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SOIL-CORROSION STUDIES, 1934. RATES OF LOSS OF WEIGHT AND PENETRATION OF NONFERROUS MATERIALS

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ABSTRACT

The soil-corrosion investigation, which was started in 1922, had its origin in the need for information concerning the effects of soils on iron and steel. Specimens of protective coatings and of nonferrous metals were added from time to time, mostly at the request of manufacturers or others who were interested in the behavior of certain materials when exposed to certain soils. A systematic study of the corrosion of nonferrous materials underground was not begun until 1932, and in the latest tests the specimens represent only copper and copper alloys. The number of nonferrous specimens exposed to soils has grown to approximately 9,000, of which about 2,500 have not been removed.

Differences in dimensions of the specimens buried prior to 1932, insufficient numbers of specimens of each material, and the introduction of too many factors that may affect corrosion have resulted in complications of the data to such an extent that in many cases positive decisions as to the rates of corrosion or the effects of possible influences on corrosion cannot be made. Nevertheless, although the dispersion of the data is large, certain tendencies are sufficiently well defined to be of practical importance. The results of the experiments should be of value also as indicators of the direction which more systematic investigations should take.

This report summarizes the effects of a large variety of soils on many nonferrous metals and alloys. Data on the corrosion of iron subjected to the same conditions are also given. In general, the nonferrous materials, with the possible exception of aluminum and its alloys, in certain soils corrode less than the ferrous materials under similar soil conditions, but none of the materials tested was free from corrosion in all soils. It appears, therefore, that in the choice of materials soil conditions should be given consideration. Unfortunately, few people have made systematic studies of soils from the standpoint of corrosion and not many can predict from the chemical or physical analysis of soils their effect on metals exposed to them.

The proper selection of materials for use underground requires special knowledge of soils, metals, electrochemistry, and economics.

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I. INTRODUCTION

The original plans for the soil-corrosion investigation, which was started in 1922, dealt primarily with ferrous pipes, although the corrosion of cable sheath was given some consideration. When it appeared that ferrous materials corroded rather rapidly under some soil conditions, it seemed desirable to obtain data on nonferrous materials which might also be used underground.

Specimens of nonferrous materials were therefore added from time to time when ferrous specimens were removed. This paper concerns itself with these nonferrous materials. Like the reports on the ferrous materials, this is a progress report, and for a complete understanding of it the reader should refer to some of the earlier reports. The most important of these is Bureau Technologic Paper 368,¹ which described the soils in the original test, gives the analyses of some of the materials, and records the results of the examination of the first nonferrous specimens that were removed after an exposure of approximately 2 years. Research Paper 95² contains data on the corrosion of lead cable sheath, and Research Papers 359 and 638³ contain corrosion data on a considerable variety of nonferrous materials.

II. PROPERTIES OF SOILS AT TEST SITES

Table 1 gives the names of the soils corresponding to the soil numbers, together with the locations of test site and the local organization cooperating in the test. Table 2 gives the properties of the soils. The test sites were selected as representative of typical soil conditions, and do not necessarily represent the prevailing soil conditions in the city near which the test was conducted. It should be remembered that within the boundaries of a city of moderate size there are usually several widely different soils.

TABLE 1.—*Identification of soils*

Soil	Soil type	Location	Cooperating organization
1.....	Allis silt loam.....	Cleveland, Ohio.....	East Ohio Gas Co.
2.....	Bell clay.....	Dallas, Tex.....	Dallas Gas Co.
3.....	Cecil clay loam.....	Atlanta, Ga.....	Dept. of Pub. Works.
4.....	Chester loam.....	Jenkintown, Pa.....	Philadelphia Elec. Co.
5.....	Dublin clay adobe.....	Oakland, Calif.....	East Bay Municipal Utility District.
6.....	Everett gravelly sandy loam.	Seattle, Wash.....	Dept. of Pub. Works.
7.....	Silt loam.....	Cincinnati, Ohio.....	Union Gas and Electric Co.
8.....	Fargo clay loam.....	Fargo, N. Dak.....	Union Light, Heat and Power Co.
9.....	Genesee silt loam.....	Sidney, Ohio.....	Tide Water Pipe Line Co., Ltd.
10.....	Gloucester sandy loam.	Middleboro, Mass.....	Town of Middleboro.
11.....	Hagerstown loam.....	Baltimore, Md.....	Dept. of Pub. Works.
12.....	Hanford fine sandy loam	Los Angeles, Calif.....	Southern Calif. Gas Co.
13.....	Hanford very fine sandy loam.	Bakersfield, Calif.....	San Joaquin Light and Power Corp.
14.....	Hemstead silt loam.....	St. Paul, Minn.....	Northern States Power Co.
15.....	Houston black clay.....	San Antonio, Tex.....	San Antonio Public Service Co.

¹ K. H. Logan, S. P. Ewing, and C. D. Yeomans, *Bureau of Standards soil-corrosion studies: I. Soils, materials, and results of early observations*. Tech. Pap. BS 22, 447 (1928) T368, 50c.

² K. H. Logan, *Soil-corrosion studies 1927-28*. BSJ Research 3, 275 (1928) RP95, 10c.

³ K. H. Logan, *Soil-corrosion studies; Nonferrous metals and alloys, metallic coatings, and specially prepared ferrous pipes removed in 1930*, BS J Research 7, 585, (1931) RP359, 10c.

K. H. Logan and R. H. Taylor, *Soil-corrosion studies 1932. Rates of loss of weight and pitting of ferrous and nonferrous specimens removed in 1932 and metallic protective coatings*, BS J Research 12, 12, (1934) RP638, 5c.

TABLE 1.—Identification of soils—Continued

Soil	Soil type	Location	Cooperating organization
16	Kalmia fine sandy loam	Mobile, Ala	City of Mobile.
17	Keyport loam	Alexandria, Va	Alexandria Water Co.
18	Knox silt loam	Omaha, Neb	Omaha and Council Bluffs Electrolysis Committee.
19	Lindley silt loam	Des Moines, Iowa	Des Moines Gas Co.
20	Mahoning silt loam	Cleveland, Ohio	Dept. of Pub. Utilities.
22	Memphis silt loam	Memphis, Tenn	Board of Water Commissioners.
23	Merced silt loam	Buttontwillow, Calif	San Joaquin Light and Power Corp.
24	Merrimac gravelly sandy loam	Norwood, Mass	Boston Consolidated Gas Co.
25	Miami clay loam	Milwaukee, Wis	Dept. of Pub. Works.
26	Miami silt loam	Springfield, Ohio	City of Springfield.
27	Miller clay	Bunkie, La	Standard Pipe Line Co.
28	Montezuma clay adobe	San Diego, Calif	San Diego Consolidated Gas and Electric Co.
29	Muck	New Orleans, La	Sewerage and Water Board.
30	Muscatine silt loam	Davenport, Iowa	United Light and Power Engineering and Construction Co.
31	Norfolk sand	Jacksonville, Fla	City Commission of Jacksonville.
32	Ontario loam	Rochester, N. Y	Dept. of Pub. Works.
33	Peat	Milwaukee, Wis	Milwaukee Gas Light Co.
34	Penn silt loam	Norristown, Pa	Philadelphia Elec. Co.
35	Ramona loam	Los Angeles, Calif	Los Angeles Gas and Elec. Co.
36	Ruston sandy loam	Meridian, Miss	Peoples Water and Gas Co.
37	St. Johns fine sand	Jacksonville, Fla	Jacksonville Gas Co.
38	Sassafras gravelly sandy loam	Camden, N. J	Camden Water Dept.
39	Sassafras silt loam	Wilmington, Del	Delaware Power and Light Co.
40	Sharkey clay	New Orleans, La	New Orleans Pub. Serv. Co.
41	Summit silt loam	Kansas City, Mo	Kansas City Gas Co.
42	Susquehanna clay	Meridian, Miss	City of Meridian.
43	Tidal marsh	Elizabeth, N. J	Standard Oil Development Co.
44	Wabash silt loam	Omaha, Neb	Omaha and Council Bluffs Electrolysis Committee.
45	Unidentified alkali soil	Casper, Wyo	Stanolind Oil and Gas Co.
46	Unidentified sandy loam	Denver, Colo	Public Service Co. of Colo.
47	Unidentified silt loam	Salt Lake City, Utah	Mountain Fuel Supply Co.
51	Acadia clay	Spindletop, Tex	Sinclair Prairie Pipe Line Co. of Tex.
53	Cecil clay loam	Atlanta, Ga	Dept. of Pub. Works.
54	Fairmount silt loam	Cincinnati, Ohio	Union Gas and Elec. Co.
55	Hagerstown loam	Baltimore, Md	Bureau of Water Supply.
56	Lake Charles clay	El Vista, Tex	Gulf Pipe Line Co.
57	Merced clay adobe	Tranquillity, Calif	Standard Oil Co. of Calif.
58	Muck	New Orleans, La	Sewerage and Water Board.
59	Peat	Kalamazoo, Mich	Dept of Pub. Utilities.
60	do	Plymouth, Ohio	Ohio Fuel Gas Co.
61	Sharkey clay	New Orleans, La	New Orleans Pub. Service Co.
62	Susquehanna clay	Meridian, Miss	City of Meridian.
63	Tidal marsh	Charleston, S. C	Commissioners of Pub. Works.
64	Unidentified alkali soil	Cholame Flats, Calif	Shell Oil Co.
65	do	Wilmington, Calif	Shell Oil Co.
66	Mohave sandy loam	Phoenix, Ariz	City Water Dept.
67	Cinders	Milwaukee, Wis	Milwaukee Gas Light Co.

TABLE 2.—*Properties of soils^a in the National Bureau of Standards soil-corrosion investigation*

(mg-eq=milligram equivalent)

A=Alkaline.

C=Not determined.

G=Good; F=Fair; P=Poor; VP=Very poor.

