Ground-Water Resources of the Republic of El Salvador Central America

By A. N. SAYRE *and* G. C. TAYLOR, JR.

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GROUND-WATER RESOURCES OF THE REPUBLIC OF EL SALVADOR, CENTRAL AMERICA

By A. N. Sayre and G. C. Taylor, Jr.

ABSTRACT

This report is based on an investigation by the writers of the U. S. Geological Survey assigned to the Institute of Inter-American Affairs to determine the ground-water resources of El Salvador, especially with reference to the development of ground water for public water supplies and for domestic use. The field work on the investigation was carried on from June 1943 through February 1944. During this period, studies were made of the water-supply problems of some 30 towns and cities in the republic.

El Salvador, smallest of the five Central American Republics, covers an area of about 13,176 square miles. The climate of the country is the savanna typical of the subequatorial belt of the tropics. There are two seasons, a wet season from June to October, inclusive, and a dry season during the low-sun period. The average annual rainfall over the country as a whole is about 75 inches, most of which occurs in the wet season.

Much of the western and central part of El Salvador is an elevated plateau ranging from 1,000 to 2,000 feet above sea level. The eastern part of the country is largely a hilly upland ranging from 500 to 1,500 feet above sea level. The plateau and upland are moderately dissected by numerous canyons and narrow valleys separated by broad sloping interfluves. Surmounting the plateau and upland are five groups of volcanic peaks which form a discontinuous highland that traverses the country from east to west. The summits of this highland rise from 5,000 to 8,000 feet above sea level. Bordering the shore line is a narrow coastal plain that rises inland to an elevation of about 500 feet.

In El Salvador, nonmarine strata of the Tertiary and Quaternary systems rest on igneous and sedimentary rocks of Cretaceous and greater age. Apparently the oldest rocks in the republic belong to the Metapân formation of late Jurassic and early Cretaceous age. The formation includes interbedded sandstone, shale, conglomerate, marl, and limestone with occasional strata of tuff and breccia. Locally the rocks of the Metapân formation are intruded by stocks and dikes of granite, granodiorite, and diorite. These intrusive rocks may be of late Cretaceous or early Tertiary age. The strata of the Tertiary system include extrusive basalt, andesite, and some intermediate and acidic extrusive rocks; volcanic ejectamenta that range from scoria to compact tuff, agglomerates, and breccia; and detrital sediments of alluvial and lacustrine origin. The strata of the three classes are interlaminated and interfingered, and they grade laterally into one another in a complex fashion. The rocks of the Quaternary system include basic lavas and pyroclastics erupted from central vents, and alluvial, lacustrine, and beach sediments deposited in the larger valleys and basins, and along the seaward margin of the costal plain.

The rocks of the Metapán formation of late Jurassic and early Cretaceous age crop out in the northern highlands of the Departamento de Santa Ana and the Departamento de Chalatenango. These rocks are not generally very permeable but may yield small supplies of good water to wells and springs from fractures or solution passages. The Upper Cretaceous (?) intrusive rocks that cut the Metapán formation are not generally permeable but fractures and weathered zones may yield small supplies of water to wells and springs.

Strata of early (?) Tertiary age crop out chiefly in the northern highlands and the eastern upland. The rocks include weathered basalt and felsitic lavas with intercalated pyroclastic rocks and detrital sediments. These rocks generally have low permeability owing to cementation and induration of the sedimentary beds and alteration of the volcanic materials. Fractures may yield small supplies to springs, and locally fragmental and scoriaceous zones in the lavas yield moderate to large supplies of water to wells and springs.

Rocks of late Tertiary (?) age underlie younger volcanic rocks and detrital materials of the central highland, the western plateau, and the coastal plain. The rocks are chiefly andesitic agglomerates, breccias, and tuffs intercalated with basaltic and andesitic lava flows. The fragmental and scoriaceous facies of the andesitic and basaltic lava flows, where present in the zone of saturation, yield moderate to large supplies of water to wells and springs.

The Pleistocene series of the Quaternary system include lake beds, the older Quaternary lavas and pyroclastics, and the older alluvium. The lake beds include water-laid clay, silt, and sand derived from pyroclastic ash, pumice, and cinders, and deposited in lava-dammed basins. The sandy and cindery beds yield moderate supplies of water to wells and springs, but the clayey beds are largely impermeable. The scoriaceous and fragmental facies of the older Quaternary lavas are permeable and yield moderate to large supplies of water to many wells and springs in the republic. Among the older Quaternary pyroclastics are pumice and cinder beds which are ordinarily productive water-bearing horizons when present in the zone of saturation. The beds of volcanic ash are generally impermeable but locally yield small supplies to wells and springs. The older alluvium, where present in the zone of saturation, yields moderate supplies of water to wells and springs.

The Recent series of the Quaternary system includes younger Quaternary lavas and pyroclastics, younger alluvium, landslides, talus, and alluvial fans, and beach and estuarine deposits. The young Quaternary lavas and pyroclastics are generally above the regional water table. However, locally perched bodies of ground water occur in these rocks that yield small supplies to shallow wells and temporary springs. The younger alluvium contains considerable water at shallow depth in the lower stream valleys. The landslide and talus masses, and the alluvial fans are generally above the regional water table. Along the coast dune sand, where present in the zone of saturation above sea level, yields small supplies of potable water to shallow dug wells.

Practically all the cities and towns in El Salvador obtain water supplies for public and domestic use from wells and springs. The majority of the supplies are obtained by gravity through pipelines from developed springs. A few towns and cities, because of their topographic position, obtain water from pumping stations located at springs lying at lower elevation. Because of improved economic conditions and the efficiency of modern pumps, wells are being used to an increasing degree as sources of public water supplies in the Republic. This report describes the water supplies of some 25 towns and cities in the Republic.

INTRODUCTION

SCOPE AND PURPOSE OF THE INVESTIGATION

This report is based on an investigation made by geologists of the Geological Survey, United States Department of the Interior, assigned to the Institute of Inter-American Affairs. The writers, of the Ground Water Branch of the Survey, were assigned to the Institute's field party in El Salvador to study critical problems of water supply as a part of the program of the Health and Sanitation Division in cooperation with the Salvadorean Government. Dr. Sayre spent 3½ months in El Salvador, from June until September 1943, and Mr. Taylor spent 7 months, from July 1943 until February 1944.

During the course of the field work, geologic and hydrologic studies were made of the water-supply problems of about 30 towns and cities in the republic. Individual reports have been prepared in both English and Spanish for each of the localities visited. They describe the geologic, hydrologic, sanitary, and economic features of existing and potential water supplies and contain recommendations for their development and improvement. These reports, in manuscript form, are available for consultation in the files of the Health and Sanitation Division field office in San Salvador, Central America, and also in the files of the Ground Water Division, U. S. Geological Survey, in Washington, D. C. The places visited are shown in plate 3.

Geologic and hydrologic studies were also made along the Pan American Highway in the 180-mile stretch from the Guatemala border to the border of Honduras. About 50 sites were selected for the development of springs or the construction of wells as roadside watering places along the highway, for travelers or stock.

The present report summarizes the general geologic and ground-water features of El Salvador, as based on field observations made in the course of more detailed municipal water-supply studies.

ACKNOWLEDGMENTS

The need for ground-water studies in El Salvador was first recognized by Lt. Col. H. W. Van Hovenburg, chief of the field party for the Health and Sanitation Division of the Institute, and Dr. Victor Arnoldo Sutter, Director of the Salvadorean Sanitation Service. It was through Colonel Van Hovenburg's initial request that the writers were assigned to the project. Dr. Sayre planned the field program and directed the first phases of the work. After Dr. Sayre's return to the United States, the field program was carried on and completed by Mr. Taylor with the capable assistance of Sres. Mario Pacheco and Carlos Alemán, engineers assigned to the field group by the government of El Salvador.

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HISTORICAL SKETCH

The first inhabitants of the region now called El Salvador, according to reports, were Indians of the Nahoa group, who migrated from Mexico. Later the Pipíl Indians entered the country and settled in the coastal area from the Guatemala frontier to the mouth of the Río Lempa. At about the same time Indians of the Chontal group settled in the eastern part of the country from the Golfo de Fonseca to the Lempa valley.

Under the leadership of Don Pedro de Alvarado, the Spaniards first entered Salvadorean territory in May 1524, founding at that time the city of San Salvador. The country remained under Spanish rule until September 21, 1821, when, as a part of the Central American Federation, El Salvador declared its independence from Spain. In January 1822, an attempt was made by Emperor Itúrbide to incorporate the Central American States in the Mexican union, but the proposed annexation was successfully resisted by armed force. In July 1823 the Congress of the Central American Federation proclaimed that the States of the isthmus were independent of Spain, Mexico, and any other country of the old or new world.

Because of dissatisfaction with the organization of the Federation, the State Legislative Congress declared on January 30, 1841, that El Salvador would resume its sovereignty and would call itself the Republic of El Salvador in Central America. It declared, moreover, that its withdrawal was only temporary, as it ultimately desired the reestablishment of a great, firmly founded Central American nation.

GEOGRAPHIC SKETCH

The Republic of El Salvador lies on the isthmus of Central America between 13°08′ and 14°24′ north latitude and 87°39′ and 90°08′ west longitude. San Salvador, capital of the republic, is approximately 1,100 miles south of New Orleans, La., in the United States.

El Salvador, smallest of the five Central American Republics, covers about 13,176 square miles. The country has the rough outline of a rectangle 160 miles long from east to west and 60 miles wide from north to south. It is bordered on the north by the Republic of Honduras, on the west by the Republic of Guatemala, on the south by the Pacific Ocean, and on the east by a part of Honduras and the Golfo de Fonseca. (See fig. 7.)

For governmental administration the country is divided into 14 departments and 259 municipalities. The largest city and the capital of the republic is San Salvador (population 97,161), located in the west-central part of the country. Other principal cities are Santa Ana (population 77,136) in the extreme west and San Miguel (population 41,109) in the eastern part of the country. La Unión on the

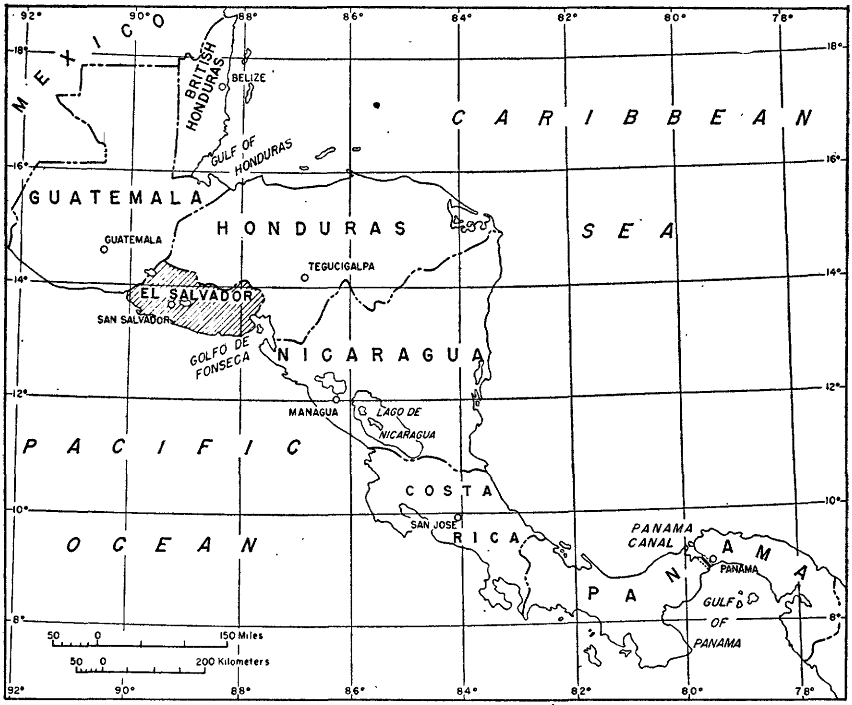

FIGURE 7.—Index map of Central America showing the location of the Republic of El Salvador.

