	4.43	------	2.70	3.91	2.32	------	.64	------
Z1	.25	21	------	------	------	.93	------	.25	------	.47	F	.34	18
Z2	.36	29	------	------	------	.90	------	.25	------	.53	15	.33	16
Z3	------	------	------	------	------	.55	F	------	------	.20	F	------	------
P	.29	11	------	------	------	------	------	.24	------	------	------	------	------
L	.00	------	------	------	------	.20	------	.25	------	.49	------	.01	------
B	.07	------	------	------	------	.31	------	.06	------	.01	------	.00	------
H	.01	------	------	------	------	.22	------	.07	------	.85	------	.00	------
N	.14	------	------	------	------	.64	------	.34	------	.06	------	.05	------
NN	.03	------	------	------	------	.34	------	.19	------	.03	------	.02	------
C1	.00	------	------	------	------	.15	F	.01	------	.08	------	.01	------
C2	.01	15	------	------	------	.11	F	.04	------	.01	------	.00	------
C3	.84	F	------	------	------	2.71	F	.08	------	.03	------	.00	------
AS	.40	[3] 0.246	.04	[3] 0.532	------	------	------	------	------	.77	[3] 1.165	.16	[3] 0.371
ES	.45	[3] .378	.02	[3] .506	------	.98	[3] 0.360	------	------	1.34	[3] .360	.32	[3] .856
D	1.28	------	.08	------	1.76	1.91	------	1.35	------	1.21	------	.26	------
F	.06	------	.01	------	------	.85	------	.34	------	.35	------	.09	------
G	.08	------	.00	------	.32	.72	------	.23	------	.31	------	.23	------

[1] For soil names see Table 3.
[2] For list of materials see Table 19.
[3] Thickness of zinc coating in ounces per square foot.

Losses are in ounces per square foot per year.
Pits in mils per year.
No pits measured on CA, CB, CY, AS, ES, D, F, or G.
F. Failure.

The zinc sprayed specimens were prepared by the metallurgical division of the Bureau of Standards and differ from most of the other materials in that they are experimental rather than commercial specimens. The amounts of zinc applied to the different specimens vary too widely to permit comparison of specimens, and the chief value of the data is that it shows that it is difficult to get a uniform coating by the method employed.

The large specimens of sheet iron and steel were buried for the purpose of comparing the corrosion of them with that of galvanized specimens of the same materials in the same soils (see Table 9). This comparison brings out the fact that in certain soils galvanized material corrodes slowly while bare iron corrodes rapidly, though in other soils galvanizing adds but little to the life of a buried structure.

5. WOOD-FIBER PIPE

Specimens of sulphur-impregnated wood-fiber pipe were buried with the metal pipe specimens. These have not been included in these tables because they must be judged by different methods. Many of these specimens absorbed some water and elongated. Whether this was due to failure of the protective coating or to injuries to the coating in many cases can not be determined. In a few places there are evidences of deterioration of the coating. On some specimens the coating is blistered, while on others it shows cracks. The fiber in some locations appears to be somewhat softened, but the extent to which the specimens have weakened has not been determined.

IX. LABORATORY INVESTIGATIONS

1. EXAMINATION OF SOIL SAMPLES

The field study of soil corrosion was intended to be of a practical nature with results directly applicable to the conditions encountered by pipe users. For this reason commercial pipe was used for specimens, and the pipes were buried much as they would be under service conditions. On this account there were variations both in pipes and soils nominally identical, and complex conditions were introduced which could only be analyzed with great difficulty. The heats from which the metals were poured are unknown, and the variations in soil conditions from day to day have not been determined. Detailed data from which a theory of corrosion could be constructed are, therefore, lacking. To supply some of these data a number of laboratory studies were undertaken in the hope that a better understanding of the problem could be obtained. The tests so far made are preliminary in character, and are discussed here because they may be suggestive to others who are considering laboratory soil-corrosion tests rather than on account of any valuable results secured.

A review of a considerable number of chemical analyses of soils indicated that under many conditions the tests usually made did not furnish an indication of soil corrosiveness, and soil analyses were postponed until it was better known what to look for. There are reasons for thinking that in some cases at least the texture of the soil or moisture conditions have a greater effect on the rate of corrosion than has the chemical composition of the soil.