Soil ^b	Soil type	Mean temperature ^c	Annual precipitation ^e	Internal drainage of test site	Moisture equivalent	pH	Total acidity mg-eq per 100 g of soil	Resistivity at 60° F	Composition of water extract mg-eq per 100 g of soil						
									Na+K as Na	Ca	Mg	CO ₂	HCO ₃	Cl	SO ₄
51	Acadia clay	69.	49.	P	47.1	6.2	13.2	ohm-cm 190	10.27	15.55	5.03	0.00	0.56	5.75	22.00
52	Alkali knoll	69.	47.	P	54.8	8.8	A	234	4.20	.33	.18	.52	1.36	1.33	1.26
1	Allis silt loam	49.2	33.8	P	28.6	7.0	11.4	1,215	.72	.25	.43	.00	.09	.09	.83
2	Bell clay	65.5	36.2	P	37.6	7.3	3.5	684	.28	1.09	.13	.00	1.18	.04	.18
101	Billings silt loam	52.0	8.8	F	30.0	7.3	A	261	5.21	19.24	1.43	.00	.66	1.56	22.48
102	do	52.0	8.8	F	20.4	7.3	A	103	22.63	16.56	3.85	.00	.56	4.67	36.82
103	do	52.0	8.8	F	30.6	7.3	A	81	22.01	13.32	2.00	.00	.18	11.09	25.70
104	Cecil clay	60.2	46.1	G	34.1	4.6	11.0	8,500							
3	Cecil clay loam	61.2	48.3	G	29.1	5.2	11.5	30,000							
53	do	61.2	48.3	G	33.7	4.6	9.6	17,794							
105	do	64.2	44.5	G	34.2	4.8	12.9	28,000							
103	do	60.	46.	G	38.8	4.8	12.8	25,000							
107	Cecil fine sandy loam	60.1	46.3	G	29.6	4.8	11.8	54,400							
103	Cecil gravelly loam	61.2	48.3	G	34.3	4.9	11.2	44,400							
4	Chester loam	54.	40.	F	22.2	5.6	7.6	6,670							
67	Cinders	46.1	30.1	VP	11.1	8.0	A	455	.77	3.03	.53	.00	.55	.08	2.89
5	Dublin clay adobe	56.4	23.4	P	28.8	7.0	6.5	1,346	.93	.48	.10	.00	.69	.03	.25
6	Everett gravelly sandy loam	51.0	34.0	G	12.2	5.9	12.8	45,100							
54	Fairmont silt loam	53.2	38.6	P	26.1	7.0	3.5	886	.59	10.10	.59	.00	.70	.08	9.05
8	Fargo clay loam	39.	21.	P	37.0	7.6	A	350	1.42	1.72	2.55	.00	.71	.01	4.43
109	Fresno fine sandy loam	63.	9.	P	18.6	8.4	A	497	2.62	.07	.10	.31	.59	1.56	.48
110	do	63.	9.	P	18.4	10.2	A	531	3.53	.07	.12	1.49	1.07	.79	.25
111	do	63.	9.	P	22.1	7.3	A	51	41.55	16.21	.44	.00	.58	34.58	23.41
9	Genesee silt loam	51.2	39.0	P	24.8	6.8	7.2	2,820							
10	Gloucester sandy loam	50.	41.	F	13.0	6.6	3.6	7,460							
11	Hagerstown loam	55.4	42.6	G	32.0	5.3	10.8	11,000							
55	do	55.4	42.6	G	32.0	5.8	10.9	5,213							
12	Hanford fine sandy loam	62.4	15.2	F	12.4	7.1	2.5	3,190	.39	.50	.16	.00	.40	.00	.14
13	Hanford very fine sandy loam	64.6	5.6	F	21.7	9.5	A	290	6.23	.09	.13	.00	1.12	1.64	3.76
14	Hempstead silt loam	44.2	27.2	F	17.2	6.2	5.6	3,520							

15	Houston black clay	68.9	27.2	P	51.4	7.5	5.0	489	2.18	.88	.20	.00	2.00	.13	.73
112	Imperial clay	71.	2.	F	30.2	7.4	A	149	22.18	14.09	1.29	.00	.36	10.94	25.98
113	do	71.	2.	F	34.6	7.4	A	102	9.56	.84	.51	.00	.63	6.26	4.06
16	Kalmia fine sandy loam	67.3	61.6	F	22.2	4.4	11.8	8,290							
17	Keyport loam	55.	42.	P	30.8	4.5	19.1	5,980							
18	Knox silt loam	50.6	27.8	G	28.4	7.3	1.4	1,410	.27	.63	.20	.00	.94	.00	.25
56	Lake Charles clay	69.	49.	P	28.7	7.1	4.5	406	3.12	.69	.47	.00	.80	1.59	3.04
114	do	69.	49.	P	35.8	7.1	C	320	2.65	.68	.26	.00	.77	1.84	.93
19	Lindley silt loam	49.5	32.0	G	28.4	4.6	10.9	1,970	.38	.32	.41	.00	.16	.03	.46
20	Mahoning silt loam	49.2	33.8	P	22.4	7.5	1.5	2,870	.25	.48	.20	.00	.51	.00	.15
21	Marshall silt loam	54.4	37.1	F	31.2	6.2	9.5	2,370							
22	Memphis silt loam	61.6	47.7	G	28.4	4.9	9.7	5,150							
115	do	65.6	51.9	G	25.7	6.9	4.7	3,450							
116	Merced clay	63.4	8.1	F	39.7	9.2	A	320	9.30	.33	.18	4.60	2.10	1.17	1.57
57	Merced clay adobe	63.	8.	P	40.9	7.7	A	128	23.40	13.50	4.51	.00	.34	1.15	37.50
117	Merced clay loam adobe	63.	8.	P	51.8	8.5	A	106	36.19	14.66	.83	.00	1.55	2.89	46.53
23	Merced silt loam	65.	6.	P	24.7	9.4	A	278	8.38	.38	.22	.02	1.87	1.12	5.57
24	Merrimac gravelly sandy loam	50	41	G	13.0	4.5	12.6	11,400							
25	Miami clay loam	46.1	30.1	F	25.8	7.2	4.7	1,780	.23	.70	.41	.00	1.01	.03	.10
26	Miami silt loam	53	37	G	16.4	7.3	2.6	2,980	.27	.50	.31	.00	.70	.03	.12
27	Miller clay	67	56	P	42.6	6.6	3.7	570	.53	1.86	1.12	.00	2.00	.08	1.54
66	Mohave sandy loam	69.7	7.8	G	16.5	8.7	A	232	6.55	.51	.18	.00	.73	2.77	2.97
28	Montezuma clay adobe	61.0	10.3	P	24.6	6.8	C	408	1.50	.06	.18	.00	.12	.99	.89
29	Muck	69.3	57.4	VP	34.5	4.2	28.1	1,270	2.15	1.92	1.55	.00	.00	1.69	2.30
58	do	69.3	57.4	VP	57.8	4.0	79.3	712	2.03	2.23	1.29	.00	.00	.47	2.54
30	Muscatine silt loam	49.9	32.1	P	29.4	7.0	2.6	1,300	.32	.65	.40	.00	.71	.09	.24
118	Niland gravelly sand	71	2	F	6.1	7.3	A	273	4.30	1.03	.64	.00	.20	5.01	.86
31	Norfolk sand	69.3	47.4	G	2.8	4.7	1.8	20,500							
120	do	67.7	57.9	G	4.4	5.7	1.3	34,400							
121	do	71.8	49.4	G	3.0	4.8	1.2	16,400							
119	Norfolk sandy loam	64.2	44.5	G	24.1	4.7	9.7	10,800							
32	Ontario loam	47.6	32.8	G	17.8	7.3	0.5	5,700	.23	.70	.12	.00	.73	.01	.42
122	Panoche clay loam	63	6.4	F	30.0	7.4	A	552	2.32	.05	.26	.00	.70	.07	1.40
33	Peat	46.1	30.1	VP	72.8	6.8	36.0	800	1.52	7.30	4.06	.00	C	2.27	2.13
59	do	49	31.1	VP	43.6	5.5	33.3	1,659	1.03	3.08	2.70	.00	.00	3.47	1.04
60	do	49	37	VP	43.4	2.6	297.4	218	2.91	10.95	2.86	.00	.00	.00	56.70
34	Penn silt loam	54	40	F	23.4	6.7	7.0	4,900							
35	Ramona loam	62.4	15.2	G	18.0	7.3	5.7	2,060	.68	.68	.49	.00	1.10	.06	.35
36	Ruston sandy loam	64.0	53.0	G	13.8	4.5	4.6	11,200							
37	St. Johns fine sand	69.3	47.4	P	7.0	3.8	15.3	11,200							

^a Measurements and determinations by I. A. Denison and R. B. Hobbs.

^b For locations of soils see table 1.

^c Data furnished by U. S. Weather Bureau. Values with no figures to the right of the decimal point are for some nearby city.

TABLE 2.—*Properties of soil in the National Bureau of Standards soil-corrosion investigation—Continued*

Soil	Soil type	Mean temperature	Annual precipitation	Internal drainage of test site	Moisture equivalent	pH	Total acidity mg-eq per 100 g of soil	Resistivity at 60° F	Composition of water extract mg-eq per 100 g of soil								
									Na+K as Na	Ca	Mg	CO ₃	HCO ₃	Cl	SO ₄		
38	Sassafras gravelly sandy loam.....	°F	40	<i>G</i>	%	3.0	4.5	1.7	ohm-cm								
39	Sassafras silt loam.....	54	40	<i>P</i>	24.2	5.6	6.6	38,600									
40	Sharkey clay.....	69.3	57.4	<i>P</i>	33.0	6.0	9.4	7,440									
61	do.....	69.3	57.4	<i>P</i>	30.8	5.9	8.6	970	.56	.58	.44	.00	.93	.07		.28	
41	Summit silt loam.....	54.4	37.1	<i>F</i>	33.1	5.5	11.0	943	.73	.68	.33	.00	.71	.10		.91	
								1,320	.30	.54	.36	.00	.78	.04		.46	
42	Susquehanna clay.....	64.0	53.0	<i>P</i>	34.8	4.7	28.2	13,700									
62	do.....	64.0	53.0	<i>P</i>	34.6	4.1	24.2	6,922									
123	do.....	65.8	43.4	<i>P</i>	37.6	4.1	21.9	6,840									
124	Susquehanna silt loam.....	66.0	42.7	<i>P</i>	36.0	4.4	28.1	1,160									
125	Susquehanna fine sandy loam.....	65.8	43.4	<i>P</i>	37.2	3.9	28.3	5,770									
43	Tidal marsh.....	52	43	<i>VP</i>	55.4	3.1	36.8	60	45.10	5.17	9.45	.00	.00	43.30		37.00	
63	do.....	66.0	45.2	<i>VP</i>	46.7	2.9	100.2	84	33.60	6.85	4.00	.00	.00	12.70		36.60	
44	Wabash silt loam.....	50.6	27.8	<i>G</i>	31.2	5.8	8.8	1,000	1.05	1.08	.66	.00	1.97	.82		.41	
UNIDENTIFIED SOILS																	
45	Alkali soil.....	47.2	15.3	<i>P</i>	14.8	7.4	<i>A</i>	263	8.15	3.70	.70	.00	.24	.18		11.98	
46	Sandy loam.....	50.0	14.1	<i>G</i>	7.6	7.0	<i>C</i>	1,500									
7	Silt loam ^a	53.2	38.6	<i>P</i>	34.3	4.4	29.8	2,120									
47	do.....	51.6	16.1	<i>P</i>	25.7	7.6	3.0	1,770	.67	.72	.39	.00	.88	.06		.48	
64	Alkali soil.....	58	16	<i>VP</i>	41.1	8.3	<i>A</i>	62	28.10	2.29	.76	.00	.89	28.80		.26	
65	do.....	62.4	15.2	<i>F</i>	26.4	7.2	<i>A</i>	148	7.65	12.40	2.20	.00	1.30	6.05		16.90	

^a Previously classified erroneously as Fairmount silt loam.

The selection of the sites for soil-corrosion tests was governed by the desire to secure soils representative of the soil types to which extensive pipe lines were exposed.

As is indicated by the names of the soil types, the textures of the soils range from coarse sands to very heavy clays. The range in texture is also indicated by the moisture-equivalent values.

The temperatures given in column 3 of table 2 are the average annual atmospheric temperatures of cities near which the specimens were buried, and show in a very general way one of the conditions which affect corrosion.