Golfo de Fonseca is the chief seaport, but considerable commerce passes through the ports of La Libertad and Acajutla.

The total population of El Salvador is 1,787,930, or an average of 135.7 inhabitants per square mile. Some 90 percent of the inhabitants are mestizos of mixed Spanish and Indian origin. There are no uncivilized Indians in the country.

CLIMATE

El Salvador, located 13° to 14° north of the equator, has a climate typical of the warm tropical regions of the world. The seasons are marked by variations in rainfall rather than by changes in temperature. Temperature and rainfall vary chiefly with altitude. The lowlands are hot and sultry but are generally drier than the moist, more temperate uplands of the interior.

As is characteristic of the subequatorial belt of the tropics, there are only two seasons, a wet period and a dry period. The rainy season lasts from June through October. May and November are marked respectively by increasing and decreasing rainfall, at the beginning and the end of the rainy season.

During the wet season there is frequent, almost daily rainfall. The rains of June and July come as short, intense showers with thunder and lightning. In August and September the storms are often prolonged in "temporals," during which rain may fall continuously for 3 or 4 days. These storms are generally regional in contrast with the local thunder showers earlier in the season.

During the dry season, winds from the north are the dominant factor controlling the weather. These winds reach the Caribbean coast of Honduras laden with moisture. Condensation and precipitation of the moisture load take place when the winds pass over the high mountain ridges of southern Honduras. Because most of the precipitation occurs on the north slopes of the mountains, the winds reaching El Salvador are generally dry and only infrequently produce rain.

In general, the rainfall in El Salvador increases with altitude, but there are many local differences owing to the alinement of the mountains with respect to wind direction. The average annual rainfall over the country as a whole is about 75 inches. Areas with elevations of more than 3,000 feet above sea level, particularly in the vicinity of the high volcanic peaks, receive 85 to 100 inches of rain annually. The driest section is in the eastern part of the country, in the departments of Morazán and La Unión, where the annual rainfall ranges from about 40 to 50 inches a year.

The following table shows the monthly, yearly, and average rainfall from 1912 to 1936 as based on data of the National Meteorological Observatory at San Salvador. This station gives a representative picture of the distribution of the rainfall in the country as a whole.

Rainfall, in inches, at San Salvador, El Salvador, Central America, 1912–36

[Based on data of the National Meteorological Observatory]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	0	0	0	.33	4.11	7.81	14.49	14.15	5.83	12.96	0.21	2.09	61.98
1913	0	0	0.27	3.86	5.66	9.30	9.00	13.08	11.29	17.94	1.97	1.34	73.71
1914	0.32	0.18	0	.73	10.80	13.25	9.36	9.96	15.79	8.86	1.47	0	70.72
1915	.30	0	.02	2.19	9.47	12.27	14.58	12.08	9.18	6.39	1.30	.86	68.64
1916	1.16	0	0	2.12	4.47	11.72	7.63	8.72	10.18	7.76	7.71	.22	61.69
1917	0	.02	.61	.40	2.68	14.00	15.21	12.12	11.54	12.89	.58	0	70.05
1918	.40	1.38	3.12	11.29	12.83	13.79	12.42	9.72	7.22	9.57	1.54	.11	83.39
1919	.50	.57	0	2.20	3.44	11.44	13.81	14.14	10.75	12.08	1.63	.16	70.72
1920	.06	0	.01	0	7.38	10.65	9.93	12.40	10.42	6.08	1.29	.07	58.29
1921	.28	0	2.08	2.91	8.05	16.21	10.40	9.72	14.86	19.80	1.81	.19	86.31
1922	.07	.92	1.38	.18	5.95	17.60	6.11	12.08	9.74	5.80	1.20	.59	61.62
1923	0	0	.18	.22	5.52	15.01	11.55	6.00	20.62	8.79	0	.57	68.46
1924	.03	.93	.22	2.44	7.01	13.38	15.68	18.51	11.05	10.53	.01	.68	80.47
1925	.79	.09	0	4.44	7.62	12.02	16.86	10.81	12.91	10.20	3.02	0	78.76
1926	.06	0	.01	1.17	8.15	16.71	12.44	17.41	7.64	7.60	1.48	.75	73.42
1927	0	.22	0	2.64	14.95	12.86	18.94	18.45	12.15	11.31	2.84	.07	94.43
1928	.12	.13	.05	.36	8.10	12.13	17.90	14.40	19.37	6.84	2.84	.83	83.07
1929	0	0	.47	0	7.78	12.28	13.48	10.12	13.50	12.38	3.54	.93	74.48
1930	.01	.28	0	.88	7.60	11.32	6.06	3.89	9.20	5.72	.05	.41	45.42
1931	0	.72	0	1.67	7.86	20.28	10.73	8.05	8.30	10.18	.99	.99	69.77
1932	.51	0	.77	2.25	8.17	14.10	12.60	18.40	18.42	12.04	.07	.99	88.32
1933	0	0	0	.08	10.58	15.65	11.92	8.38	12.31	8.92	0	.32	68.16
1934	.26	.95	0	.77	11.12	22.49	8.24	13.92	17.05	9.40	2.32	.22	86.74
1935	0	0	.29	.16	12.86	10.19	6.77	11.10	13.40	14.30	.65	.12	69.84
1936	.05	.53	.13	1.05	6.18	24.25	11.45	15.03	13.39	13.95	7.47	0	93.48
Average	.20	.28	.38	1.77	7.93	14.03	11.90	12.11	12.24	10.49	1.84	.50	73.67

PHYSIOGRAPHY

GENERAL FEATURES

El Salvador, though small in area, is a region of considerable physiographic diversity. Much of the western and central part of the country is an elevated plateau of moderate relief ranging from 1,000 to 2,000 feet above sea level. Along its margins the plateau has been dissected by numerous deep canyons and narrow valleys separated by broad sloping interfluves. The eastern part of the country is chiefly low hilly uplands with well-integrated stream valleys, and it ranges from about 500 to 1,500 feet above sea level.

Surmounting the western plateau and the eastern uplands are five groups of volcanic peaks which form a discontinuous mountainous highland that traverses the country from east to west. The basal slopes of the volcanic groups range from 2,000 to 3,000 feet above sea level, but the summits rise from 5,000 to 8,000 feet.

Along the northern frontier of El Salvador the outlying ridges of the Central American Cordillera extend from southern Honduras into the northern parts of the departments of Santa Ana, San Miguel, Morazán, and western Chalatenango. The crests of many of these ridges are more than 3,000 feet above sea level.

Bordering the shore line is a coastal plain which rises inland to an elevation of about 500 feet. From the Guatemala border to the valley of the lower Río Lempa the plain is generally narrow and rises sharply to the interior plateau within a few miles of the coast. East of the Río Lempa the coastal plain merges almost imperceptibly with the low hilly uplands of the eastern interior of the country.

The Río Lempa, which rises in the highlands of Guatemala and Honduras, enters El Salvador near the northwestern corner of the country. For the first 35 miles of its course in El Salvador it flows southwest through narrow canyons and valleys. It then turns abruptly eastward and flows on a much lower gradient for about 70 miles, first through the lowland plains of southern Chalatenango and northern San Salvador and then through a somewhat narrower valley, where the river forms the Honduras frontier. Near Sensuntepeque the river bends to the south and then follows a southwesterly course for about 60 miles to the sea. In the upper part of this last stretch the river occupies a relatively narrow valley, which gradually widens to 3 or 4 miles where the stream flows out on the coastal plain about 20 miles above its mouth. The general relations of topographic features and drainage in the republic are shown in plate 3.

PHYSIOGRAPHIC DISTRICTS

The land forms that make up the landscape of El Salvador may be divided roughly into five physiographic districts: The central highlands, the western plateau, the eastern upland, the northern highlands, and the coastal plain.

CENTRAL HIGHLANDS

The central highlands include most of the areas above 2,000 feet that cross the middle of the country in an irregular, discontinuous band, as shown in plate 3. The highlands include five principal groups of clustered volcanic peaks with their associated and overlapping eruptive fields. Most of the land forms in the highlands are relatively young and have been built up by volcanic processes that are still active. The forms include lava and tuff cones, cinder cones, lava and tuff fields, and other initial volcanic surfaces with associated explosion craters and collapse calderas. The five volcanic highland groups from west to east are Apaneca-Santa Ana, San Salvador, Cojutepeque, San Vicente, and Tecapa-San Miguel.

The Apaneca-Santa Ana highland is distinguished from the other volcanic clusters of the central highlands by the nearness of the eruptive centers to one another and their linear, chainlike arrangement.[1] There are numerous eruptive centers in the group, of which only the larger features are described here. The principal volcanoes of the group from west to east, with their elevations above sea level, are: Volcán de Apaneca (6,015 feet), Lagunita (5,788 feet), Laguna Verde (5,930 feet), Cerro San Juan (6,035 feet), Águila (6,322 feet), Laguna de Rana (6,540 feet), Naranjo (6,448 feet), Santa Ana (7,751 feet), and Izalco (6,126 feet).

The Volcán de Apaneca, about 5 miles southeast of Ahuachapán, apparently is a deeply eroded volcano of basaltic lava and pyroclastic rocks without vestiges of a crater. The volcanoes of Lagunita and Laguna Verde are about 4½ and 5 miles, respectively, east-southeast of Ahuachapán. Each contains a well-developed summit crater enclosing a small crater lake. East of Laguna Verde is Cerro San Juan, which appears to be an eroded volcano with several remnant crests. Along the north flank of the mountain are six or more active groups of gas fumaroles, steam vents, hot springs, and mud geysers. The temperatures and discharges of many of the hot springs are reported to fluctuate markedly with the seasons. The greatest discharges and lowest temperatures occur in the wet season when ground-water storage, depleted during the dry season, is replenished by meteoric water from rain. Apparently the waters of the hot springs are mixtures of the cool, normal meteoric ground water and hot juvenile water from deep-seated sources associated with volcanism. Mixing of the two types of water probably takes place at shallow depth in the vicinity of the hot-spring orifices. The temperature at which the spring water

[1] Sapper, Karl T., Los volcanes de la America Central: Studien über Amerika und Spanien, no. 1, p. 38, Halle (Saale), Max Niemeyer, 1925.

emerges from the orifices depends principally on the relative proportions of the two waters in the mixture. In the wet season the lowest temperatures occur because of the relatively greater proportion of cool meteoric ground water in the mixture. At the same time the spring flow is greater because of excess ground-water overflow from abundant rain. In a number of instances, orifices which yield hot water in the wet season become steam vents in the dry season. According to Dollfus and de Montserrat,[2] many of the hot springs and steam vents also discharge sulfur dioxide, hydrogen sulfide, carbon dioxide, and nitrogen. In the vicinity of the vents and spring orifices, these gases in conjunction with steam and thermal waters have formed primary deposits and alteration products through action on the adjacent country rock. Renson and Puente,[3] who analyzed these products, concluded that they were chiefly sulfates of aluminum, iron, calcium, and magnesium, but mixed carbonate, silicate, and sulfate of calcium, iron oxide, and aluminum silicate were also noted.