While one might expect from the electrolytic theory of corrosion that the hydrogen ion concentration in the soil should indicate its corrosiveness, the curves in Figures 10 and 11 do not indicate a close relation between hydrogen ion values and rates of corrosion. Authorities differ as to methods of determining pH values of soils, and the apparent lack of relationship may be due to the ways in which the hydrogen ion data were obtained. For this reason a more detailed study of the subject is planned.

When the 1922 pipe specimens were buried, samples of each soil were obtained for future study. These samples have been used for determining their electrical resistivity when saturated with water and the amount of water required for saturation. A small piece of sheet steel was buried in a wet sample of each soil as a laboratory corrosion test for the purpose of comparing laboratory and field results and developing, if possible, a satisfactory accelerated test.

Figure 23 is a comparison of the results of the laboratory corrosion tests with the field results for the same soils. If the two sets of data checked, the points should fall on a straight line running through the origin of coordinates. Examination of the points plotted in Figure 20 shows that certain soils tend to fall in such a line, but that some fall below and others above the line. A study of the moisture condition of the soils in the field indicates that for dry, well-drained soils the corrosion losses in the laboratory were greater than would be expected from the field data, while for soils which were very wet in the field the reverse is generally true. This suggests that the amount of moisture in the soil affects the rate of corrosion and indicates that if laboratory tests are to check field tests they must approximate the moisture conditions of the field. This makes satisfactory laboratory testing difficult, since frequently little is known as to the range of moisture conditions which the material will encounter at any given field location.

While on the subject of the relation between laboratory and field results, it may be well to revert to the discussion of Figure 12 and to point out the fact that while this graph roughly indicates a relation between the soil water analyses of Mr. Collins and the bureau's corrosion results, Mr. Cain's total immersion tests, using the same soil waters, did not check the field results or indicate that one water was more corrosive than another. Evidently there is need for standardization in methods of corrosion testing. Before such standardization can be accomplished much more must be known about the factors which influence soil corrosion.

2. EFFECT OF SIZE OF SOIL PARTICLES

In this connection some of the results of the experiments to determine the effect of the size of the soil particles are of interest. Seven sizes of particles were used, ranging from gravel and sand, passing a No. 8 sieve, to English china clay, passing a 350-mesh sieve. Ten per cent moisture was added to each of the materials except the coarsest, which would only retain about 4 per cent. In cans of these materials were buried thin strips of sheet steel carefully cleaned and weighed, after which the cans were sealed. The losses after two and three weeks were not entirely consistent, but possibly showed a tendency to decrease slightly with the size of the particle, as is shown in Figure 24. The irregularities in results may have been caused by differences in the compositions of the materials used.

The point of greatest interest was the appearance of the corroded specimens. On the strips buried in the larger sized materials the corrosion took the form of more or less regular closed lines or rings with bright metal both inside and outside the ring. This is illustrated in Figure 25.

It will be noted that the maximum corrosion did not occur where the oxygen was excluded by contact between the gravel and the steel, but just outside this contact area. The steel in the coarser sand was covered by small rust spots, while that in the china clay showed rather large corroded areas adjacent to which were areas of similar size showing no corrosion. In this experiment the corrosion appears to be controlled by the presence of moisture; for example, in the case of the gravel probably the pebbles which were in contact with the metal were surrounded by a ring of moisture held by capillary action while the pressure of the pebble against the steel kept moisture from the metal within the ring and the lack of sufficient water accounted for the absence of corrosion outside of the ring.