The mean annual precipitation shown in column 4 has a bearing on corrosion, but the effect of precipitation is modified by its distribution throughout the year, by surface and subsurface drainage, and by the capacity of the soil to hold moisture. The character of the subsurface drainage is indicated in column 5. The moisture equivalent given in column 6 is a measure of the capacity of the soil to retain moisture and is the percentage of moisture (in terms of the dry weight of the soil) which is retained by a soil sample when subjected to a centrifugal force of 1,000 times gravity.

The moisture-equivalent values range from 2.8 percent for Norfolk sand to 72.8 percent for the peat soil at Milwaukee.

The acidity or alkalinity of the soil solution is indicated by the pH values, which range from 2.6 for the peat soil at Plymouth, Ohio, to 10.2 for the Fresno fine sandy loam at Kerman, Calif.

Some soils have a greater capacity to maintain their acidity than others. This is shown by the total acidity of the soil, expressed in milligram equivalents of hydrogen per 100 grams of soil. The greatest total acidity value, 297.4, was found for the peat at Plymouth, Ohio. The pH value for this soil was 2.6, while a tidal marsh with a pH value almost as low, 3.1, showed a total acidity about one-eighth as large. It will be noted also from the values of total acidity that soils which are more alkaline than the conventional neutral point, pH 7, often contain hydrogen ions.

The resistivity of the soil indicates capacity to conduct the electric currents which flow in the course of the corrosion process. It also indicates the amount of salts in the soil solution. This soil property is so important that in certain localities it is a fairly satisfactory indicator of the corrosivity⁴ of the soil with respect to ferrous materials.

Table 2 shows that the resistivities of soils in the soil-corrosion investigation range from 54,400 ohm-cm for the Cecil fine sandy loam to 51 ohm-cm for the Fresno fine sandy loam (111). These values are for saturated soils at 60° F. In the more-arid regions the soils are at times nearly dry and the values for their resistivities in the field are considerably greater than those given in the table. The physical properties of some of these soils and their relations to the corrosion of iron are described in RP696.⁵

Water extracts of soils were prepared as follows: A suspension of soil and water in the ratio 1:5 was shaken mechanically at intervals for a total of 24 hours during a period of 72 hours. The compositions of the water extracts, as shown in table 2, are important because of

⁴ E. R. Shepard. *Pipe line currents and soil resistivity as indicators of local corrosive soil areas*. BS J. Research 6, 683 (1931) RP239.

⁵ I. A. Denison and R. B. Hobbs. *Corrosion of ferrous metals in acid soils*. J. Research NBS 13, 125 (1934) RP696, 5c.

the effect of the salts in solution on the resistivity of the soil and because of their influence of the character of the corrosion products, which may form protective deposits.

Since underground corrosion has been found to depend largely on soil conditions, an examination of table 2 will make clear that averages of corrosion data from different soils are of little practical value in the estimation of what is to be expected in any one locality.

Those interested in the classification of soils and their distribution will find part III of the Atlas of American Agriculture⁶ helpful. The paper does not discuss corrosion.

Table 3 shows the nonferrous materials reported in this paper, their symbols, dimensions, and actual or nominal compositions. In all cases except the lead the analyses were furnished by the manufacturer supplying the material. Such analyses are quite satisfactory for the study of underground corrosion since the precision with which rates of corrosion can be determined is not usually sufficient to show the effects of small changes in the composition of the materials tested.

III. CORROSION OF NONFERROUS METALS AND ALLOYS

1. CORROSION OF LEAD

Lead is used underground principally to provide a flexible connection between water mains and services, as water service pipe, and as a sheath for power and telephone cables. Power and telephone cables are usually drawn into ducts and therefore not exposed directly to soil action, although ducts may contain silt. Occasionally lead-covered cables are laid in direct contact with the soil, although this is not generally considered the best practice, partly because of the danger of damage when the soil is disturbed.

Four varieties of lead specimens appear in the soil-corrosion investigation, as shown in table 3. Table 4 shows the rates of corrosion for the cable sheath materials. For the rates of corrosion comparison of wrought iron and steel buried approximately 12 years in the same soils are included. Each rate for the lead is based on a single specimen. Most of the antimonial lead specimens were of approximately twice the area of those of commercial lead. The maximum rates of penetration of the former as recorded in the table represent the average of the two deepest pits on separate halves of the specimen. In the earlier reports the recorded maximum rate of penetration regardless of the dimensions of the specimen, is based upon the average of the deepest pit on each side of the specimen.

It is of interest to note that in certain soils which are very corrosive with respect to iron, such as Hanford very fine sandy loam, Merced silt loam, and other alkali soils, lead corrodes but slowly. Table 4 shows that in 32 out of 35 cases the antimonial lead specimens *A* lost weight more rapidly than those of commercially pure lead, *H*, also the rate of penetration was greater in 20 instances. Similar indications of the greater corrodibility of the antimonial lead specimens were observed on previous examinations of these materials. It will be noted, however, that the variation in the rates of corrosion in different soils is much greater than the differences between the two materials.

⁶ C. F. Marbut. *Soils of the United States*. Part III of the Atlas of American Agriculture, July 1935, Government Printing Office, \$5.00.

TABLE 3.—Form, dimensions, and chemical composition of materials

LEAD ALLOYS *

Symbol	Material	Form	Dimensions ^b	Chemical composition (in percent)					
				Cu	Zn	Sn	Pb	Ni	Other elements
NN	Hearth refined lead.	Cast	<i>Inches</i> 6×2×.25	0.002			99.99		0.004 Bi.
N	Chemical lead	do	6×2×.25	.57			99.93		0.009 Ag.
H	Commercial lead	Sheet	22×3.5×.11	.013			99.95		0.037 Bi.
A	Antimonial lead	do	22×8.5×.12	.062			99.12		0.82 Sb.

COPPER ALLOYS

E	Copper	Pipe	17×1.1×.108	99.97					
C	do	do	12×1.7×.145	99.9					
M	do	do	12×.9×.06	99.93					
A	do	do	13×1.7×.144	99.94					0.018 P.
P	do	do	12×.9×.06	99.94					0.015 P.
M ^c	do	do	12×1.5×.062						
H	do	Sheet	6×2×.05	99+					
3	Brass	Cast	Irregular	91.86	7.72	0.08	0.34		
2	do	do	do	87.06	5.31	5.86	1.77		
1	do	do	do	85.48	6.20	3.52	4.80		
F	do	Pipe	12×1.7×.143	85.18	14.80				0.01 Fe.
H	do	do	17×1.1×.108	84.99	14.97		.01		0.03 Fe.
4	do	Cast	Irregular	74.94	20.12	1.43	2.57		0.94 Fe.
H	do	Pipe	12×1.7×.143	71.28	27.39	1.30	.01		0.02 Fe.
Bl	do	Sheet	6×2×.05	70	30				
K	do	Pipe	12×1.7×.08	67.08	31.07		.84		Trace of Fe.
J	do	do	13×1.7×.145	66.50	33.06		.42		0.02 Fe.
B	do	do	12×.8×.103	60	40				
B ²	do	Nipple	2×.8×.106	60	40				
L	do	Pipe	12×1.7×.08	60.06	39.58		.36		Trace of Fe.
Me	do	Ell.	2×.7×.16	59.00	38.50		2.50		
A	do	Rod	12×.4	47.00	40.50		2.50	10	
E	Bronze	Pipe	12×1.7×.141	97.15		1.80			{0.01 Fe. 1.04 Si.
L	Bronze	Plate	6×2×.25	90		10			
N ^d	Cu-Si alloy	Pipe	12×1.7×.145	98.11		.14		0.01	{0.11 Fe. .18 Mn. 1.49 Si.
D	do	do	12×1.7×.143	95.46				.08	{.21 Fe. 1.06 Mn. 3.19 Si.
G	Cu-Ni alloy	do	12×1.7×.145	74.45	4.99			20.04	{0.52 Mn. 3.5 Fe, 9.5 Al.
N	Cu-Al alloy	Rod	12×.4	87.00					
Z1	Zinc	Sheet	6×2×.06		99.5				
Z ²	do	Plate	6×2×.25		99.5				
P	do	Sheet	6×2×.06	(*)	(*)	(*)	(*)	(*)	(*)

ALUMINUM ALLOYS

				Cu	Fe	Si	Mn	Al	
C1	Aluminum	Sheet	6×2×.06	0.09	0.33	0.3	0.03	99.25	
C2	Al-Mn	do	6×2×.06	.16	.51	.44	1.12	97.75	0.02 Zn.
C3	Duralumin	do	6×2×.06	4.10	.30	.23	.62	94.23	0.52 Mg.

* Analysis by J. A. Scherrer, National Bureau of Standards.

^b Dimensions of plates and sheets given as (length)×(width)×(thickness); dimensions of pipes as (length)×(outside diameter)×(wall thickness); dimensions of rods as (length)×(diameter).^c These specimens have streamlined caps and couplings soldered in place.^d Some of these specimens have brazed joints.

* Standard composition.

TABLE 4.—Rates of loss of weight and maximum penetration lead cable sheath exposed 10 to 12 years

Soil ^a	Cable sheath rates of loss (oz/ft ² /yr)		Rates of penetration (mils/yr)		Ferrous pipe	
	A ^b	H ^c	A ^b	H ^c	Rates of loss (oz/ft ² /yr)	Rates of penetration (mils/yr)
1	0.345	0.173	8.1	9.4	0.79	7.5
2 ^d	.095	.067	2.0	2.1	.51	4.7
3 ^d	.062	.069	.8	1.8	.37	5.8
4	.149	.177	5.3	4.3	.57	8.2
5 ^d	.185	.135	11.8	4.0	.57	3.5
6 ^d	.035	.025	1.0	1.1	.10	1.7
10	.074	.088	1.7	1.3	.40	3.8
11	.040	.034	1.9	1.3	.17	6.2
14	.181	.049	5.2	2.0	.39	8.2
15 ^d	.051	.036	1.4	2.5	.68	5.1
17	.037	.028	2.9	1.7	.80	3.5
18	.042	.016	1.6	1.3	.24	3.8
19	.113	.040	2.8	1.3	.29	5.5
20	.304	.268	6.6	4.4	.52	5.2
22	.155	.085	2.5	1.6	.64	5.6
24	.021	.015	1.3	1.6	.12	2.2
25	.045	.028	3.0	2.4	.28	3.9
26	.041	.018	1.8	2.5	.32	3.5
27 ^d	.095	.067	3.3	2.7	.66	4.9
28	.221	.069	4.0	1.0	1.70	16.4
29 ^d	.353	.343	1.4	1.1	1.50	11.4
30	.201	.126	5.7	4.4	.47	4.8
31 ^d	.026	.022	1.3	.7	.24	2.8
32	.050	.028	1.0	1.5	.30	5.2
34	.260	.067	7.6	9.2	.38	3.7
35 ^d	.019	.017	2.1	3.4	.16	1.9
36 ^d	.046	.032	1.2	1.4	.23	4.0
38	.032	.025	1.0	2.1	.20	2.4
39	.148	.099	3.5	3.0	.47	5.8
41	.049	.039	1.6	1.6	.51	6.9
43	.043	.019	1.9	1.2	1.31	7.8
44	.070	.038	1.7	1.1	.30	5.8
45	.038	.021	1.2	2.0	.85	7.7
46	.081	.015	2.8	1.2	.38	6.2
47	.130	.122	4.8	9.1	.25	2.2

^a See table 1 for names of soils.