East of Cerro San Juan are the volcanoes of Águila and Laguna de Rana. The volcano of Laguna de Rana has a small summit crater enclosing a shallow marshy lake. A short distance to the south is the isolated volcanic cone of Naranjo, with an oval-shaped crater 450 feet long and about 65 feet deep. The rocks in the vicinity of the crater are largely volcanic cinders.[4]

The largest volcano in the western group is Volcán de Santa Ana, which is also the highest point in El Salvador. According to Sapper,[5] there is some evidence of a progressive shifting of the center of eruption toward the east. There are two semicircular remnants of old crater walls west of the principal crater, which is about 3,100 feet long and 2,300 feet wide. Farther to the southeast is a still younger but deep crater. According to historical records, the volcano was active several times between 1520 and 1570. There was then a period of quiescence of more than 300 years until the eruptions of 1874 and 1880 which covered the town of Sonsonate with a blanket of ashes 4 inches deep. The rocks composing the volcano are chiefly andesitic and basaltic lava flows with associated pyroclastics.

To the east of Volcán de Santa Ana is the large caldera sink of Coatepeque. This closed depression appears to have been formed by explosion and later enlarged by collapse. The lake that fills the bottom of the depression is almost round and is about 3½ miles wide and 400 feet deep. The walls of the caldera rise steeply on all sides 350 to 650 feet above the lake surface.

On the southern slope of Volcán de Santa Ana and about 8 miles

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[2] Sapper, Karl T., op. cit., p. 40, 1925.
[3] Idem.
[4] Idem.
[5] Idem.

northeast of Sonsonate is the Volcán de Izalco, which is one of the few volcanoes known to have been formed within historic times. According to Larde,[6] the upbuilding of the volcano apparently began with the eruption in March 1722 of lava flows and ash from a satellite vent on the slope of Volcán de Santa Ana. There were then minor eruptions from time to time until February 1770, when the first major activity occurred. At this time a large flow of lava poured out of the vent and scoria, rock fragments, and ash were ejected explosively and were accompanied by strong earthquakes in the neighboring region. From this time until 1856 the volcano was intermittently active for periods of several months to a few years, alternating its explosions of fragmental materials with the effusion of lava. Notable activity occurred in 1783, 1798, 1803, 1825, and 1838. From 1856 until the present the activity and frequency of eruptions has gradually increased. At present Izalco is possibly the most active volcano in Central America. Eruptions of ash, cinders, and volcanic bombs commonly occur at intervals of 15 to 20 minutes. From its beginning as a satellite vent, the cone has been gradually built up to a height of 2,600 feet above its base through the accumulation of fragmental products and basaltic lava flows.

The San Salvador highland is separated from the Apaneca-Santa Ana highland by the 15-mile gap of the Zapotitán basin. The chief physiographic features of the highland are Volcán de San Salvador with its satellite cones and eruptive centers, the great sink of Laguna de Ilopango, and the high east-west ridge locally known as the Cadena Costera (Coast Range).

Volcán de San Salvador (elevation 6,337 feet) is about 7 miles northwest of the city of San Salvador. Evidently it has been long exposed to erosion. Deep canyons score its flanks and drain radially from its crest, which has no apparent vestiges of a summit crater. Southwest of Volcán de San Salvador, and separated from it by a topographic saddle, is the Boquerón or volcano of Quezaltepeque (elevation 6,133 feet), which is evidently younger. A huge crater about 1,500 feet deep, about 4,000 feet in diameter, and almost circular in outline lies in the upper part of the volcano. At the time of the writers' visit, in September 1943, the volcano was inactive, but a small cinder cone built on the floor of the crater was observed. According to Sapper,[7] the cone was formed during the eruption of June 1917, immediately following the disappearance of a crater lake which had boiled away as a consequence of the eruption. The cone, which rose about 100 to 130 feet above the floor of the crater, resulted from the

[6] Larde, Jorge, Geología general de Centro-America y especial de El Salvador: Imprenta Nacional, San Salvador, p. 31, 1924.
[7] Op. cit., p. 53.

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accumulation of ash and cinders which accompanied the explosion of steam and other gases during the eruption.

About 6 miles west of San Salvador is the western edge of the Ilopango volcanic sink, which lies near the eastern end of the San Salvador highland. Laguna de Ilopango occupies the lowest part of this sink. In places the lake is more than 650 feet deep, and it is about 7 miles long from east to west and 5 miles wide from north to south. Its water surface is about 1,565 feet above sea level. The depression is bordered on all sides by steep, precipitous slopes which rise from 800 to 1,000 feet above the lake surface. The bordering slopes have been deeply dissected by short canyons of streams draining centripetally toward the lake. The outlet of the lake, at the eastern end, drains into the Río Jiboa by way of the canyon of the Desague. The canyon apparently was formed by the headward erosion of a tributary of the Río Jiboa, which cut back through the soft tuff and ash forming the rim of the depression. The Ilopango depression appears to have been formed in Pleistocene or Recent time by explosions at one or more adjacent vents, with subsequent enlargement of the sunken area by collapse and integration of the adjoining craters previously formed.

The Cadena Costera (Coast Range) of El Salvador is a high ridge trending in an east-west direction for 40 miles, extending from about 10 miles southwest of Laguna de Zapotitán to the eastern end of Laguna de Ilopango. (See pl. 3.) Through much of its length the crest of the ridge ranges from about 2,500 to 3,500 feet above sea level. The ridge is bordered on the north by an 800-foot escarpment dissected by numerous short ravines draining northward to the Río Lempa and Laguna de Ilopango. The southern flank slopes more gradually to the coast, though it too is dissected by many deep parallel canyons of streams draining southward to the sea.

Directly east of Laguna de Ilopango, and separated from the San Salvador highland by a low area only a few miles wide, is the Cojutepeque highland. It is a moderately dissected hilly region with elevations ranging from 2,500 to about 3,000 feet above sea level. The only pronounced elevation in the region is the Volcán de Cojutepeque at the southern outskirts of the city of that name. The crest of the volcano rises about 3,320 feet above sea level and 425 feet above the surrounding country. The summit crater is about 700 feet in diameter. Its eastern wall has been destroyed by erosion.

The San Vicente highland includes the area above 2,500 feet around the Volcán Chichontepec southwest of the city of San Vicente (see pl. 3). It is separated from the Cojutepeque highland on the north and west by the valleys of the Río Jiboa and Río Acahuapa. Volcán Chichontepec (elevation 7,065 feet above sea level) has two peaks.

According to Sapper,[8] the eastern peak has a well-preserved crater, and the western peak has a crater which has been breached toward the east. There has been no activity at either of the craters in historic times. Both of the summit areas are well-covered with a heavy forest. On the northwest slope of the volcano, at an elevation of about 2,665 feet, are the fumaroles of San Vicente. Dolfus and de Monteserrat[9] suggest that the gases emitted from the vents are perhaps 95 percent water vapor with small amounts of sulfur dioxide, hydrogen sulfide, carbon dioxide, nitrogen, and oxygen. In the same vicinity there are also several small hot springs and a mud volcano about 30 inches high.

The Tecapa-San Miguel highland lies in the east-central part of the republic and is separated from the San Vicente highland by the 15-mile gap of the lower Río Lempa valley. Five volcanoes with their overlapping eruptive fields and several minor peaks make up the highland. The principal volcanoes, and their elevations above sea level are: Volcán de Tecapa (5,210 feet), Volcán Usulatán (4,712 feet), Cerro del Tigre (5,388 feet), Volcán Chinameca (4,555 feet), and Volcán de San Miguel (6,849 feet). Volcán de Tecapa lies immediately south of the town of Alegría. The summit is west-northwest of the crater, in a somewhat eccentric position. The crater is approximately 2,500 feet in diameter, and its floor is occupied by a lake about 1,150 feet long and 850 feet wide. The crater walls, composed chiefly of andesite lava flows, rise 1,150 feet above the lake surface at the highest point. On the west side of the crater, where erosion has notched the wall, the rim is only about 75 feet above the lake surface. Directly southwest of Jucuapa is Cerro del Tigre, an enlongate volcanic mass whose crest and flanks have been considerably dissected and reduced by stream action. Volcán de Usulatán, which is about 7 miles north of the city of that name, has vestiges of two large summit craters which closely adjoin each other. However, both have been partly destroyed by erosion and are open to the east. Sapper[10] is of the opinion, from their state of preservation, that Cerro del Tigre and Volcán de Usulatán are older volcanoes than Volcán Tecapa. None of these has been active in historic times.

Volcán Chinameca, south of the city of Chinameca, is notable for the large size of its summit crater, which is 6,500 feet in diameter. The crater walls, composed of andesite lava flows, rise 1,500 feet above the crater floor at the highest point, but at one point where erosion has breached the wall the rim is only 300 feet above the floor.

Volcán de San Miguel is perhaps the most perfectly formed volcanic cone in El Salvador. On all sides its slopes rise abruptly from the surrounding lowlands. It is only on the northwest that its basal

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[8] Sapper, Karl T., op. cit., p. 56.
[9] Idem.
[10] Op. cit., p. 57.

slope converges with a spur ridge from Volcán Chinameca at an elevation of about 3,500 feet. Its slopes are only slightly dissected by small gullies which drain radially away from the crater rim. Lava fields, covering extensive areas around the base, were formed by eruptions from small aventitious cones. The summit crater of the volcano is approximately 2,500 feet in diameter, and its infacing walls are composed of volcanic scoria, breccia, and lava flows. At the time of the junior author's visit in December 1943, a vertical-walled crater pit about 800 feet deep and 1,600 feet in diameter existed near the east-northeast wall of the summit crater. Surrounding the pit was a flat, narrow bench of loose cinders and scoria, strewn with volcanic bombs and rock fragments. This bench, which represents a former level of the crater floor, is being destroyed by landslides which take place along fissures concentric around the lip of the pit. A small secondary cinder cone which had been built on the bench level is now practically destroyed by the landslides. Several large fumaroles were observed at the bottom and in the lower walls of the pit. They fill the pit at periodic intervals with white clouds of steam, sulfur dioxide, and hydrogen chloride. Recorded eruptions of basaltic lava from satellite vents on the flanks of the volcano occurred in 1762, 1787, 1811, 1819, 1844, 1848, and 1867. Ash and cinder eruptions occurred at the summit crater in 1699, 1769,1798, 1845–47, 1854–57, and 1879.