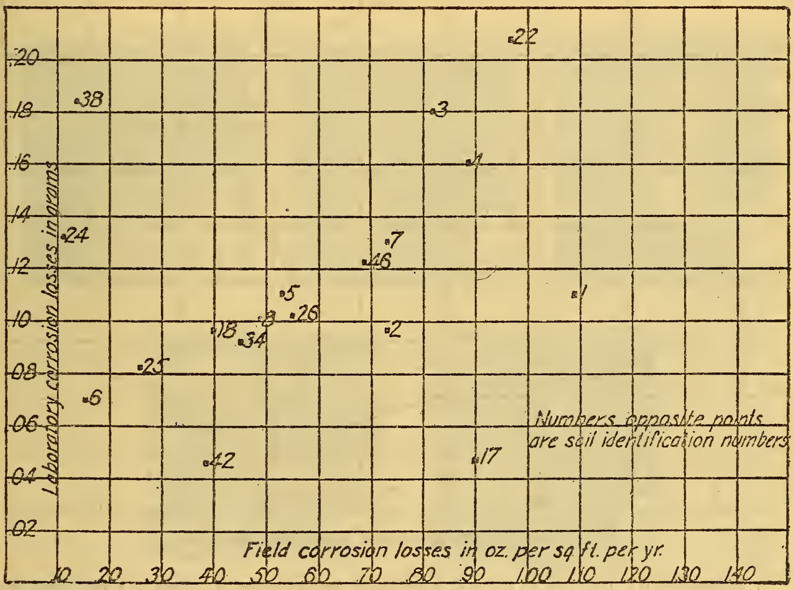

Fig. 23.—*Comparison of field and laboratory corrosion tests*

In the case of the smaller sizes of particles the corrosion appears to have occurred at points of contact between the particles and the metal.

3. EFFECT OF TEMPERATURE

The results of an experiment intended to show the effect of temperature are shown in Figure 26. Thin sheets of steel were buried in cans of sifted silty clay soil from the Bureau of Standards grounds and four specimens maintained at each of three temperatures, 25, 57, and 85° C. Half of the specimens were removed after two and the remainder after three weeks. The data indicate greater corrosion at the higher temperature. This may partially explain the greater corrosion generally found in the Southern States, although other factors are probably of more importance.

4. EXTENT OF PROTECTION DUE TO GALVANIZING

The extent to which galvanizing protects a metal surface after part of the base metal has been exposed is of considerable interest. Mills[8] cites a condition in which a sleeve of zinc cast on a steel tube protects the tube in an oil well against corrosion for a distance of 8 feet beyond the end of the zinc casting.

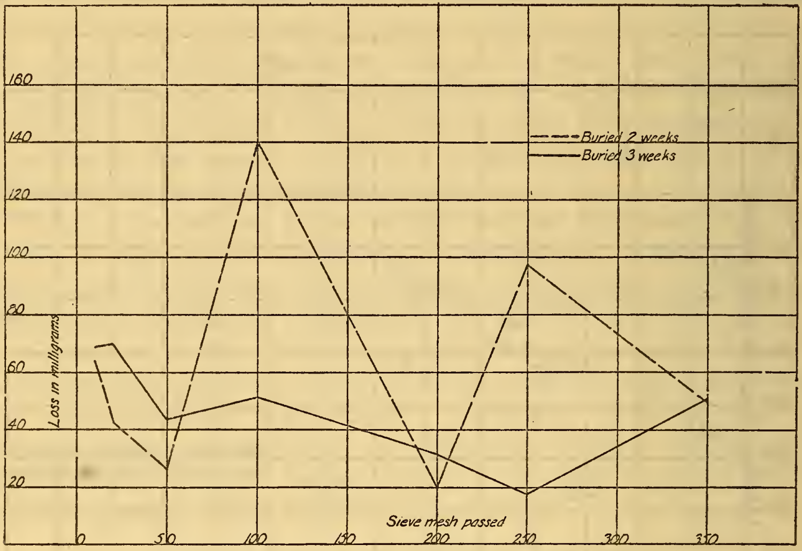

FIG. 24.—*Effect of size of sand on corrosion*

To determine the protected area on galvanized sheet, the zinc was ground from a triangular area at one end of a sheet and the sheet placed in a vessel of tap water. Within two weeks rust covered the triangle to within about one-half inch of the galvanized surface. In examining this sheet the rust was brushed off. An attempt to obtain another coat of rust failed, although the sheet was replaced in the same water and later in dilute solution of sulphuric acid and in salt water. Why the iron corroded at first and failed to corrode later has not been determined.

The zinc was machined from a 17-inch specimen of 2-inch galvanized pipe to within 2 inches of each end and the pipe immersed in tap water. Rust formed to within about 2 inches of the galvanized surface. Figure 27 shows three views of this pipe. It has been suggested

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[3] R. Van A. Mills, Protection of Oil and Gas Field Equipment Against Corrosion, Bureau of Mines Bulletin No. 223.