^b Antimonial lead.

^c Commercial lead.

^d The antimonial lead specimens in these soils were 4.25 inches wide and the rate of penetration is based on the depth of the one deepest pit.

In most of the soils the rate of corrosion of the lead specimens is much lower than that of the corresponding ferrous specimens. In Allis silt loam (1), Dublin clay adobe (5), Mahoning silt loam (20), Muscatine silt loam (30), Penn silt loam (34), Ramona loam (35) and in the unidentified silt loam at Salt Lake City (47), the averages of the rates of penetration for the lead specimens are greater than for the corresponding ferrous specimens. These soils are not severely corrosive with respect to ferrous materials. Their chief common characteristic is their low content of sulfates, as will be seen in table 2. It will also be seen from comparing tables 2 and 4 that the lead did not corrode severely in soils high in sulfates.

The data in table 4 should be used with considerable caution for several reasons. Two specimens of the same material in the same soil may not corrode at the same rate. This is illustrated in table 5 where it will be noted that in some instances one specimen corroded

50 percent more rapidly than another specimen of the same material under nominally the same soil condition. This illustrates a soil-corrosion phenomenon which is common to all outdoor soil-corrosion

TABLE 5.—Dispersion of rates of corrosion of lead

SOIL 22.—12-YEARS' EXPOSURE

Material	Loss of weight	Maximum penetration
	oz/ft ² /yr	mils/yr
A197.....	0.168	3.2
A198.....	.129	2.3
H197.....	.087	1.4
H198.....	.082	2.0

SOIL 29.—10-YEARS' EXPOSURE

A62.....	0.446	1.4
A63.....	.259	1.4
H62.....	.443	1.3
H63.....	.242	1.0

tests in which the soils are not in some way modified to secure unusually uniform soil conditions. The data as here presented do not reveal the effect of shape or area on the depth of penetration as has been shown in Research Paper 883.⁷ Likewise changes in the rate of corrosion are not indicated.

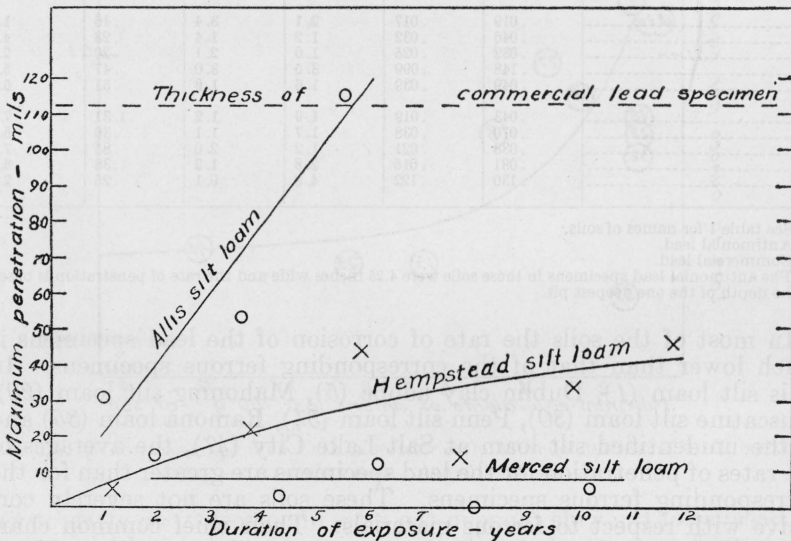


FIGURE 1.—Pit depth-time graphs for lead sheaths in three soils.

The influence of duration of exposure on the depth of the pits on lead is illustrated in figure 1. The pit depths are the averages of the

⁷ K. H. Logan. *Soil-corrosion studies 1934*. Rates of loss of weight and penetration of ferrous specimens. J. Research NBS 16, 431 (1936) RP883.

two deepest pits, one on each side on each of two specimens, one of commercial lead and the other of antimonial lead. It is noted that in Merced silt loam, a soil high in sulfates, the pits increased in depth very little, if at all, as the period of exposure was prolonged. Apparently, a very effective coating, probably of lead sulfate, was formed. In Hempstead silt loam the penetration continued but at a decreasing rate; while in Allis silt loam the penetration was approximately proportional to the duration of exposure up to 6 years, at which time the specimens were punctured.

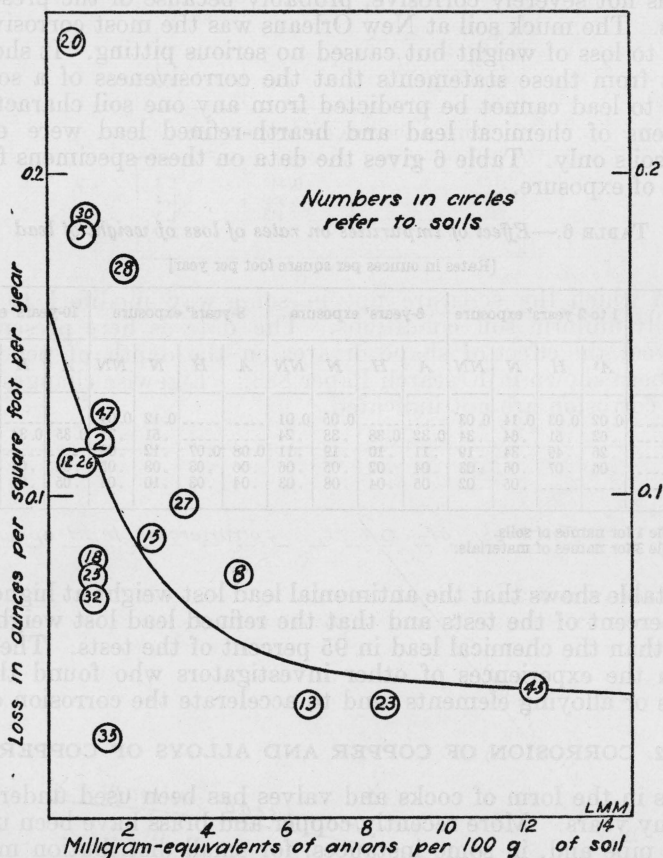


FIGURE 2.—Correlation of rates of corrosion of lead with concentration of chlorides, bicarbonates, and sulfates.

Because of the wide range in the rates of corrosion, an attempt was made to determine what soil characteristics resulted in high rates of corrosion of lead. This has not been altogether successful because of insufficient data and the large number of different factors involved in each soil condition. Figure 2 shows the relation between the concentration of chlorides, bicarbonates, and sulfates in some of the soils to the averages of the rates of loss of weight for periods of exposure varying between 2 and 12 years. The addition of the available data for other soils would not materially affect the shape of the curve,

although it would be extended. Sulfates predominated in these soils. Although the curve shows in a general way that the salts tended to reduce the corrosion of lead, it should not be used for determining the loss of lead because the rates used are average rates, whereas, as was shown in figure 1, the change in the rate of corrosion with time is different for different soils.

In general, soils containing large quantities of organic material and soils which are poorly drained, appear to be corrosive to lead, but exceptions to this statement may be found. For example, the tidal marsh is not severely corrosive, probably because of the presence of sulfates. The muck soil at New Orleans was the most corrosive with respect to loss of weight but caused no serious pitting. It should be evident from these statements that the corrosiveness of a soil with respect to lead cannot be predicted from any one soil characteristic. Specimens of chemical lead and hearth-refined lead were exposed to five soils only. Table 6 gives the data on these specimens for four periods of exposure.

TABLE 6.—Effect of impurities on rates of loss of weight of lead

[Rates in ounces per square foot per year]

Soil ¹	1 to 2 years' exposure				6-years' exposure				8-years' exposure				10-years' exposure			
	A ²	H	N	NN	A	H	N	NN	A	H	N	NN	A	H	N	NN
13.....	0.02	0.03	0.14	0.03	-----	-----	0.05	0.01	-----	-----	0.12	0.04	-----	-----	0.04	0.01
29.....	.62	.51	.64	.34	0.32	0.38	.38	.24	-----	-----	.51	.31	0.35	0.34	.51	.28
42.....	.26	.49	.34	.19	.11	.10	.19	.11	0.08	0.07	.12	.08	-----	-----	.18	.07
43.....	.06	.07	.06	.03	.04	.02	.05	.06	.06	.03	.08	.05	.04	.03	.08	.06
45.....	-----	-----	.05	.02	.05	.04	.08	.03	.04	.03	.10	.04	.05	.04	.09	.02

¹ See table 1 for names of soils.

² See table 3 for names of materials.

The table shows that the antimonial lead lost weight at higher rates in 74 percent of the tests and that the refined lead lost weight more slowly than the chemical lead in 95 percent of the tests. These data confirm the experiences of other investigators who found that impurities or alloying elements tend to accelerate the corrosion of lead.

2. CORROSION OF COPPER AND ALLOYS OF COPPER

Brass in the form of cocks and valves has been used underground for many years. More recently copper and brass have been used for service pipe and, in some instances, for small distribution mains.

The copper-rich alloys used in this investigation are listed in table 3. Table 7 gives the corrosion data obtained from the specimens in 42 soils. As a rule two specimens of each material were removed from each location, but in a few cases one or more of the specimens were not found. Usually the loss of weight of these two specimens did not differ greatly, but in some cases one showed a loss 50 percent greater than the other.

These averages suggest that the rod A, which is an alloy of copper, zinc, lead, and nickel, is less resistant to soil action than the alloy of copper, aluminum, and iron.

The copper-zinc-lead-nickel alloy (A) was most susceptible to attack. The forged brass alloy (Me) corroded more rapidly than the alloy M. Both were relatively susceptible to attack.

TABLE 7—Corrosion of copper-rich alloys ¹ exposed 8 years

M=Shallow metal attack, no roughening of the surface but no definite pitting.
 P=Definite pitting, no pits greater than 6 mils.
 U=Unaffected by corrosion.
 S=Severe uniform corrosion, impossible to measure penetration because of even destruction of surface.
 D>Selective corrosion such as dezincification over large areas.
 d>Selective corrosion in spots.
 Z=Destroyed by dezincification.