WESTERN PLATEAU

The western plateau of El Salvador includes most of the area between 500 and 2,500 feet above sea level west of the Río Lempa (see pl. 3). It includes intermontane upland valleys, basins, and plains lying around and between the central and northern highland areas. Several isolated volcanoes north of the central highland are also included in this district. Most of the land forms in the western plateau are older than those in the central highlands and have been constructed by volcanic processes now inactive. Erosion has reduced original constructional forms such as volcanic cones, lava flows, and ash beds to undulating plains and valleys with occasional isolated buttes and hills.

West of Santa Ana is the plain of Candelaria (llano de Candelaria), which slopes northwestward from the base of the Apaneca-Santa Ana highland to the Río de Paz. East of Lago de Güija is a moderately dissected upland which slopes eastward to the Río Lempa. Lying between the Apaneca-Santa Ana and San Salvador highlands is the Zapotitán basin (valle de Zapotitán), which drains northward to the Río Lempa by way of the Río Sucio. This basin is contiguous on the northeast with the plain of Aguilares (llano de Aguilares), which slopes northward to the Río Lempa from the base of the San Salvador highland. Rising above this plain near the junction of the Río

Acelhuate and the Río Lempa is the volcano of Guazapa (elevation 4,582 feet). (See pl. 3.) According to Sapper,[11] erosion has destroyed the original summit crater, and nothing remains but the radiating network of the principal feeder dikes.

North of the Río Lempa the plains of Chalatenango (llano de Chalatenango) slope southward to the river from the dissected highland and plateau of the northern and western parts of Departamento de Chalatenango.

EASTERN UPLANDS

The eastern uplands include most of the areas east of the Río Lempa ranging from about 500 to 1,500 feet above sea level. The land forms are apparently older than neighboring parts of the central highlands. Much of the republic east of San Miguel is composed of subdued, rounded hills of moderate relief, dissected by broad, well-integrated stream valleys. This topography has been developed from older volcanic rocks whose original constructional forms have been largely destroyed by erosion. To the northwest these uplands merge with the northern highlands of northern Morazán and La Unión departments, and to the southwest, with the coastal plain.

NORTHERN HIGHLANDS

The northern highlands occupy small areas between 2,000 and 6,000 feet above sea level in the northern part of El Salvador (see pl. 3). They are southward extensions of the Central American Cordillera of southern Honduras. The land forms are in a youthful stage of erosion. Sharp-crested ridges with steep slopes, dissected by deep, narrow valleys and canyons, make up much of the topography. One of the most prominent ridges of the northern highlands lies east of the upper Río Lempa in the northwestern part of Departamento de Chalatenango. Smaller highland areas occupy the northern part of Santa Ana, the northwestern corner of Cabañas, and the northern parts of San Miguel, Morazán, and La Unión departments.

COASTAL PLAIN

The coastal plain of El Salvador rises inland from the shore line to an elevation of about 500 feet. (See pl. 3.) Near the Guatemala frontier the plain is about 3 miles wide and gradually merges inland with the western plateau. An embayment reaches inland about 12 miles in the vicinity of Sonsonate and the Río Grande. At La Libertad the coastal plain is only a few hundred feet wide. Westward from this point it widens into the lower Lempa Valley, where it reaches perhaps 20 miles inland. East of the Río Lempa it narrows to a width of 10 to 15 miles. Southwest of Laguna del Camalotal are the

[11] Op. cit., p. 73.

Colinas de Jucuarán, a dissected ridge about 18 miles long. This ridge rises to an elevation of about 2,500 to 3,000 feet above sea level and 2,000 feet above the adjacent coastal plain.

Where it merges with the plateau in the western part of the country and with the uplands in the east, the interior margin of the coastal plain is a sloping surface of erosion cut in old volcanic rocks by numerous parallel streams draining to the coast. Seaward this surface merges in unbroken profile with a surface of alluviation formed by stream deposition, with some modification by wave and current action.

GEOLOGY

SEQUENCE AND GENERAL FEATURES OF THE ROCKS

In El Salvador nonmarine strata of the Tertiary and Quaternary systems rest on igneous and sedimentary rocks of Cretaceous and greater age. Apparently the oldest rocks in El Salvador belong to the Metapán formation [12] of late Jurassic and early Cretaceous age. The formation includes interbedded sandstone, shale, conglomerate, marl, and limestone, with occasional strata of tuff and breccia. These rocks occur in the Metapán region of Departamento de Santa Ana and in the northern part of Departamento de Chalatenango. Locally the rocks of the Metapán formation are intruded by stocks and dikes of granite, granodiorite, and diorite. These intrusive rocks may be of late Cretaceous or possibly early Tertiary age.

The strata of the Tertiary system include extrusive basalt, andesite, dacite, and acidic extrusive rocks; volcanic ejectamenta that range from scoria to compact tuff, agglomerate, and breccia; and detrital sediments of alluvial and lacustrine origin. Strata of the three classes are interlaminated and interfingered, and they grade laterally into one another in a complex fashion. The rocks of the Quaternary system include basic lavas and pyroclastics erupted from central vents, and alluvial, lacustrine, and beach sediments deposited in larger valleys and basins, and along the seaward margin of the coastal plain.

SUMMARY OF THE GEOLOGIC HISTORY

According to Larde [13] and Sapper,[14] and to observations of the writers, the geologic history of El Salvador appears to include the following general sequence of events:

During Jurassic and Cretaceous time marine embayments covered the Central American isthmus from time to time and limestone, sandstone, and shale were deposited in the submerged areas. Toward the

[12] Imlay, Ralph W., Cretaceous formations of Central America and Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, no. 8, pp. 1114–1116, 1944.

[13] Larde, Jorge, op. cit., pp. 79–81, 1924.

[14] Sapper, Karl T., op. cit., pp. 1–3, 1925.

end of the Cretaceous, emergence of the isthmus began, but deposition in the submerged areas continued until Pliocene time, when the Central American isthmus emerged in approximately its present form.

Volcanism began along the Pacific margin of the isthmus probably during the Cretaceous and continued intermittently to the present. The first rocks were probably extruded in fissure eruptions[15] of andesitic and basaltic lava with associated felsitic lavas. Later in Tertiary time explosive volcanic activity began, probably at closely spaced central vents. During this time pyroclastic materials such as tuff, explosion breccia, and volcanic agglomerate formed extensive deposits. Contemporaneously with these eruptions, erosion was active in the upbuilt areas, and deposition of detrital materials took place in the lowland valleys and basins.

According to Larde,[16] Cretaceous strata and early Tertiary volcanic beds in the northern highlands of El Salvador have been deformed by folding and faulting, whereas somewhat younger strata in the same region have not been disturbed. This evidence would suggest that the structural movements probably occurred in early or middle Tertiary time.

The upbuilding and activity of the modern volcanoes in the central highlands of El Salvador probably started at the beginning of Quaternary time,[17] and have continued to the present. At first great quantities of pyroclastic materials were produced by explosive eruptions, which later were accompanied by the extrusion of basaltic and andesitic lava.

As a consequence of the lava extrusions, drainage lines were blocked from time to time, and detrital sediments eroded from the neighboring highlands were deposited in the resulting ponded areas. During periods of quiescence at volcanic centers, streams reduced the lava barriers, eroded the earlier detrital and volcanic materials, and deposited alluvial sediments in low, open valleys along the coastal plain.

The general sequence, character, and water-bearing properties of the rock strata of El Salvador are summarized in the following table and are described at length on following pages:

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[15] Sapper, Karl T., op. cit. p. 1.
[16] Larde, Jorge, op. cit., p. 33, 1924.
[17] Sapper, Karl T., op. cit., p. 1.

Generalized stratigraphic section of the rocks of El Salvador, Central America

Geologic age		Geologic unit	General character	Water-bearing characteristics
Quaternary	Recent	Beach and estuarine deposits.	Light-colored wind-blown sand in dunes along coast. Dark-colored basaltic and andesitic sand and gravel in beaches. Estuarine muck, silt, and clay at Bahía de Jiquilisco and Estero Grande de Jaltepeque.	Dune sand where present in the zone of saturation above sea level yields small supplies of potable water to shallow dug wells.
		Landslides, talus, and alluvial fans.	Landslide masses in deep canyons. Talus forms aprons at bases of cliffs and steep slopes. Alluvial fans of boulder trains, sand and gravel deposited by torrential streams on steep slopes.	Landslide and talus masses unimportant as water-bearing materials. Fanglomerates yield considerable water when present in the zone of saturation, but are generally above the water table.
		Younger alluvium.	Sand, silt, and gravel derived from erosion of pre-existing rock and alluvial deposits. In flood plains along present stream channels and along the seaward margin of the coastal plain.	Contains considerable water at shallow depth in lower stream valleys.
		Younger Quaternary lavas and pyroclastic rocks.	Basalt and andesite lavas with compact, scoriaceous, and fragmental facies. Extruded from adventitious vents on flanks of larger volcanic centers, notably San Miguel, San Salvador, Santa Ana, and Izalco volcanoes. Pyroclastic materials includeash, pumice, and cinders derived from explosive eruptions at central vents. Blanket the flanks of volcanoes of central highlands and neighboring areas.	These materials are commonly above the regional water table, but local perched ground-water bodies yield small supplies to shallow wells and temporary springs. Scoriaceous and fragmental facies of the lavas, and pumiceous and cindery pyroclastic rocks are permeable and serve as intake areas for ground-water recharge.
	Pleistocene	Older alluvium.	Sand, gravel, and. locally, boulders. Similar to younger alluvium but is topographically higher. In terraces along Río Lempa and its larger tributaries.	Yields moderate supplies of water to wells where present in the zone of saturation.
		Older Quaternary lavas and pyroclastic deposits.	Basalt and andesite lava flows with compact, scoriaceous, and fragmental facies erupted from the central and satellite vents of the central highlands. Pyroclastic materials include ash, breccia, pumice, and cinders, intercalated with lavas to form main mass of volcanoes of central highlands of El Salvador.	Scoriaceous and fragmental facies of the lavas are permeable and supply many wells and springs in the republic. Pumice and cinder beds are ordinarily productive water-bearing horizons when present in the zone of saturation. Ash beds are ordinarily impermeable but locally yield small to moderate supplies of water to wells and springs.
		Lake beds.	Water-laid clay, silt and sand derived from pyroclastic ash, pumice, and cinders, deposited in lava-dammed basin. Locally interbedded with lava and subareal pyroclastic deposits. In certain localities contain bones of elephants and other mammals.	Sandy and cindery beds yield moderate supplies of water to wells and springs. Clayey beds largely impermeable.

Generalized stratigraphic section of the rocks of El Salvador, Central America—Con.