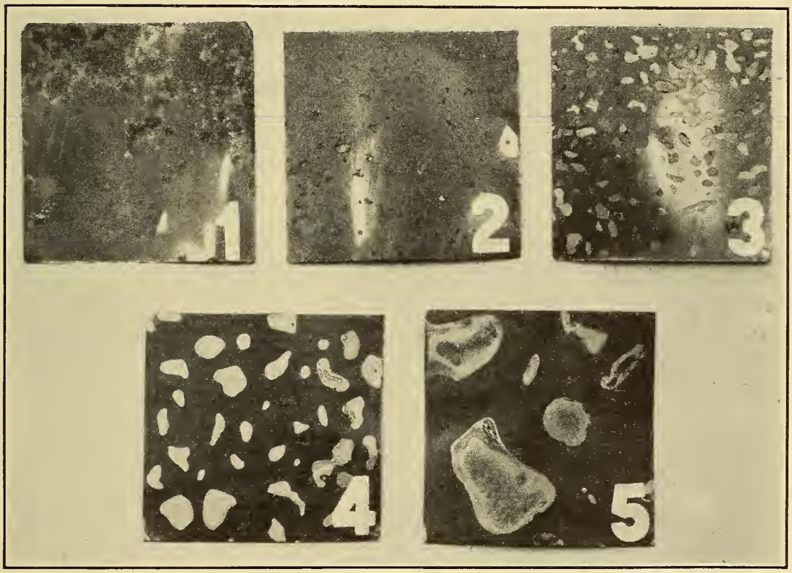

Fig. 25.—*Steel sheets showing effect of size of particles*

that the extent of the protected area in the experiments under discussion depends upon the conductivity of the electrolyte.

5. GALVANIC CURRENTS

In several locations when the earth had been removed down to the tops of the specimens tests apparently indicated small currents flowing between specimens. Conditions were, therefore, approximately duplicated by placing two specimens a foot apart in a box of moist earth. Measurements on the surface of the earth between the specimens indicated a current apparently flowing from one to the other. The nature of this current was revealed when the indication remained constant after one of the specimens was removed; that is, the current flowed not from one specimen to the other, but between different points on the same specimen.

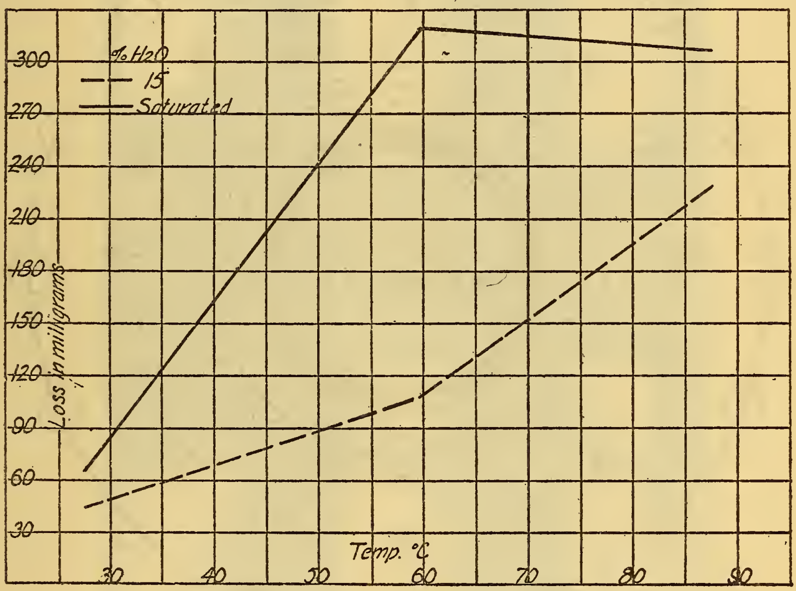

FIG. 26.—*Effect of temperature on corrosion*

This is further illustrated by an experiment suggested by some work by E. R. Shepard. A single large graphitic pit was formed electrolytically on the side of a section of 6-inch cast-iron pipe. The pipe was placed vertically in a tank of tap water so that the pit was half immersed, and measurements of the difference of potential between two nonpolarizing electrodes 4½ inches apart on 16 pipe radii were made. Figure 28 shows the magnitude and direction of the potential differences. These are, of course, only components of the local potential due to the current flowing from the pit to the surface of the pipe. Similar tests with the pipe in moist earth gave similar results, except that for some cause the values were larger and the positive sector was smaller. It is evident that a current flowed outside the pipe from the pit to other portions of the pipe in accordance with the electrolytic theory of corrosion. The most interesting feature of the experiment is that the effects of this current covered such a wide area and could be so easily detected.