Soil ²	Average rate of loss of weight (oz/ft ² /yr)						Condition of surface and pit depth ³					
	Copper pipe		Brass		Cu-Zn-Ni rod A	Cu-Al-Fe rod N	Copper pipe		Brass pipe B	Cu-Zn-Ni rod A	Cu-Al-Fe rod N	
	M	P	Pipe B	Ell Me			M	P				
1	0.060	0.063	0.097	0.185	0.157	0.057	1.5	P	M, D	P	M, D	
2	.073	.016	.080	.228	.131	.046	P	P	P, D	P	M, d	
3	.027	.029	.074	.109	.156	.063	P	P	1.2, d	1.2	D	
4	.019	.019	.144	-----	.176	.070	1.3	M	P, D	1.3	D	
5	.068	.087	.054	.525	.141	.061	M	M	M, D	P	D	
6	.055	.025	.039	.033	.070	.0025	M	M	M, d	P	U	
7	.039	.052	.171	-----	.307	.044	P	P	P, D	1.2	M, D	
8	.024	.019	.018	.319	.136	.026	1.5	1.3	M, d	1.5	1.3, d	
9	.041	.041	.105	.112	.116	.0082	P	P	P, D	P	M	
10	.100	.103	.182	.198	.231	.036	P	P	1.3, D	1.0	D	
12	.312	.278	.222	-----	.199	.090	1.5	S	P, D	M	P, d	
13	.023	.031	.101	.024	.012	.028	P	P	M, D	M	M, d	
14	.040	.025	.044	.089	.096	.017	P	.9	P, d	1.9	M, d	
15	.013	.016	.030	-----	.045	.026	M	M	D	d	d	
16	.067	.058	.170	.166	.234	.093	3.3	1.9	1.3, D	.9	d	
17	.037	.040	.059	.257	.108	.049	M	M	M, d	P	D	
18	.0076	.0077	.021	.070	.044	.013	U	M	M, d	1.3	U	
19	.039	.040	.122	.067	.165	.027	1.1	P	P, d	1.3	M, d	
20	.042	.039	.044	.193	.138	.044	1.5	1.2	P, d	P	M, d	
22	.068	.070	.195	.283	.277	.075	1.9	1.0	1.1, D	P	M, D	
23	.118	.135	.752	1.853	.288	.169	1.9	1.3	Z	U	D	
24	.017	.019	.022	.045	.040	.021	M	M	U	P	D	
25	.012	.011	.051	.142	.126	.043	P	U	P, D	P	D	
26	.010	.011	.048	.101	.103	.026	U	M	M, D	P	1.9, d	
27	.019	.031	.050	-----	.121	.032	P	M	M, D	P	D	
28	.084	.079	.080	-----	.163	.107	P	P	M, D	P	M, D	
29	.123	.116	.275	-----	.257	.082	P	P	P, D	1.9	M, d	
31	.021	.025	.045	.082	.070	.039	M	P	M, d	P	1.0	
32	.049	.018	.089	.152	.129	.016	U	M	1.0, D	1.3	d	
33	.137	.117	.175	.218	.208	.040	.9	1.0	P, D	1.3	M, d	
34	.016	.022	.057	.080	.177	.021	M	P	M, D	P	d	
35	.017	.016	.020	.422	.063	.039	M	P	D	1.0	D	
36	.023	.024	.056	.049	.113	.022	P	P	1.3, d	1.3	M, d	
37	.169	.162	.152	.274	.175	.060	1.8	1.3	P, D	P	M, d	
38	.025	.043	.028	.037	.034	.019	M	P	M, d	P	U	
40	.125	.168	.349	.330	.385	.092	2.3	4.1	1.8, D	1.9	d	
41	.036	.040	.083	.083	.155	.020	P	M	.9, D	P	d	
42	.047	.049	.095	.089	.154	.057	P	1.1	P, D	1.9	P, D	
43	.635	.555	.026	.022	.007	.022	S	S	M, d	U	2.3	
44	.079	.061	.175	-----	.248	.026	P	P	1.3, D	2.4	P, d	
45	.033	.030	.016	.214	.081	.030	1.0	1.0	d	1.0	D	
47	.052	.0053	.0031	.027	.0046	.0038	U	U	D	M	D	

¹ See table 3 for identification of materials.

² See table 2 for names of soils.

³ The letters indicate the condition of the worse of 2 specimens. The figures are rates of maximum penetration, in mils per year.

It is necessary to point out here the fact that brasses high in zinc sometimes undergo selective corrosion known as dezincification in which there is little or no pitting and a loss of strength and service life greater than is indicated by the loss of weight. Extreme cases of dezincification are shown in figure 3. In most cases the specimens high in zinc were not pitted and no attempt was made to determine

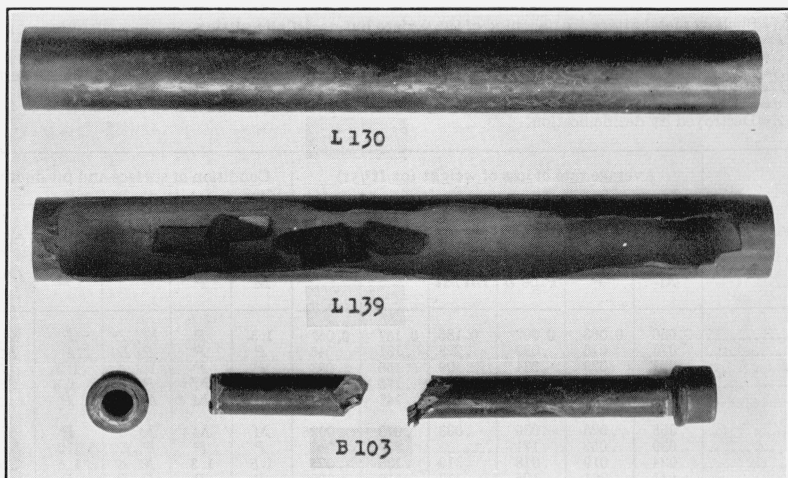


FIGURE 3.—*Dezincification of Muntz metal.*

L130, Exposed for 2 years to an alkali soil; *L139*, exposed 2 years to cinders; *B103*, exposed 10 years to Merced silt loam, an alkali soil.

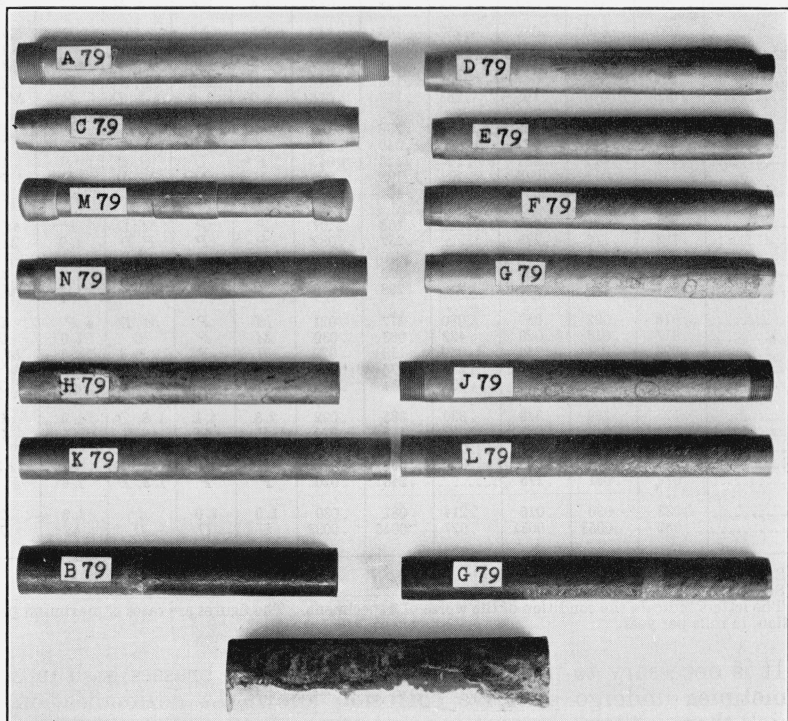


FIGURE 4.—*Nonferrous specimens from a peat soil.*

See table 3 for identification of the nonferrous materials. At the bottom of the figure specimen *B79* is wrought iron, *G79* is cast iron, and the unnumbered specimen is a cement-asbestos pipe. The lengths of the specimens are from 10 to 14 inches.

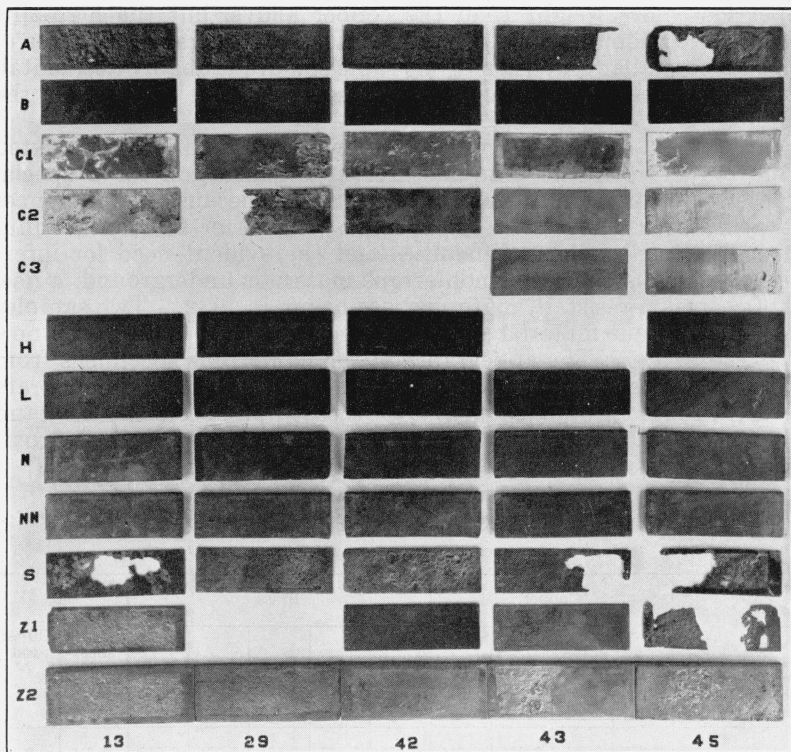


FIGURE 5.—Condition of miscellaneous specimens.

Conditions of miscellaneous specimens exposed to five soils for approximately 10 years. *A*, Open-hearth iron; *B*, brass; *C1*, aluminum; *C2*, Al-Mn alloy; *C3*, duralumin; *H*, copper; *L*, bronze; *N*, chemical lead; *NN*, refined lead; *S*, copper bearing steel; *Z1*, rolled zinc; *Z2*, cast zinc. The soils are as follows: 13, Hanford very fine sandy loam; 29, muck; 42, Susquehanna clay; 43, tidal marsh; 45, unidentified soil containing sulfates.

the depth of the dezincification. The worse of the two specimens at each locality is indicated in table 7, but in most cases the specimens of the same material did not differ greatly.

Six widely different soils were chosen from the original test sites for tests of materials which were not available in sufficient quantities to permit their burial at all test sites. Five of these soils are severely corrosive with respect to iron. Table 8 shows the rates of loss of weight for all the copper-alloy specimens removed from these soils. The figures are based on the losses of weight of two specimens. It will be noted that the rates of corrosion of all of the copper alloys are low except in soil 43, a tidal marsh high in sulfides. In this soil copper lost more weight than the copper alloys, but the high-zinc alloys showed some local dezincification. The differences in rates of corrosion of similar materials in the same soil are probably accidental. Such differences are characteristic of soil-corrosion data from the field.

Prior to 1932 such nonferrous specimens as were buried were tested at the request of some manufacturer or organization for a special purpose. Comparison of materials is difficult because of differences in exposed areas, durations of exposures and other accidental influences. Because of these difficulties and the evident need for information on the usefulness of nonferrous materials underground, a new test of corrosion-resistant materials was begun in 1932. Two samples of each nonferrous material were removed from each of 14 of the new test sites in 1934. The appearance of the nonferrous specimens from the peat soil is shown in figure 4. At the bottom of the figure are shown a wrought iron specimen, *B79*, a cast-iron specimen, *G79*, and a specimen of a cement-asbestos pipe. The specimens are approximately 12 inches long.