Geologic age		Geologic unit	General character	Water-bearing characteristics
TERTIARY	LATE TERTIARY (?)	Pyroclastic deposits and lavas.	Pyroclastic deposits include extensive masses of andesitic agglomerate, breccia, and tuff intercalated with basalt and andesite lava flows. Underlie younger volcanic rocks and detrital materials of the central highland, the western plateau, and the coastal plain.	Fragmental and scoriaceous facies of andesite and basalt lava yield moderate to large supplies of water to wells and springs where present in the zone of saturation. Pyroclastic materials ordinarily impermeable but locally yield small to moderate supplies of water to wells and springs.
	EARLY (?) TERTIARY	Volcanic rocks and related sedimentary rocks.	Weathered basaltic, andesitic, and felsitic lavas, with intercalated pyroclastic rocks and detrital sediments including sandstone, conglomerate diatomaceous beds, and, locally, carbonaceous and clay strata. In the northern highlands and eastern uplands.	These rocks generally have low permeability due to cementation and induration of sedimentary beds and alteration of volcanic materials. Fractures may yield small supplies to springs. Locally fragmental and scoriaceous zones in the lavas yield moderate to large supplies of good water to wells and springs.
CRETACEOUS (?)	UPPER CRETACEOUS (?)	Intrusive rocks.	Granite, granodiorite, and diorite intrusive into Metapán formation. In northern highlands of Santa Ana and Chalatenango departments.	These rocks are not generally very permeable, but fractures and weathered zones may yield small supplies to wells and springs.
JURASSIC and CRETACEOUS	UPPER JURASSIC and LOWER CRETACEOUS	Metapán formation.	Sandstone, shale, conglomerate, marl, and limestone with a few strata of tuff and breccia. In northern highlands of Santa Ana and Chalatenango departments.	These rocks are not generally very permeable but may yield small supplies to wells and springs from fractures or solution passages.

PHYSICAL CHARACTER AND WATER-BEARING PROPERTIES OF THE STRATA

QUATERNARY SYSTEM

RECENT SERIES

BEACH AND ESTUARINE DEPOSITS

Along the coast of El Salvador are extensive beaches with local dune ridges, bars, and estuaries. The beaches are commonly composed of dark-colored sands and gravels of andesitic and basaltic composition. They are best developed where the coastal plain is relatively narrow and competent streams carry large amounts of coarse material to the shore line. The dune ridges occur in favorable localities along beaches with prevailing onshore winds and with abundant sand. The dune sands are generally made up of the lighter particles of the sands composing the beaches.

The beach deposits, sand bars, and dune ridges are permeable to water. Where these materials are saturated with fresh water to a height of a few feet or more above sea level, they furnish small domestic supplies to shallow dug wells. Such water supplies are used by fishing villages near Bahía de Jiquilisco Bay, Estero Grande de Jaltepeque, and other scattered localities along the coast.

The estuarine deposits are made up of organic muck, silt, and clay laid down in tidal flats and anastomosing channels on low, swampy shore lines. They are best developed where the coastal plain is wide and the streams entering the sea are sluggish. The chief present sites of estuarine deposition are Bahía de Jiquilisco, between the outlets of the Río Lempa and Río San Miguel, and Estero Grande de Jaltepeque between the outlets of the Río Jiboa and Río Lempa. Each of these bays is protected by a sand bar that parallels the coast and rises a few feet above sea level. These bars apparently have been formed by the action of longshore currents and by wave action during storms. The estuarine deposits have very low permeability, and, moreover, they lie within the range of tidal fluctuations. Hence they yield no potable water to shallow wells.

LANDSLIDES, TALUS, AND ALLUVIAL FANS

Throughout El Salvador, landslides, talus aprons, and alluvial fans occur in favorable situations. Notable landslides are associated with Pleistocene and Recent volcanic materials along the scarps surrounding Laguna de Ilopango, in the adjacent canyon of the Río Jiboa, and in stream canyons draining north to the Río Lempa from the San Salvador highland. Conditions favorable to the development of landslides appear to include the following principal factors: An unstable slope, perhaps oversteepened by stream erosion at its base; a gliding plane such as a saturated clay stratum; and a heavy competent bed overlying a relatively weak or unconsolidated bed. These conditions are often attained along streams that have cut deep canyons into heavy lava flows or masses of volcanic agglomerate overlying soft layers of tuff, pumice, and cinders. Sliding takes place when intercalated layers of clay or old soil zones become saturated. Most of the present landsliding occurs in the wet season after torrential downpours of several days' duration.

Talus aprons or slopes are developed in the summit areas of the active volcanic peaks where the vegetative cover is poor or lacking. Rock streams several hundred feet long, composed of loose lava blocks, clinkers, and cinders, are common on the upper, outer slopes of San Miguel, Usulatán, Boquerón, Izalco, and Santa Ana volcanoes. Talus aprons skirt the infacing walls of the summit craters of all these peaks.

Alluvial fans of small extent occur around the bases of the principal volcanoes at the lines of convergence of the steep upper slopes and the gently inclined lower slopes. They are formed by deposition from ephemeral streams which drop their loads of detritus in their lower courses where the gradient becomes less steep. These streams flow only after heavy rainstorms on the upper slopes of the volcanoes.

The fan material is usually coarse but poorly sorted. Most of the material is composed of coarse sand with cobbles and pebbles, but boulders several feet in diameter are not uncommon. Small alluvial fans have also been observed in localities where torrential streams with steep gradients debouch from narrow canyons on to flood plains with low gradients. A typical example is the fan formed by the Quebrada Seca, which enters the Lempa flood plain from the west just above the mouth of the Río Acahuapa.

The landslide masses are too small and restricted to be of importance as water-bearing formations in El Salvador. The talus aprons and slopes are generally above the regional water table and are probably rather thoroughly drained. However, because of their permeability they are locally important as catchment areas for the precipitation that falls on the upper slopes of the volcanoes. They tend to divert water underground rather than to allow it to run off on the surface. The alluvial fans are generally above the water table, but locally their basal parts are saturated and water overflows in small perennial springs. The headwater tributaries of the Río Jiboa and Río Acahuapa that drain off the slopes of Volcán Chichontepec are fed in part by springs of this type.

YOUNGER ALLUVIUM

The younger alluvium forms the bars and banks, and floors the channels of the Río Lempa, Río Jiboa, Río San Miguel, and their larger tributaries. In places it underlies the seaward margin of the coastal plain and veneers pediment surfaces of the interior margin. It usually comprises sand, silt, and water-worn gravel. Along the Río Lempa it generally is reworked older alluvium mixed with basaltic and andesitic pebbles and cobbles of local origin. According to Larde [18] it contains pebbles of limestone, granite, diorite, basalt, and andesite along the southern margin of Departamento de Chalatenango. Downstream the percentage of locally derived material increases. The younger alluvium along the Río San Miguel consists of materials derived principally from basic and silicic lavas and pyroclastics of probable Tertiary age. The seaward margin of the coastal plain is underlain by sand, gravel, and silt deposits of similar origin from the mouth of the Río San Miguel to the mouth of the Río Lempa. Along the Río Jiboa the younger alluvium includes materials from basic lavas and pyroclastics of Recent and Pleistocene age. Similar materials underlie the coastal plain from the mouth of the Río Jiboa to the mouth of the Río Lempa and veneer the pediment surface of the inland margin of this plain. From Sonsonate south to the shore line

[18] Larde, Jorge, Geología general de Centro-America y especial de El Salvador: Imprenta Nacional, San Salvador, p. 34, 1924.

is a wide embayment of the coastal plain which is veneered in part by stream deposits of the Río Grande and neighboring streams.

The younger alluvium along most of the stream valleys is quite permeable. Where it is saturated in its lower part, it yields moderate to large supplies of water to wells of shallow depth. Domestic wells develop water from this source along the Río Lempa, especially below the mouth of the Río Acahuapa and along the lower courses of the Río Jiboa and Río San Miguel.

YOUNGER QUATERNARY LAVAS AND PYROCLASTIC DEPOSITS

A large part of the central highlands and adjoining areas of El Salvador is covered by soft to semiconsolidated pyroclastic materials interbedded with lava flows of probable Recent age. These materials make up the minor lava domes and cinder cones around the bases and on the flanks of the major volcanic peaks. They also compose much of the material in the summit areas of the volcanic peaks, including vent and explosion breccias in the summit craters. The pyroclastic materials include principally beds of ash and pumice, interbedded with lesser amounts of cinders and explosion breccia. The pyroclastic fragments are commonly less than a foot in diameter. The lava flows include chiefly andesite and basalt. The upper and basal parts of the flows are ordinarily vesicular, but the interior parts are compact. The tops of some of the flows are blocky and fragmental, whereas others are relatively smooth and ropy.

Most of the lava flows were extruded from adventitious vents on the flanks of the major volcanoes and for this reason are more localized than contemporary pyroclastic deposits, which are distributed by air currents. Conspicuous lava flows around the bases of San Miguel, San Salvador, and Santa Ana volcanoes are of such recent date that original volcanic surfaces have not been scarred by erosion and a soil cover has not been developed by weathering, even under the extreme tropical conditions.

Most of the pyroclastic material that blankets the central highlands originated in explosive eruptions at the main vents of the principal volcanoes of the central highlands. The coarser materials, including breccias, agglomerates, and cinders, were deposited on the flanks and in the vicinity of the volcanoes. The finer ash and pumice were carried farther by air currents and deposited over wider areas. The younger Quaternary pyroclastic materials and lavas merge downward imperceptibly with similar rocks of Pleistocene age and can be distinguished from them only by the absence of weathering and the degree of freshness of original constructional surfaces.

The finer-grained pyroclastic materials, equivalent in grain size to silt and clay, are essentially impermeable. The coarser materials, including pumice and cinders, are moderately to highly permeable.

Volcanic breccias and agglomerates, because fine material fills the interstices between large fragments, have a low but appreciable permeability.

The massive facies of the lava flows are essentially impermeable. On the other hand, there is considerable permeability in the blocky and fragmental zones that constitute the upper and lower parts of some layers, in the interspersed sheets and tongues of scoria, and in fractured zones. Altogether these permeable facies have considerable aggregate capacity to transmit water.

The younger Quaternary pyroclastic deposits and lavas lie above the regional water table over much of the area in which they occur and hence are generally rather thoroughly drained. However, the permeable facies of these rocks are important as ground-water catchment areas, for they tend to divert rainwater underground rather than to allow it to run off over the surface.

The permeable facies of the lava flows, cinder, and pumice beds supply small temporary springs which are fed by local bodies of perched ground water. Such springs usually fail a few weeks after the dry season begins, and they do not flow again until the first heavy rains of the wet season have renewed the depleted ground-water storage. Along the Pan American Highway between San Salvador and Cojutepeque, and in many other sections of the country, springs of this type are used as temporary sources of water by rural inhabitants and travelers. Many of these springs rise from thin beds of pumice that overlie impermeable ash beds. Others rise from fissures, crevices, or other pervious zones in andesite or basalt flows above compact lava. Most of these springs flow in direct response to heavy rainstorms, and the dry-weather flow is markedly lower. Few of the springs from the younger pyroclastics and lavas that were observed yield more than a few gallons a minute on the average.

PLEISTOCENE SERIES

OLDER ALLUVIUM

The older alluvium forms terraces 25 to 50 feet above the present stream beds. It occurs as scattered remnants in protected places along the Río Lempa and its larger tributaries. With the exception of these remnants the terraces have been largely destroyed in the present cycle of stream erosion.

The older alluvium consists chiefly of gravel, sand, and silt. Along the Río Lempa the finer material is more abundant below the mouth of the Río Acahuapa, and coarser materials more abundant upstream. In some places the older alluvium appears to pass under the present stream bed, but in other places it is only a thin veneer on rock-cut surfaces. The older alluvium includes fragments that are chiefly of the resistant rock types that crop out in the headwaters of the Río Lempa, which rises in the highlands of the Central American isthmus. The rock types include silicic and basic lavas, crystalline and metamorphic rocks, and limestone. Local rock types are not as commonly present as they are in the younger alluvium.