After two years the experiment was repeated. During this time the surface of the pit had taken up additional oxygen and had a dark, rust-colored appearance. The results of the test were similar to those obtained earlier except the direction of the current was reversed. The surface of the pit was then scraped until most of the reddish discoloration was removed and the test repeated. The current was then found to flow from the pit to the uncorroded surface of the pipe as in the original experiment.

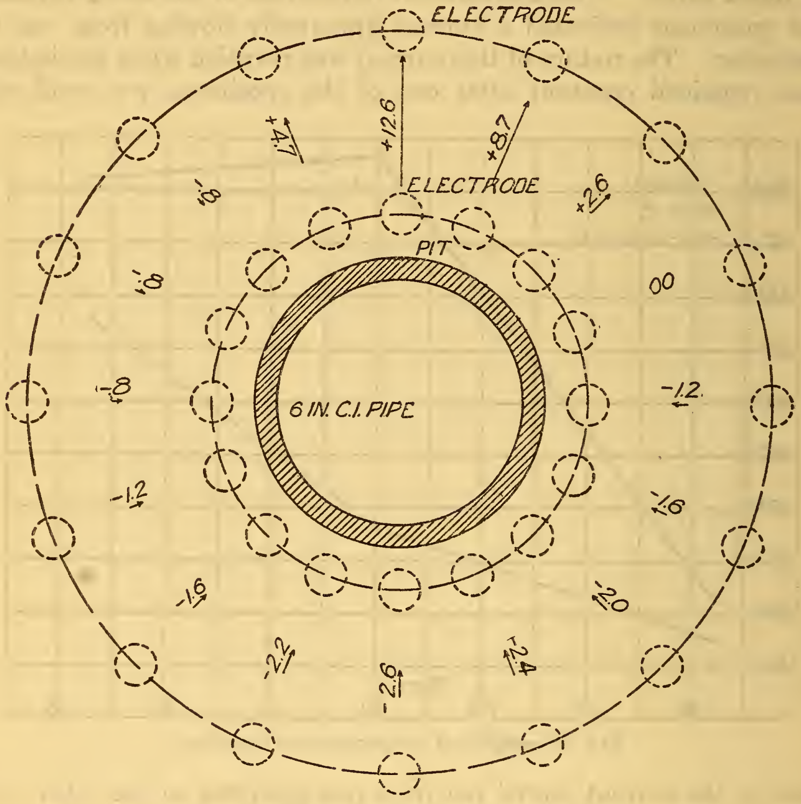

Fig. 28.—*Galvanic potentials due to corrosion*

Arrows indicate direction and magnitude of measured component of galvanic potential between electrode. Figures indicate millivolts drop between electrodes 4½ inches apart.

Thus, it appears that the polarity of the corrosion product with respect to the pipe surface depends upon the degree of oxidation of the corrosion products. The interpretation of this experiment is worthy of some discussion, since the statement has frequently been