TABLE 8.—Rates of loss of weight of copper alloys¹ in 6 soils

[In ounces per square foot per year]

Soil ²	Copper				Brass					Bronze sheet L	Cu-Al rod N
	Pipe			Sheet H	Pipe H	Sheet B ¹	Pipe B	Ell Me	Rod A		
	E	M	P								
18.....	0.052	0.023	0.031	0.015	0.022	0.077	0.101	0.024	0.012	0.015	0.028
24.....		.017	.019				.022	.045	.040		.021
29.....	.040	.123	.116	.116	.061	.153	.275		.257	.131	.082
42.....	.080	.047	.049	.044	.105	.051	.095	.089	.154	.046	.057
43.....	.562	.635	.555		.070	.010	.026	.022	.007	.460	.022
45.....	.028	.033	.030	.015	.020	.074	.016	.214	.081	.049	.030

¹ See table 3 for analyses of materials.

² See table 1 for names of soils.

The average rates of loss of weight of the nonferrous specimens are given in table 9 and the conditions of the specimens are shown in table 10. In cases where specimens subjected to similar conditions differed, the worse condition was recorded.

Because rates of corrosion frequently change with time, and because not many specimens have been examined, definite conclusions should not be drawn from these tables. In general, tables 9 and 10 confirm the data in tables 7 and 8. It should be remembered that cinders from other sources may differ considerably from those used at site 67.

Since data on the corrosion of copper appear in several tables discussion of the effects of soils on this material has been withheld until all of these tables have been presented. From these tables it will be seen that copper corrodes most rapidly in soils containing sulfides. The scale which is formed under these conditions does not appear to have much protective value. Copper corrodes rapidly also in some cinders, perhaps because they also contained sulfides. This should be kept in mind when light-weight pipe is used in city streets containing cinder fills.

In most soils, however, the rate of corrosion of copper and its alloys is much lower than that for ferrous materials, as will be seen by comparing the data in tables 7, 8, 9, and 10 with the last two columns of table 4. It is interesting to note in tables 7, 8, 9, and 10 that in the tidal marshes (soils 43 and 63), the Muntz metal pipe appears definitely superior to the copper pipe.

TABLE 9.—Rates ¹ of loss of weight of nonferrous specimens exposed approximately 2 years

Soil ²	Tough pitch Cu	Deoxi- dized cop- per ³	Red brass	Admir- alty metal	Two and one leaded brass	Brass— 66% Cu; 33% Zn	Muntz metal	Bronze— 97% Cu; 1% Si; 1.8% Sn	Alloy— 98% Cu; 1.5% Si	Alloy— 95% Cu; 3% Si	Alloy— 75% Cu; 20% Ni, 5% Zn
	C	A	F	H	K	J	L	E	N	D	G
51.....	0.21	0.20	0.17	0.16	0.085	0.17	0.35	0.26	0.18	0.23	0.14
53.....	.062	.061	.060	.070	.13	.052	.097	.12	.097	.090	.059
55.....	.072	.075	.068	.079	.11	.094	.10	.16	.076	.080	.061
56.....	.059	.051	.054	.040	.080	.042	.072	.12	.075	.050	.033
57.....	.0036	.0062	.0054	.0061	.041	.041	.24	.031	.012	.012	.0099
58.....	.066	.082	.061	.096	.13	.11	.10	.094	.054	.056	.074
60.....	.71	.76	.76	.59	.59	.89	.90	.84	.68	.69	.72
61.....	.10	.062	.12	.18	.12	.12	.17	.20	.14	.14	.13
62.....	.080	.079	.077	.11	.15	.12	.17	.17	.11	.13	.091
63.....	.64	.55	.27	.12	.23	.021	.069	.57	.80	.61	.32
64.....	.35	.74	.17	.13	.12	.30	2.11	.41	.72	.35	.041
65.....	.26	.90	.27	.16	.072	.72	1.27	.25	.58	.58	.089
66.....	.055	.15	.092	.12	.13	.18	.33	.20	.10	.11	.11
67.....	1.56	1.97	1.66	2.75	3.39	8.20	(4)	1.61	2.74	2.09	1.03

¹ Average for two specimens in ounces per square foot per year.

² See table 1 for names of soils.

³ See table 3 for analyses of materials.

⁴ Destroyed.

Sufficient data are not available for plotting the relation of the period of exposure to the corrosion for individual soils. A comparison of the average rates of loss of weight for the materials listed in table 7 with corresponding data for 4-year-old specimens indicates little or no change in the rates of corrosion. This may indicate that the corrosion-resisting properties of copper are due to low electrochemical potential rather than to the formation of protective films, or that such films as are formed reach their maximum effectiveness very soon after the material is exposed to soil.

3. CORROSION OF ALUMINUM AND ZINC

Data on specimens of aluminum and zinc removed in 1934 are shown in table 11, together with those for other specimens of the same dimensions and periods of exposure. The appearance of these specimens is shown in figure 5. (Specimens C1, C2, and C3.) The blank spaces represent lost specimens. In the case of the aluminum

TABLE 10.—Surface condition¹ and rate of penetration of nonferrous specimens exposed approximately 2 years

M=Shallow metal attack, roughening of surface but no definite pitting.
 P=Definite pitting but no pits greater than 6 mils.
 U=Apparently unaffected by corrosion.
 S=Severe uniform corrosion; impossible to measure penetration because of uniform destruction of surface.
 D=Selective corrosion over large areas, 1. e., several square inches per square foot.
 d=Selective corrosion in small spots.
 Z=Destroyed by dezincification.

Soil ²	Tough pitch copper	Deoxidized copper ³	Red brass	Admiralty metal	Two and one leaded brass	Brass—66% Cu; 33% Zn	Muntz metal	Bronze—97% Cu; 1% Si; 1.8% Sn	Alloy—98% Cu; 1.5% Si	Alloy—95% Cu; 3% Si	Alloy—75% Cu; 20% Ni; 5% Zn
	C	A	F	H	K	J	L	E	N	D	G
51.....	M	M	M	M, d	M, D	M, D	M, d	P	M	M	d, M
53.....	M	P	4.1	6.1, d	M, d	5.1, d	P, d	6.6	P	P	P, d
55.....	P ³	P	6.3	11.6	M, d	5.8	5.3, d	7.4	P	5.8	4.3, d
56.....	M	M	M ³	M, d	M, d	M, d	d	6.5	P	M	M, d
57.....	M	U	4.2	P, d	M	M, d	M, d	12.6	M	M	d
58.....	P	M	M	P, d	M, d	M, d	P, d	6.0	M	M	7.0
60.....	P	5.2, S	7.8	5.2	P, d	9.4	7.8, d	14.1	6.8	P	8.3
61.....	P	P	P	8.4, d	P, d	10.5, d	P, d	P	P	M	P, d
62.....	P	4.1	5.2	8.8	P, d	P, d	P, d	9.9	P	4.7	P, d
63.....	4.3	M	P	M	P	P	M	13.4	P	P	P
64.....	5.8	S	12.0	13.1, d	M	P, d	P, D	11.0	5.8	13.1	P
65.....	P	S	5.2	18.3	M, d	M, d	M, D	12.0	4.2	P	P
66.....	P	6.3	P	M, d	M, d	M, d	P, d ³	6.3	9.4	P	M, d
67.....	17.3	21.8	14.9	25.7	29.2	Z	Z	21.2	23.2	17.3	12.4

¹ Condition or rate of maximum penetration on worse of 2 specimens; figures are in mils per year.

² See table 1 for names of soils.

³ One specimen only.

alloys the loss was due in most cases to the almost complete destruction of the specimens. Table 11 is comparable with similar tables in earlier reports.⁸

TABLE 11.—Rates of loss of weight and penetration of miscellaneous metals and alloys buried approximately 10 years

P=Definite pitting, no pits greater than 6 mils.
 S=Severe surface corrosion, impossible to measure penetration because of even destruction of surface.
 M=Shallow metal attack, roughening of surface but no definite pitting.
 D=Dezincification over large areas.
 d=Dezincification in spots.
 f=Failure of 1 or more holes.

Material ^b	Soil 13 ^a		Soil 29		Soil 42		Soil 43		Soil 45	
	Loss ^c	Pits ^d	Loss	Pits	Loss	Pits	Loss	Pits	Loss	Pits
NN, refined lead.....	0.010	1.1	0.28	1.4	0.068	P	0.062	0.9	0.020	1.1
N, chemical lead.....	.037	1.7	.51	1.3	.18	2.5	.076	1.2	.088	1.8
H, copper.....	.015	M	.12	S	.044	P			.015	P
B, brass.....	.077	M, D	.15	P	.051	M, D	.010	M, d	.010	M, D
L, bronze.....	.015	1.1	.13	5.5	.046	M	.46	1.1	.049	3.1
Z1, sheet zinc.....	.35	4.0	.46	3.9	.085	1.7	.23	3.3	f	f
Z2, cast zinc.....	.34	7.0	.53	5.5	.078	1.8	.22	6.8	.94	9.8
P, sheet zinc.....	.19	5.2	.38	f	.11	2.0	.45	3.7	f	f
Cl, aluminum.....	.009	2.1	f	f	.035	f	.016	P	.047	f
C2, Al-Mn-alloy.....	.038	f	.096	f	.020	1.4	.021	1.3	.031	1.9
C3, Duralumin.....					.14	f	.014	M	f	f
A, open-hearth iron.....	.98	f	.58	6.2	.56	7.0	f	f	f	f
S, steel+0.2% Cu.....	f	f	.69	f	.54	5.9	f	f	f	f

^a See table 1 for names of soils.

^b See table 3 for names and analyses of materials.

^c Loss is given in ounces per square foot per year.

^d Rate of maximum penetration in mils per year.

⁸ See table 20, Tech. Pap. T368; table 8, Research Pap. RP359; and table 12, Research Pap. RP368. References to these papers have been made in earlier parts of this report.

Figure 6 shows the relation of the average maximum penetration to the duration of exposure of zinc specimens to five soils. Each point is based on the average of the deepest pits on each of two specimens. In two of these soils the rates of penetration appear to increase with the period of exposure.

Table 11, as well as similar tables previously published,⁹ shows that the purer zinc (hearth refined) corrodes less rapidly than the zinc which contains more impurities.