The sand and gravel facies of the older alluvium are quite permeable, and may yield moderate supplies of water to wells where present in the zone of saturation. However, because of their limited areal extent, and elevation above present stream levels, these deposits are not important as water-bearing materials in El Salvador.

OLDER QUATERNARY LAVAS AND PYROCLASTIC DEPOSITS

The main masses of the large volcanoes comprising the central highlands of El Salvador are made up of lava and pyroclastic materials of probable Pleistocene age. These materials underlie and grade upward into Recent lavas and pyroclastic deposits, from which they differ principally in degree of weathering and consolidation. They include basalt and andesite lava flows and pyroclastic rocks that are chiefly ash and pumice with lesser amounts of volcanic breccias, agglomerates, and cinders. The lava flows occur in compact, scoriaceous, and fragmental facies, and are intercalated with the pyroclastic rocks. Most of these materials apparently originated in eruptions at the principal vents of the central highlands.

The basin of Lago de Güija on the Guatemala frontier was probably formed during the Pleistocene by lava flows from neighboring volcanoes that blocked the local drainage. Larde [19] believes this lake is now considerably smaller than formerly, owing to the recent filling of the basin by sediments and the lowering of the outlet by stream down cutting.

In the Apaneca-Santa Ana highland large masses of basalt and andesite lava of probable Pleistocene age are present on the north flank but are not found to the south. In pyroclastic deposits erupted from volcanoes composing this highland abundant remains of mastodons of Pleistocene age have been found at a place called Huesera in the canton of Guineo, a few miles north of Laguna de Coatepeque.

According to Larde [20] the Sonsonate area is also underlain by lava, ash, and cinders formed by Pleistocene eruptions of neighboring volcanoes.

The masses of San Salvador and Boquerón volcanoes are composed chiefly of basaltic and andesitic lava flows interbedded with breccias, ash, pumice, and cinders. Plant fossils and elephant remains have been found in pyroclastic materials erupted from these volcanoes near

[19] Larde, Jorge, op. cit., p. 24, 1924.
[20] Op. cit., p. 32.

Colón, near Jayque, and near the city of San Salvador. According to Larde these fossils resemble present forms and suggest the Pleistocene age of the main mass of these two volcanoes.

The main mass of the San Vicente highland and of the Tecapa-San Miguel highland also appear to be made up chiefly of Pleistocene lavas and pyroclastic rocks. Fossil insects and elephant remains reported to occur in the tuffs at Sisimico, near San Vicente, suggest that the last eruptions from volcanoes in this vicinity took place in Pleistocene time.[21]

The scoriaceous and fragmental facies of the lava flows are highly permeable to water and supply many wells and springs in the republic. Pumice and cinder beds ordinarily are productive water-bearing horizons when present in the zone of saturation. The ash beds have low permeability and yield only meager supplies of water to wells.

In the city of San Salvador some 20 wells obtain their supplies from the scoriaceous and fragmental zones of a basaltic lava bed of probable Pleistocene age. Wells ending in this stratum at depths ranging from 100 to 325 feet are reported to yield 500 to 700 gallons a minute with little drawdown. The springs of La Chacra and El Coro at the eastern outskirts of San Salvador flow from the same stratum. Each of these springs discharges several hundred gallons a minute with little variation in flow during the year.

About 3 miles west of Nueva San Salvador on the Pan American Highway are the springs of Los Chorros, which issue from a bed of permeable cinders overlying an impermeable stratum of volcanic tuff. The discharge of these springs, estimated at 1,200 gallons a minute, is reported to be relatively constant throughout the year. Near Quezaltepeque, Antiguo Cuscatlán, and San Martín are springs rising from similar materials. The discharges of these springs range from 10 to 1,500 gallons per minute.

LAKE BEDS

Water-laid deposits of clays, silts, and sands of volcanic origin underlie considerable portions of the plains, basins, and valleys of the western plateau of El Salvador. Most of these materials were probably deposited in shallow lakes or swamps, but near the highland margins are occasional interbedded stream deposits, lava flows, and subareally deposited pyroclastic materials.

The extensive plain of Candelaria, lying between Río de Paz, Volcán Chingo, and the northern foothills of the Apaneca-Santa Ana highland, appears to be underlain in large part by lake or swamp deposits. Larde [22] has suggested that the basin in which these deposits were laid down was formed as a result of the upbuilding of the surrounding

[21] Larde, Jorge, op. cit., p. 45.
[22] Op. cit., p. 27.

volcanic masses. The basin was then filled with materials eroded from the neighboring highlands. Subsequently the Río de Paz cut headward through the highland barrier and drained the basin. This stream is now entrenched, and its tributaries have deeply dissected the basin deposits.

Near San Lorenzo, Departamento de Ahuachapán, elephant remains of probable Pleistocene age are reported to have been found in water-laid, cream-colored pumiceous clays. In the vicinity of El Refugio in the same department, tuffaceous silt, clay, and sand underlie the surface to depths of 100 to 150 feet. Similar materials underlie the plain of Candelaria from the city of Santa Ana west and northwest to the Guatemala frontier.

Lacustrine and swamp deposits of probable Pleistocene age underlie a large part of the lowland plains and valleys between the San Salvador highland to the south, the Apaneca-Santa Ana highland to the west, the northern highlands of the Departamento de Chalatenango to the north, and the Cojutepeque highland to the east. This lowland includes three contiguous subareas. They are the Zapotitán basin between the Apaneca-Santa Ana highland and the San Salvador highland, the plain of Aguilares lying north of the San Salvador highland and south of the Río Lempa, and the plains of Chalatenango lying south of the city of Chalatenango and north of the Río Lempa.

Larde[23] has suggested that a lake of considerable size may have existed in this lowland area during the late Pliocene or early Pleistocene. The development of such a lake is attributed to the blocking of the Lempa drainage by volcanic accumulation in the area near the present mouth of the Río Sumpul. Sediments carried by streams draining from the neighboring highlands were deposited in the basin area. At some later time the Río Lempa lowered its outlet from the lake and its tributary streams, adjusting to the lowered base level, entrenched themselves in the basin deposits.

Much of the Zapotitán basin is underlain by water-laid deposits of silt, clay, and occasional beds of sand of volcanic origin. Near the junction of the Río Sucio with the Río Lempa, laminated micaceous clays are reported to occur. Similarly, the plains of Aguilares and Chalatenango appear to be underlain principally by massive tuffaceous silt and clay with occasional beds of sand.

South of San Francisco, in the eastern uplands of El Salvador, is a lowland area almost completely surrounded by hills and ridges. Larde[24] reports that earthy deposits underlying parts of the lowland contain remains of Pleistocene mastodons in vertical position. He suggests that the animals were trapped in swamps in which the sediments were deposited.

[23] Op. cit., p. 36.
[24] Op. cit., p. 43.

The silt and clay beds of the lake deposits are essentially impermeable and yield little or no water to wells. The sandy beds have moderate permeability and yield small supplies to wells. Locally, interbedded strata of cinders or pumice occur in the deposits. Where these strata are present in the zone of saturation, they yield moderate to large supplies of water to wells.

In Departamento de San Salvador, from Guazapa along the San Salvador-Tejutla road to the Río Lempa, dug wells obtain small domestic supplies from pervious alluvial or lacustrine deposits at depths of less than 100 feet. Near Atiquizaya, in Departamento de Ahuachapán, are numerous swampy areas fed by springs issuing from a bed of sand and cinders. Many of the individual springs flow from 10 to 50 gallons a minute, and aggregate discharges from the swamp areas range from 500 to 2,000 gallons a minute. Dug wells from 25 to 35 feet deep in the town of Atiquizaya obtain domestic supplies from the same stratum. The lake-bed deposits also supply springs and wells to the northwest of Santa Ana, in the Zapotitán basin, and in the southern part of the Departamento de Chalatenango near the Río Lempa.

TERTIARY SYSTEM

LATE TERTIARY (?) PYROCLASTIC DEPOSITS AND LAVAS

The greater part of the central highlands, the western plateau, the coastal plain, and the eastern uplands are underlain by volcanic rocks of probable late Tertiary age. These rocks do not crop out extensively at the surface except in the eastern uplands. They are made up in large part of pyroclastic materials, including extensive masses of volcanic agglomerate, breccia, and tuff that locally are interbedded with lava flows. The widespread distribution of the pyroclastic materials seems to indicate the predominance of explosive volcanic activity over liquid eruptions during the late Tertiary, for flow rocks are relatively restricted in their occurrence. Andesitic and basaltic materials are the most common flow-rock types, dacite rocks crop out in many places in the eastern uplands, and rhyolites occur locally.

According to Larde and the observations of the writers, andesitic agglomerate crops out from beneath younger rocks in many places in the Apaneca-Santa Ana highland, in the Sonsonate and Ahuachapán areas, and on the edges of the Zapotitán basin. North and northeast of the Zapotitán basin it crops out occasionally from beneath younger rocks as far as the valley of the Río Lempa. The agglomerate strata over most of this area consist chiefly of heterogeneous, unsorted masses of andesite lava fragments enclosed in tuffaceous or clayey matrix. The rock fragments range from the size of pebbles to boulders several feet in diameter.

The coast range, Cadena Costera, which lies to the south of Laguna de Ilopango and the city of San Salvador, is made up of volcanic rocks which in large part are inferred to be of late Tertiary age. These rocks include tuffaceous clays and compact andesitic agglomerates with occasional intercalated basalt and andesite lava flows.

North of Laguna de Ilopango andesitic agglomerate crops out occasionally from beneath a cover of Recent and Pleistocene pyroclastic deposits of Volcán de San Salvador and Volcán Guazapa.

The Cojutepeque volcanic highland is also built up on a platform of compact andesitic agglomerate and tuff. This relation would suggest a Pleistocene age for at least Volcán Cojutepeque and its surrounding field of soft or semiconsolidated ash and pumice deposits.

The late Tertiary (?) rocks are exposed almost continuously in the southward-facing escarpment overlooking the valley of the Río Acahuapa. Road cuts along the Pan-American Highway, which follows this escarpment, between kilometers 50 and 55 east show a heterogeneous assortment of volcanic breccia, agglomerate, and tuff with occasional interbedded lava flows.

The Tecapa-San Miguel highland apparently is also built up on a base of late Tertiary (?) rocks, but these are almost completely covered by younger rocks erupted from the volcanoes of the highland. South of the valley of the Río Sesori, clayey andesitic agglomerates with occasional basalt intrusions are reported to occur.[25] These rocks are probably of late Tertiary age.

The coastal plain south of the Tecapa-San Miguel highland, between the Río Lempa and Río San Miguel, is underlain by beds of clayey andesitic or basaltic agglomerate. Over most of the area these beds are covered by younger detrital and volcanic materials. The contiguous plain to the southeast of San Miguel is underlain by similar rocks.

Larde[26] reports that clayey agglomerates intercalated with basalt and andesite lava flows make up most of the Colinas de Jucuarán, which lie near the coast southwest of Laguna del Camalotal.