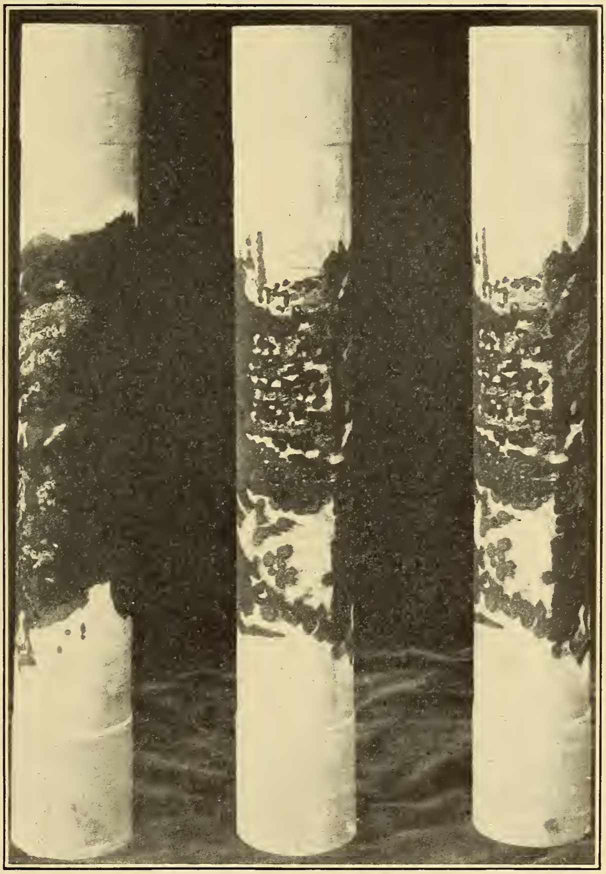

FIG. 27.—*Extent of protection due to galvanizing*

made that corrosion once started accelerates corrosion. Taking, first, the case where current was found to flow from the corrosion product to the uncorroded metal, does this indicate that the metal beneath the corrosion product is being destroyed? The answer depends on whether the conduction between the metal and the corrosion product and the metal is metallic or electrolytic. In the latter case only will there be corrosion of the metal.

The data of the experiment are insufficient to answer the question, but Table 5 indicates that the rate of penetration decreases as the age of the specimen increases. This suggests that the origin of the galvanic current is in or at the surface of the corrosion product and that the flow is caused by the further oxidation of that product. The experiment shows that when oxidation has continued far enough the direction of the galvanic current is reversed. In the case where the current flows from the iron to the soil and thence to the corrosion product conditions are right for further corrosion of the iron, and one would expect the maximum galvanic current at points very close to the corrosion product. This would result in the spreading of the pit rather than its deepening, and this is the tendency which Tables 4 and 5 indicate, since they show that the rate of pitting decreases much faster than the rate of corrosion.

X. SUMMARY

The results which have been discussed represent the earlier stages of the Bureau of Standards investigation. While the 1924 and 1926 results are, in general, similar, there are reasons for thinking that new factors may influence later results. Of the 14,000 specimens buried only about 2,000 have been removed for examination, and the results cover but 4 of the 10 or more years through which the tests are to continue.

On account of the possibility of the entrance of new influences as the specimens grow older, because of the apparently decreasing rate of corrosion indicated by the 1926 specimens, and because of the large differences in corrosion of the different specimens of the same material under nominally similar conditions and the few specimens of each material so far examined, it is unwise at present to draw conclusions as to the relative merits of the materials under test or the probable life of any of them.

Both the 1924 and 1926 specimens indicate that the type of corrosion is in some way associated with the locality in which the specimens are buried. It has been assumed that the effects found are due to some characteristics of the soil of the locality. Serious corrosion has been observed in several localities and on account of this an attempt to associate corrosion with soil characteristics seems the logical thing to undertake.

While the corrosiveness of several soils must be recognized, attention should also be called to the fact that in the majority of soils the rate of corrosion is low and in some it is practically negligible.

There seems to be a tendency for the rate of corrosion to decrease with time in many soils, and the rate of penetration of the pipe wall apparently decreases still more rapidly.

While no one material that is suitable for general use for pipe lines now appears superior to all others in all soils, there is an indication that a saving can be effected by the proper selection of a pipe material with respect to the soil condition which it will encounter.

The investigation of bituminous coating materials indicated that the thin dip coatings under test furnished insufficient protection against severely corrosive soil conditions.

While these tests of coatings are incomplete and inadequate, they also indicate that a coating satisfactory for one soil may not be satisfactory for another, and that in order to use data on protective coatings tested in one locality for predicating results to be obtained in another locality soil conditions must be studied. On this account, and because serious corrosion has been found in some localities, a thorough study of protective coating materials and methods for their application is greatly needed.

The tests on the nonferrous metals have not continued long enough to yield many data. Such data as are available indicate that the rate of corrosion of copper and its alloys is generally low and nearly uniform. Pitting occurs on lead and zinc in some soils, and the corrosion of some alloys of aluminum is rapid under some soil conditions.

The laboratory tests so far made have not been extensive, but serve to indicate that only very carefully controlled experiments can be expected to yield results of value.

Finally, the reader is asked to remember that this is but a preliminary report on work that is scarcely more than well begun, that the investigation was intended only to answer some practical corrosion questions, and that great caution should be exercised in drawing conclusions before more data are available.

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XII. INDEX TO SOIL NAMES AND CITIES

WASHINGTON, October 15, 1927.