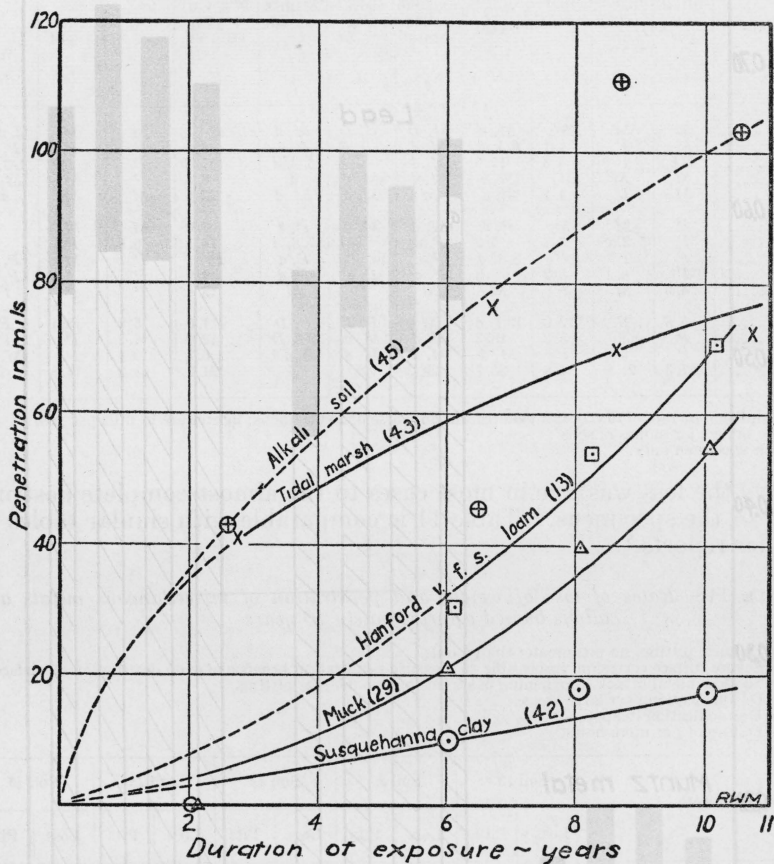


FIGURE 6.—Relation of the maximum penetration of zinc to the duration of exposure.

Under some circumstances the corrosion of the aluminum and aluminum-manganese alloy occurs mostly beneath the surface of the metal which is raised to form blisters beneath which a white powder is found.

It was not practicable to remove all of this powder without destroying some of the uncorroded metal and for this reason the losses of weight for the above mentioned materials as given in table 11 are inaccurate. They show, however, in a general way at least, the relative corrosiveness of the soils with respect to these materials. Since, as

⁹ p. 544 Tech. Paper BS T368; p. 594, Research Paper RP359; p. 138, Research Paper RP638.

has been shown, soils differ greatly in many ways, general conclusions as to the usefulness of thin aluminum sheet underground should not be drawn. The data indicate that the effect of the soil on the aluminum alloy should be investigated before the material is used underground.

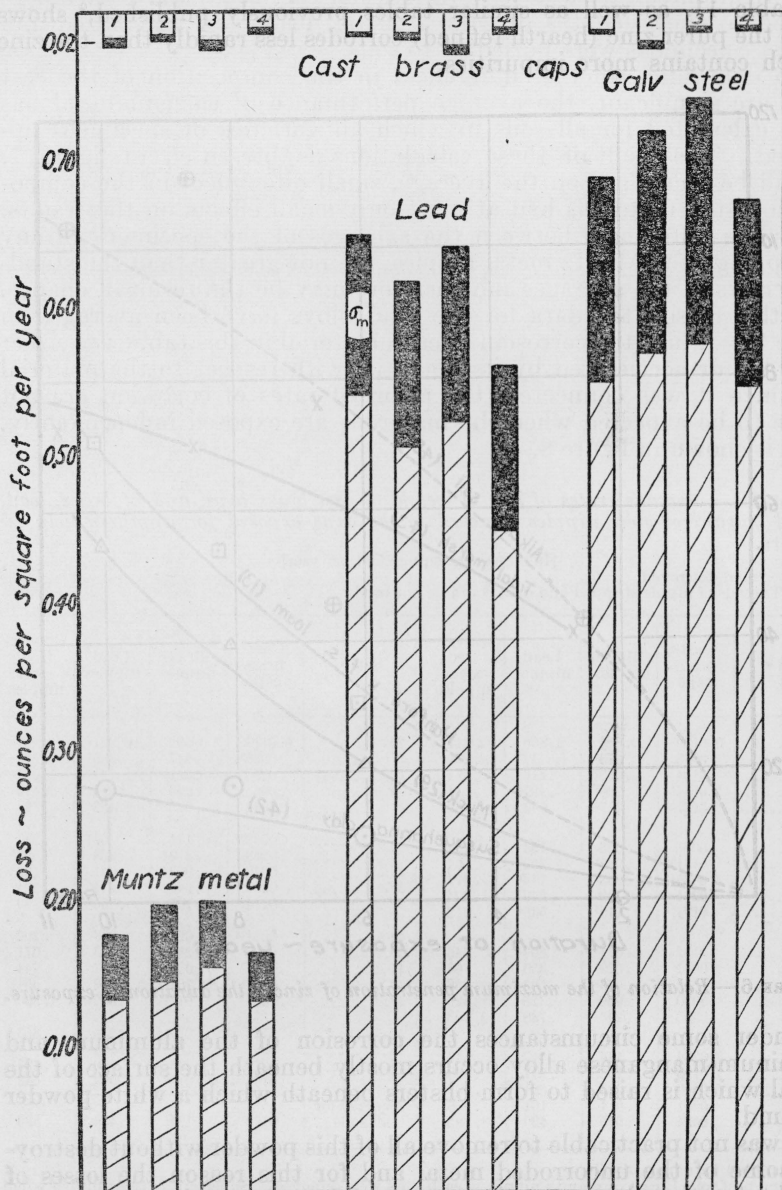


FIGURE 7.—Average rates of corrosion of cast-brass fittings and attached nipples in 15 soils.

At the top of the figure are shown the average rates of corrosion of four cast-copper alloys in the form of caps. Below are the rates of corrosion of the nipples attached to each variety of cast cap. See table 3 for analyses of materials. The solid ends of the column show the standard errors, σ_m , of the averages.

IV. EFFECT OF INTERCONNECTING DIFFERENT METALS

Several experiments have been undertaken to determine the effect of placing two metals in contact under several soil conditions. The earliest of these in the National Bureau of Standards soil-corrosion investigation consisted of four varieties of cast-brass alloys each connected to short lengths of Muntz metal, lead, and galvanized-iron pipe. Specimens were buried in 45 soils.

To determine whether differences in the composition of the cast caps are significant, the average performance of each material has been calculated for all soils in which all varieties of specimens appeared. The result of these calculations is presented in figure 7. It will be seen that, on the average, small differences in the composition of the materials had at most only small effects on the results. Thus the differences between the averages of the specimens in any group, e.g., the Muntz metal nipples, are not greater than the standard errors of the averages and therefore may be the result of chance. For this reason the data for the four alloys have been averaged in table 12. Since the corrosion of each material in this table was either retarded or accelerated by its potential with respect to the material to which it was connected, the recorded rates of corrosion are not those to be expected when the materials are exposed independently. This is shown in figure 8.

TABLE 12.—Average¹ rates of loss of weight of cast brass caps, and of brass, lead, and galvanized-steel nipples attached to the caps exposed for approximately 10 years.

[In ounces per square foot per year]

f = Specimen destroyed.

(1) = Threads of nipple stripped and data could be not used.

Soil ^a	Cast-brass caps	Brass nipples	Lead nipples	Galvanized steel nipples	Soil ^a	Cast-brass caps	Brass nipples	Lead nipples	Galvanized steel nipples
1-----	0.0159	0.624	1.808	2.317	26-----	0.0117	^b 0.092 ³	0.321	0.221
2-----	.0083	.073	(1)	.230	27-----	.0036 ¹¹	.117	.385 ¹	.293
3-----	.0144	.053	.416 ³	.311	29-----	.0259 ¹⁰	.561 ²	(1)	1.924
4-----	^b .0184 ⁸	.268 ³	.487 ²	.651 ³	30-----	.0065	.066	.284	.410
5-----	.0137 ¹¹	.317 ²	.943	1.368 ⁵	31-----	.0044	.025	.422	.296
6-----	.0081	.026	.154	.121	32-----	.0062 ¹¹	.111	.263 ³	.240
7-----	.0134 ³	.033 ³	.352 ¹	.604	33-----	.0558	.319 ³	.288	.592 ⁵
8-----	.0065 ¹⁴	.093 ⁵	.143 ³	.477 ³	35-----	.0046	.0034	.041	.132
9-----	.0261	.192	.549	.424	36-----	.0089 ¹¹	.049	.414	.224
10-----	.0171 ¹⁴	.210 ⁵	.536 ⁵	.672	37-----	.0214 ¹¹	.165	.430 ³	.740
11-----	.0132	.071	.693 ²	.346	38-----	.0054 ¹⁰	.023	.218	.202
13-----	.0041	.079 ³	.356	.766	40-----	.0196	.256	.493	.671
14-----	.0038	.033	.565	.258	41-----	.0084 ⁹	.099	.597	.244
15-----	.0030	.050	.328	.425	42-----	.0087 ¹⁰	.101 ³	.782	.654
17-----	.0350	.246	.738	1.103	43-----	.1467 ⁷	.017 ²	.032 ²	1.580 ¹
19-----	.0234	.136	.517	.354	44-----	.0142	.039	.286	.353
20-----	.0196	.153	.617	.538	45-----	.0291	.154	.135	<i>f</i>
22-----	.0142	.203	.691	.907	46-----	.0072	.046	.140	.693
24-----	.0061	.014	.101	.078	47-----	.0105 ¹¹	.019 ³	.093	.443
25-----	.0094	.075	.429	.185	Average for all soils	.0172	.134	.434	.580

^a See table 1 for names of soils.

^b From most soils 12 cast caps and 4 nipples of each kind were removed. Superscript gives number when other than normal.

Figure 8 shows that rate of loss of weight of the cast-brass caps was about half that for copper pipe in the same soils. This may have been the result of cathodic protection or because the cast alloys were more resistant to corrosion. The latter conclusion is suggested by the relative rates of corrosion of the castings, since those containing the least copper corroded the least.

The value for the Muntz metal nipples was about 50 percent higher than for pipes of the same material, while that for the galvanized

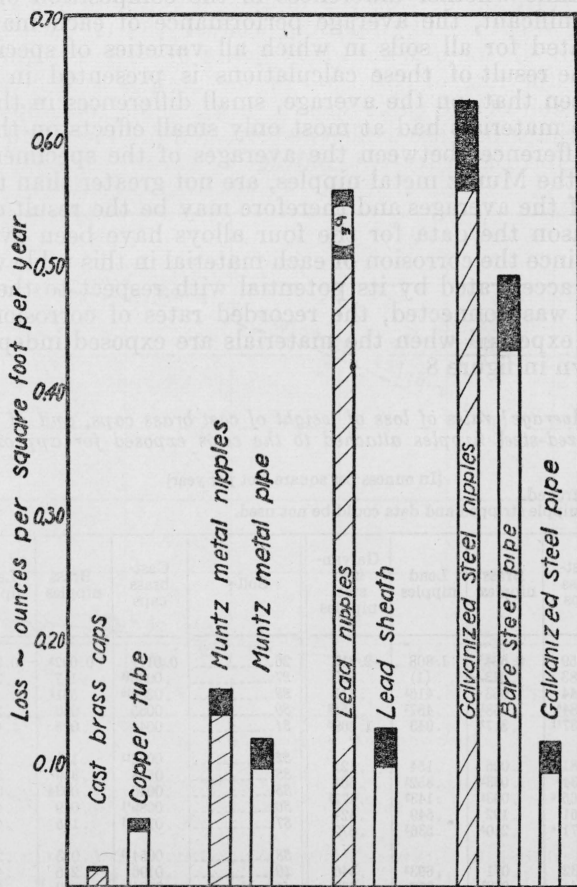


FIGURE 8.—Effect of interconnecting different metals.