The capacity of the late Tertiary (?) rocks to transmit water varies widely. The volcanic agglomerates, breccias, and tuffs which compose the pyroclastic facies of the rocks generally have low permeability. The low permeability of the agglomerates is due to the tight, fine-grained tuffaceous material that fills the voids between rock fragments. Locally the breccias are highly permeable owing to the absence of fine material between angular rock fragments. Except for secondary tabular partings, the tuff beds are essentially impermeable. When these partings are present, the tuff beds have the capacity to transmit water slowly.

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[25] Larde, Jorge, op. cit., p. 47.

[26] Op. cit., p. 51.

In spite of their low permeability the late Tertiary (?) pyroclastic rocks yield small supplies of water to shallow dug wells and sustain small perennial springs in many parts of the country. For example, at Tejutepeque in the Departamento de Cabañas dug domestic wells obtain small water supplies from pumice lenses and tabular partings in volcanic tuff and agglomerate at depths of 20 to 30 feet. Water supplies from similar rocks and at comparable depths are obtained by domestic dug wells at Chapeltique and Chirilagua in Departamento de San Miguel and at San Carlos and Jocoro in Departamento de Morazán. At the village of El Carmen near Cojutepeque a spring issuing from sand streaks and partings in andesitic agglomerate has been developed for the public supply. In this same region are several other small springs that rise from volcanic tuff and agglomerate.

Intercalated with the pyroclastic rocks are basalt and andesite lava flows. The massive facies of the interior parts of the lava flows are essentially impermeable, but the blocky and fragmental zones that form the upper and lower parts of some layers may be quite permeable. These zones, together with interspersed sheets and tongues of scoria and fracture zones, have considerable aggregate capacity to transmit water. For example, near Panchimalco the springs of La Catarata issue from joints and fissures in a tongue of andesitic lava above an impermeable bed of tuff and breccia. The flow of these springs, estimated at 1,200 gallons a minute, is relatively constant throughout the year.

At Usulatán are the springs of Molinos, which are among the largest in El Salvador. The combined discharge of the three principal spring heads is estimated at 50 cubic feet per second or approximately 22,500 gallons a minute. The springs issue from a tongue of late Tertiary (?) andesitic lava in the scoriaceous and fractured zone above the contact with an underlying stratum of tuff.

The large springs of Inchanmichen and Santa Irene near Zacatecoluca and the springs of Las Dantas which supply the city of San Salvador also issue from late Tertiary (?) flow rocks or open-textured volcanic breccias.

EARLY TERTIARY VOLCANIC ROCKS AND RELATED SEDIMENTARY ROCKS

A diverse group of volcanic and sedimentary rocks underlies large parts of the northern highlands, the eastern uplands, and adjacent areas bordering on the Honduras frontier. These rocks underlie late Tertiary (?) rocks and rest on rocks of probable Cretaceous age. For this reason they are considered to be of probable early Tertiary age. The writers have not critically examined these rocks, and hence the following discussion is based principally on observations by Larde and Sapper.

The early (?) Tertiary rocks include weathered extrusive lavas of andesite and basalt with associated phonolite, trachyte, dacite, and rhyolite. These rocks are interbedded and intercalated with pyroclastic volcanic rocks and detrital sediments that include sandstones, conglomerates, and, locally, beds of diatomaceous materials and carbonaceous clays.

Sapper [27] suggests that the lavas were extruded principally in fissure eruptions during the upbuilding of the Central American Cordillera, but the widespread occurrence of interbedded pyroclastic materials would seem to indicate that explosive eruptions from central vents were common during the deposition of these materials.

During the accumulation of the lavas, streams apparently were actively eroding adjacent upland areas and depositing detrital materials in low areas. These materials were incorporated with the lava flows and pyroclastic rocks as sandstone and conglomerate. The diatomaceous beds and carbonaceous clays possibly were laid down in shallow lake basins formed by the damming action of the lava flows.

In the Sierra de Alotepe of the Metapán area, in northern Santa Ana, gray and green porphyries, andesites, and phonolites are reported to occur.[28] Similar rocks with conglomerate, sandstone, and diatomaceous sediments make up much of the mass of the Sierra de Chalatenango in the northern part of Departamento de Chalatenango. Near the city of Chalatenango beds of lignite and carbonaceous clay are reported to be associated with the extrusive rocks.

According to Larde [29] the dissected plateau between the Río Torola and Río Sesori and to the east of the Río Lempa is underlain by hard shales, conglomerates, laminated clays, carbonaceous sediments, porphyries, and ancient volcanic rocks. These rocks he considers to be equivalent to similar rocks in the northern part of Departamento de Cabañas near Jutiapa and Ilobasco. The hills of San Francisco and Sociedad in the central part of Morazán are also made up of volcanic rocks of probable early Tertiary age.

Larde [30] reports the occurrence of hard shale, conglomerates, pyroclastics, and siliceous lavas in the central and northern parts of Departamento de La Unión. Near Santa Rosa, carbonaceous beds similar to those near Ilobasco and Jutiapa are reported.

Petrographic examinations have been made by Hague and Iddings[31] of several types of the early (?) Tertiary rocks in various parts of the Republic. Pyroxene andesites and hornblende-pyroxene andesites occur in several localities near the Río Sumpul for a distance of 15

[27] Sapper, Karl T., Los volcanes de la America Central: Studien über Amerika und Spanien,, no. 1, p. 38, Halle (Saale), Max Niemeyer, 1925.

[28] Larde, Jorge, op. cit., p. 22.

[29] Op. cit., p. 41, 4.

[30] Op. cit., p. 49.

[31] Hague, A., and Iddings, J. P., Notes on the volcanic rocks of the Republic of El Salvador, Central America: Am. Jour. Sci., vol. 32, 3d ser., pp. 26–31, 1886.

miles above its mouth. Dacite occurs along the highway 3 to 4 miles northeast of Jocoro, near Santa Rosa, about 9 miles east of Chalatenango, and in many other localities where the early (?) Tertiary rocks are exposed.

The tuffs and tuffaceous agglomerates that make up the pyroclastic facies of the rocks are usually composed of dense and impermeable materials. In many localities, however, small secondary joint planes and partings are well developed. These openings give the rock considerable permeability and capacity to transmit water.

The detrital sandstones and conglomerates interbedded with the lava flows and pyroclastic materials generally have low permeability because their initial pore spaces have been largely destroyed by induration and cementation. Secondary openings generally are not well developed.

The capacity of the early (?) Tertiary rocks to transmit water varies widely, owing to the heterogeneity of the rock types. The lavas generally have lower permeability than similar rocks of younger age. In many areas they have been considerably altered by weathering or hydrothermal action, and as a result their initial permeability has been reduced. Locally the scoriaceous and fragmental facies of the lava flows are sufficiently permeable to sustain small springs and yield small to moderate water supplies to wells.

Typical examples of the occurrence of water in the early (?) Tertiary rocks are found at Sensuntepeque, San Francisco, and Santa Rosa. At Sensuntepeque in Cabañas the three principal springs used by the townspeople for water supply rise from rocks of probable early Tertiary age. Each of these springs rises from tabular openings in dense, indurated volcanic tuff which forms the hill on which the town is situated. The average discharge of each spring is about 50 gallons a minute, and the flows are relatively constant throughout the year. At San Francisco and Santa Rosa dug wells 25 to 50 feet deep obtain small domestic supplies from tabular openings in dense tuffs and tuffaceous agglomerates. The springs of Las Anonas and Chorreras, which supply the town of Santa Rosa, issue from joint planes and fractures in andesitic lava flows. The combined discharge of these springs is about 25 gallons a minute.

CRETACEOUS AND JURASSIC SYSTEMS

LOWER CRETACEOUS AND UPPER JURASSIC SERIES

Metapán formation.—Underlying the early Tertiary volcanic rocks and cropping out in several areas along the northern frontier of El Salvador are interbedded sandstone, shale, conglomerate, marl, and limestone with occasional strata of tuff and breccia. These rocks, the Metapán formation, are of Lower Cretaceous and Upper Jurassic age.

They are especially well developed in the Metapân region in the northern part of the Departamento de Santa Ana. Solution cavities in limestone beds are common, and caves with secondary stalactite and stalagmite deposits are reported in a few localities. Dolomitic limestones occur in the mountains east of the Río Lempa on the Honduras frontier, and crystalline limestones are found along the headwater tributaries of the Río Sumpul.

The water-bearing properties of the sedimentary rocks have not been examined by the writers. It is probable that they generally have low permeability, although locally, where solution openings are present, the limestone strata may supply large springs.

Locally the rocks of the Metapân formation are intruded by dikes and stocks of granite, granodiorite, and diorite. These rocks are thought to be of late Cretaceous age but possibly are early Tertiary. They occur extensively in the Metapân area of Departamento de Santa Ana. According to Larde [32] they also appear near Tejutla, Dulce Nombre de María, and San Francisco Morazân in Chalatenango. These rocks are of only local occurrence and are not important as sources of ground-water supply. Probably they are not generally very permeable, but fractures in them may supply small amounts of water to springs.

GROUND WATER

INTRODUCTION

Essentially all the water that occurs in the rocks of El Salvador originates as rain. Except in areas of active volcanism little of the water in El Salvador is so warm or contains so much dissolved matter that it can be considered connate or juvenile. A part of the rainfall returns to the atmosphere by direct evaporation from the land surface, a part flows directly to the streams and is carried away, and another part seeps into the soil and rocks. Of this last part some is also returned to the atmosphere by evaporation from the soil and by transpiration of plants. The rest percolates downward through cracks, crevices, and interstices of the rocks until it reaches the water table—the upper surface of the zone of saturation—below which all openings are saturated with water. The water in the saturated zone below the water table is known as ground water. The water moves slowly under the influence of gravity toward areas of lower elevation, where it flows into bodies of surface water or is discharged by evaporation and transpiration.

Where permeable rocks are present in the space between the land surface and the water table, the ground-water body exists as if impounded in a reservoir and its upper surface, the water table, is free

[32] Op. cit., p. 33.

to rise or fall as water is added to or discharged from the rocks. The water table may rise during or after protracted heavy rainfall as more of the rock is saturated and may fall during dry periods as part of the rock is unwatered by evaporation, by transpiration, and by discharge through seeps and springs.

In El Salvador the fluctuations of the water table reflect the seasonal distribution of the rainfall. The water table reaches its highest stages in October or November at the end of the rainy season. The lowest stages usually occur at the end of the dry season in April or May.

The rise of the water table during the rainy season is a measure of the accumulation of water in underground storage. It indicates the excess of replenishment over loss by natural discharge in spring flow, in evaporation, and in transpiration of plants.

The water accumulated underground in the rainy season is dissipated by the flow of springs and other discharge during the dry season. The loss in storage during this season is indicated by the decline of the water table in wells and the gradual diminution of spring flow. In El Salvador the dry-season flow of streams is sustained almost entirely by spring discharge, as very little rainfall occurs during this period.