The cross-hatched columns show the average rates of corrosion of the materials affected by galvanic action. The solid ends of the columns show the standard errors (σ_m) of the averages.

nipples was six times that for galvanized pipe in the same soils. The values for the galvanized nipples were about 25 percent greater than for unprotected steel pipe. Facts to be considered in this connection are that there was no zinc on about one-half inch of the nipples where they were threaded and probably the coating on the nipples was not as heavy as on the pipes.

A surprising result shown in figure 8 is that the lead nipples lost weight almost as rapidly as those of galvanized steel. Of course a partial explanation of this fact is that the density of the lead is nearly

50 percent greater than that of the other metals. This explanation, however, scarcely seems adequate since in service lead connected to brass cocks has a reputation for lasting much longer than galvanized steel under similar conditions. It seems probable that if the nipples had been longer and larger with respect to the cast caps the results of the test would have been somewhat different.

The most striking difference was between the rates of loss of the lead nipples and the corresponding rates for the lead cable sheath. The average rate of loss for the nipples was about five times that for the cable sheath. The relation between the two when exposed to Hempstead silt loam is shown in figure 9. There seems to be a tendency for the rate of corrosion of the nipples to decrease. The rate of corrosion of the cable sheath in the same soil appears to be constant, perhaps because sufficient corrosion products had not been deposited to form an effective coating.

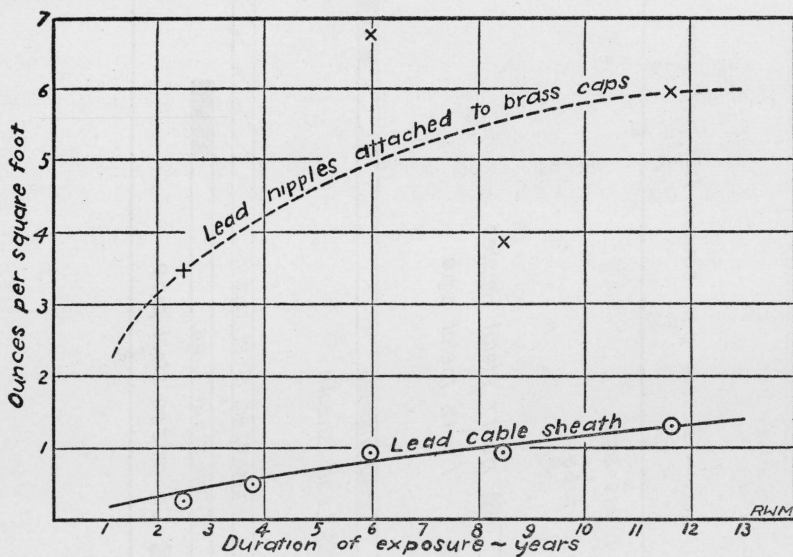


FIG. 9.—Comparison of losses of weight of lead nipples and cable sheath for different periods of exposure.

The soil-corrosion investigation contains three other sets of materials buried for the purpose of studying galvanic corrosion. The forms of these specimens are shown in figure 10. The unlabeled specimen consists of two strips of cast iron united by a brazed joint. The pipe from which the sections were cut was cast in a mold in which portland cement was used to prevent the metal from sticking to the sand. The pipe manufacturer who prepared the specimens left the cement on them because this is the way the joint would be used in practice. For the same reason no care was taken to remove the flux used in making the joint. The uneven distribution of the corrosion may therefore be accounted for in several ways. However, after 8 years' exposure to a corrosive soil there was no serious corrosion at the joint.

Specimens of copper pipe joined by copper stream-line soldered fittings (*M1*, fig. 10) and specimens of a copper-silicon alloy pipe

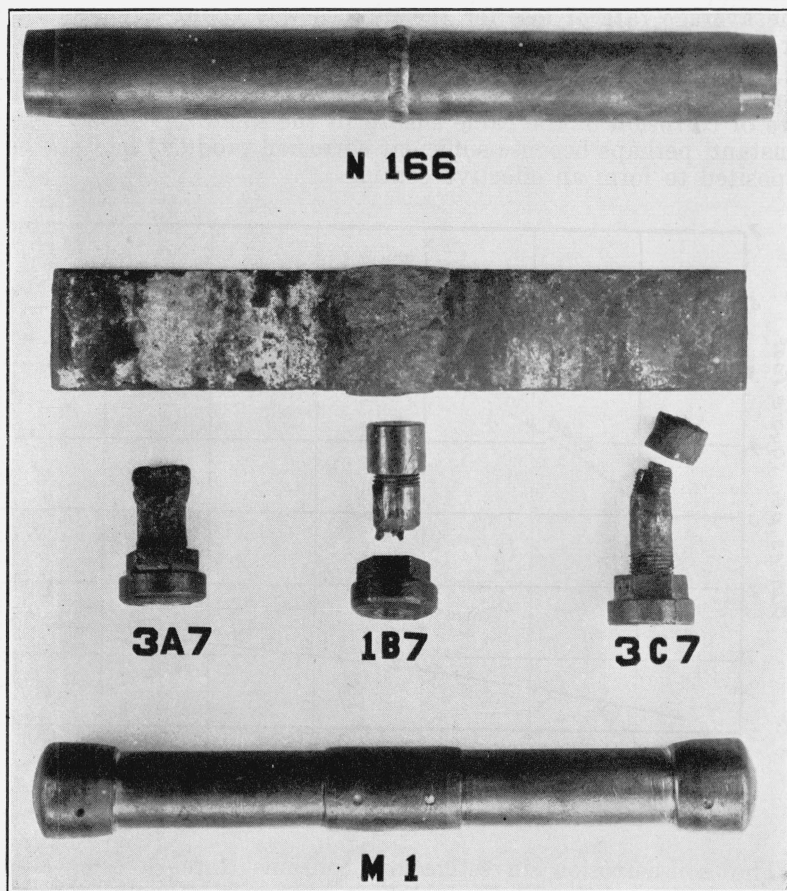


FIGURE 10.—Types of specimens used in studying the effect of joining dissimilar metals.

N, Copper-silicon alloy exposed to peat soil for 2 years; unnumbered, brazed joint on cast iron exposed 8 years; **3A7**, **1B7**, **3C7**, cast brass caps attached to lead, Muntz metal, and galvanized steel, respectively, and exposed for 10 years to Allis silt loam; **M1**, soldered joints on copper pipe exposed 2 years in a tidal marsh.

with bronze welds at the middle of the specimens (*N166*, fig. 10) showed no definite evidence of corrosion which could be attributed to galvanic action after 2 years' exposure. The brass caps and attached nipples shown also in figure 10 are from a soil which is severely corrosive. They show the form of the specimens reported on in figures 8 and 9, and in table 12.

V. DETERIORATION OF NONMETALLIC PIPE

In addition to the large variety of specimens of metallic pipe and sheet, the soil-corrosion investigation includes two varieties of nonmetallic pipe developed for the transportation of water. These specimens buried while the materials were being developed do not represent the materials now marketed by those who furnished them. In both cases the manufacturers believe that their more recent products have overcome the weaknesses shown by the specimens.

The oldest nonmetallic specimens in the test were of wood fiber, coated inside and out with a bituminous substance which cracked and lost its plasticity in some soils. The fiber absorbed sufficient moisture to cause some of the specimens to increase in length about 5 percent. No tests of strength of the materials have been made. The coating had such a low melting point that it softened and became sticky when the specimens were exposed to the sun at the warmer test sites. The results of the test suggest that the pipe material itself should be more nearly moisture-proof since it has been demonstrated that moisture penetrates most thin bituminous coatings. It has also been shown that it is very difficult to secure and maintain a perfectly continuous bituminous coating on a pipe line because of the nature of bitumens.

The other material is composed of 85 percent of portland cement with the addition of 15 percent of asbestos fiber. The specimens of this material were exposed for approximately 2 years to 15 soils severely corrosive with respect to ferrous materials. As the specimens absorbed moisture, loss of weight determinations were not made. The specimens showed no pitting and it seemed best therefore to determine their condition by inspection.

The following comments were made by a representative of the manufacturer: "Inspection of specimens of asbestos cement pipe has shown surface corrosion on those samples which were in contact with acid soils and cinders. Also, some surface disintegration has been noted on those specimens in contact with soils containing soluble sulphates."

The test specimens were not representative of the grade sold as pressure pipe; therefore, the results may not be representative of what could be expected in the case of the more dense structure of pipe intended for pressure service. Until the specimens have been exposed for longer periods a detailed report on the condition of each specimen would add little to the above quotation.

VI. SUMMARY

The data on the nonferrous specimens were insufficient to justify positive conclusions as to the rates of corrosion of the materials under any specific soil condition. However, the following conclusions are suggested by the data.

1. No metal or alloy has been found superior to all others for all soil conditions, but for each condition some suitable material is available.

2. With but few exceptions the rates of loss of weight and penetration were less for the nonferrous specimens than for the ferrous specimens subjected to the same soil conditions.

3. Lead in contact with some soils became badly pitted within a few years. Until the causes of this pitting are better understood, cable sheaths should be placed in direct contact only with soils known to be noncorrosive.

4. The differences in the rates of corrosion of different varieties of lead were small but the purest lead corroded the least. Antimonial lead appeared to corrode at a slightly higher rate than the commercial lead cable sheaths.

5. The rate of corrosion of lead gradually decreased in some soils but appeared to be maintained in certain soils such as tidal marshes.

6. The presence of chlorides, bicarbonates, and particularly sulfates, in soils favors the formation of films or deposits which retard corrosion of lead.

7. Copper and alloys high in copper corroded slowly in most soils. The highest rates of corrosion of copper occurred in soils containing sulfides.

8. The rates of corrosion of all copper alloys were higher in cinders than in any type of soil tested.

9. The corrosion of copper and high-copper alloys was more nearly uniform over the surface than was the corrosion of ferrous materials in most soils.

10. Muntz metal dezincified in a considerable number of soils and probably should not be exposed to severe soil conditions.

11. The rates of corrosion of copper and brass appeared to change less with time than did the corresponding rates for ferrous materials.

12. Zinc corroded rather rapidly in a few soils. In some soils the loss of weight of zinc was nearly proportional to the duration of the exposure. In such soils effective protective films were not formed. The protection which a zinc coating affords under such soil conditions is the result of cathodic protection at the expense of the zinc or due to the corrosion resistance of the zinc-iron alloy layers.

13. Aluminum and some of its alloys corroded rapidly under most of the soil conditions to which they were exposed.

14. The interconnection of dissimilar metals exposed to soil resulted in the partial protection of one of them and in more rapid corrosion of the other. Sometimes, however, the formation of corrosion products of one of the materials prevented continued corrosion.

The cleaning, weighing, and measuring of the specimens was done mostly by R. B. Hobbs, L. M. Martin, and I. Bohrer, on whose skill and care the reliability of the data largely depends. The last two made and checked most of the computations and assisted in the preparation of the tables and drawings. Dr. I. A. Denison and Mr. Martin made many valuable suggestions as to the interpretation of the data.

WASHINGTON, August 13, 1936.