GROUND-WATER RESOURCES BY DEPARTMENTS

DEPARTAMENTO DE AHUACHAPÁN

GENERAL FEATURES

The Departamento de Ahuachapán is in the extreme western part of El Salvador. (See pl. 3.) It has an area of about 830 square miles and a population of about 91,000. The department includes the western part of the Apaneca-Santa Ana highland of the central highlands district, parts of the western plateau district including the southern extension of the plain of Candelaria, and the extreme western part of the coastal-plain district (pl. 3).

Within the department the Apaneca-Santa Ana highland is underlain by Recent, Pleistocene, and late Tertiary (?) pyroclastics and lavas. The plains of Candelaria are underlain by Pleistocene lacustrine deposits and pyroclastics. The seaward margin of the coastal plain is formed of beach, bar, and dune deposits. Young alluvial deposits of silt, sand, and gravel mantle the surface of the coastal plain, a seaward-sloping surface cut on pyroclastic and flow rocks of late Tertiary (?) and Pleistocene age. Similar rocks underlie the section of the western plateau between the Apaneca-Santa Ana highland and the coastal plain.

GROUND-WATER CONDITIONS

The lacustrine deposits that underlie the plain of Candelaria include water-laid tuffaceous silts with interbedded strata of pumiceous and cindery sand and gravel. Pyroclastic deposits of similar physical character are interbedded with the lacustrine deposits along the margins of the plain. The silts, clays, and fine sands that compose most of the lacustrine deposits are largely impermeable, but interbedded strata of sand and gravel yield small to moderate supplies of water to dug wells and springs. The position of the regional water table beneath the plain is controlled largely by the drainage level of the larger stream valleys and canyons that are tributary to the Río de Paz. These streams rise on the northern slopes of the Apaneca-Santa Ana highland and drain north and northwest across the plain of Candelaria.

The lower parts of these streams are perennial, being fed in the dry season by springs that rise along the stream channels. Commonly the springs issue along seepage lines from beds of pumiceous or cindery sand and gravel overlying impervious strata of tuffaceous silt or clay. The yield of individual springs is small, but the aggregate discharge of the springs along a line of seepage may amount to as much as 50 to 100 gallons a minute.

These spring lines represent outcrops of the regional water table. Generally wells for domestic and stock supplies in the plain of Candelaria must be dug approximately to the level of the spring lines to obtain adequate water supplies. In the vicinity of Atiquizaya the depth to water ranges from about 25 to 35 feet. At El Refugio a perched water table occurs about 200 feet below the land surface, but 2½ miles east of town the regional water table at one well is reported to be more than 350 feet below the surface. About 1½ miles southeast of El Refugio dug wells on the Mendoza and Salazar coffee plantations obtain small domestic supplies at depths of 160 to 180 feet. These wells end in water-bearing beds of cindery sand interbedded with tuffaceous silt.

In the Apaneca-Santa Ana highland of Ahuachapán department there are few wells, but numerous springs of small to moderate flow emerge in the canyons draining to the north and to the south of the highland ridge. Springs are the principal source of water supply in this region, and many have been developed for municipal and domestic use and for the washing of coffee at coffee plantations.

The permanence of a spring in this region depends principally on the size and extent of the ground-water intake area contributory to it. The high-level springs on the upper slopes of the volcanoes generally fail in the dry season, but springs in the deeper canyons are perennial. Most of the perennial springs in the Apaneca-Santa Ana highland issue from Pleistocene and late Tertiary (?) rocks. The springs issuing from Recent rocks are generally temporary. Many of the larger springs in the highland issue from tongues of jointed and fractured Pleistocene andesitic lava interbedded with impermeable volcanic tuff and agglomerate. Many springs are found in the deeper canyons and issue from lava above the contact with underlying impermeable pyroclastic rocks. Smaller springs issue from thin beds of pumice or cinders in late Tertiary (?) tuffs and agglomerates.

The ground-water conditions in the coastal plain in Departamento de Ahuachapán are not well known, but extensive parts of this region are underlain by Recent sand and gravel deposits that should yield moderate supplies of water to wells and springs.

LOCAL SUPPLIES

AHUACHAPÁN

The city of Ahuachapán (population about 15,000) has a water supply of about 210,000 gallons of water daily, or 14 gallons per capita. Of the total supply approximately 150,000 gallons a day is raised by a centrifugal pump from Aponilla spring and 60,000 gallons a day is obtained by gravity through a pipeline from Los Piedrones springs.

Aponilla spring is about a mile east of the city. It issues from a ledge of jointed and fractured basaltic lava about 15 to 20 feet above the channel of a moderately deep ravine.

Los Piedrones springs are in the Apaneca-Santa Ana highland about 3 miles southeast of Ahuachapán. The springs rise in two groups about 1,500 feet apart along the channel of a headwater tributary of the Río Ahuachapán. The water issues as seeps from thin beds of pumice and cinders within massive tuff and tuff agglomerate strata. The total discharge of the two spring groups is about 40 gallons a minute.

ATIQUIZAYA

The municipal water supply of Atiquizaya (population approximately 6,000) is about 72,000 gallons a day during the rainy season and between 40,000 and 50,000 gallons a day in the dry season. The water is carried by gravity through a pipeline from Tortuguero spring. This spring rises in a canyon on the north slope of Cerro San Juan approximately 4 miles south of the city. The water issues from joints and fractured zones in the base of a flow of a Pleistocene andesitic lava that rests on a ledge of impermeable tuff agglomerate. The wet-season discharge is about 75 gallons a minute.

Within the city of Atiquizaya are many open dug wells used for private domestic supply. All these wells are less than 35 feet deep and extend only a few feet below the water table. They tap a water-

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bearing stratum of coarse cindery sand that underlies much of the Atiquizaya area. Three groups of springs, Ahuijuyo, El Coco, and Talule, issue from the same water-bearing stratum in the vicinity of the city. In each group the water rises in a small area of general seepage where open valley heads have been cut into the water-bearing stratum. Talule springs feed into a swampy tract lying directly west of the city. For malarial mosquito control the swamp has been artificially drained by a ramified system of open ditches which have an estimated total discharge of about 500 gallons a minute.

DEPARTAMENTO DE CABAÑAS

GENERAL FEATURES

The Departamento de Cabañas is in the north-central part of El Salvador and includes the northern part of the Cojutepeque highland district and bordering areas in the western plateau district. (See pl. 3.) The Cojutepeque highland within the department is underlain by Pleistocene and late Tertiary (?) lavas and pyroclastic rocks. Early (?) Tertiary volcanic and related sedimentary rocks underlie most of the western plateau within the department.

In the Cojutepeque highland dug wells are used to a limited extent, but springs are the chief source of domestic and municipal water supply. Numerous springs of small to moderate flow emerge in the headwater canyons and ravines of the Río Jiboa, Río Titihuapa, and Río Acahuapa, and smaller streams draining north to the Río Lempa. The loose or semiconsolidated Pleistocene deposits of ash and pumice that mantle much of the Cojutepeque highland appear to be generally too thin and discontinuous to sustain perennial springs in Cabañas. Most of the perennial springs in the highland rise from late Tertiary (?) lavas and pyroclastic rocks. Near Tejutepeque several perennial springs were observed that rise from crevices or tabular partings in late Tertiary (?) volcanic agglomerate or tuff. The discharges of these springs range from about 5 to 30 gallons a minute each. The springs on the Santa Rita farm, about 1½ miles west of Tejutepeque, are typical examples.

In Tejutepeque domestic water supplies are obtained principally from dug wells 20 to 30 feet deep that tap pumice lenses and partings in volcanic tuff and agglomerate. The yields from wells are small, and water levels are reported to fluctuate 5 to 10 feet during the year.

In the western plateau sections of Cabañas water supplies are obtained chiefly from small springs that rise from early (?) Tertiary pyroclastic rocks. The high-level springs are generally temporary but the springs in the deeper valleys and canyons draining to the Río Lempa and Río Titihuapa usually flow throughout the dry season.

LOCAL SUPPLIES

SENSUNTEPEQUE

The city of Sensuntepeque (population about 8,000) is in the eastern part of Cabañas. The municipal distribution system supplies about 12,000 gallons a day which is pumped from a "captación" (spring-development structure) at Catorce de Julio (Fourteenth of July) springs. This supply is inadequate for the demand, so that washing and bathing are done principally at El Chorro and La Mina springs, which have been developed and improved for local use.

Catorce de Julio springs are located about a quarter of a mile south of the center of the city at the head of a small open valley. The springs appear to issue from platy partings and vertical joints in dense, compact volcanic tuff. The total discharge is estimated at about 60 gallons a minute.

La Mina and El Chorro springs are located a quarter of a mile northwest and north of the city in small spring alcoves. These springs issue from tabular openings in volcanic tuff. La Mina spring has a discharge of about 50 gallons a minute, and El Chorro spring about 25 gallons a minute.

It appears that the entire hill on which Sensuntepeque is built is made up of early (?) Tertiary pyroclastic rocks which in this vicinity are compact, fine-grained, green and red tuffs with occasional thin stringers of scoria and cinders. Ground water in this vicinity appears to move principally through crevices in these rocks. The elevations of Catorce de Julio, La Mina, and El Chorro springs suggest that the water table of the water-bearing zone that feeds the springs is about 90 feet below the surface at the Alcaldía in Sensuntepeque.

DEPARTAMENTO DE CHALATENANGO

The Departamento de Chalatenango lies north of the Río Lempa in the northern part of El Salvador. The population is approximately 102,500. Within the department are parts of the northern highlands and of the western plateau, which includes the plains of Chalatenango. (See pl. 3.)

The principal segment of the northern highlands enters the department from Honduras in the northwest and parallels the Río Lempa in a southwesterly direction along the western margin of the department. Smaller areas of the northern highlands occur in the northern part of the department, south of the Río Sumpul. The parts of the western plateau within the department include the areas adjoining the northern highlands and the plains of Chalatenango in the south.

Within the department the northern highlands are made up of early Tertiary volcanic rocks with related sedimentary rocks, and of Upper Jurassic and Lower Cretaceous sandstone, shale, conglomerate, marl, and limestone, with occasional beds of tuff and breccia, of the Metapán formation. Locally the Metapán formation is intruded by dikes and stocks of granite, granodiorite, and diorite of probable Upper Cretaceous age.

Most of the western plateau area appears to be underlain by early (?) Tertiary volcanic and sedimentary rocks, but the plains of Chalatenango are underlain in part by late Tertiary (?) volcanic rocks and Pleistocene lacustrine and alluvial deposits.

In the northern highlands and adjacent sections of the western plateau there are few wells, and springs are the chief source of water supply for domestic and municipal use. Numerous springs of small to moderate flow occur in the headwater canyons and ravines of streams draining to the Río Lempa or the Río Sumpul. The high-leval springs usually fail early in the dry season because their contributory catchment areas are small and ground-water storage is limited. The lower springs in the larger and deeper valleys are usually perennial and sustain the dry-season flow of the streams. For example, the Río Soyata, about 1½ miles south of Tejutla, has a dry-season discharge of about 2 cubic feet per second, or about 900 gallons a minute, sustained by the aggregate flow of several small springs that rise from crevices and joint partings in dense, fine-grained basalt or andesite, which forms the country rock in this vicinity. About 2½ to 4½ miles south of Tejutla several small springs along the Río de Salitre that rise from partings and crevices in very dense, welded volcanic tuff or rhyolite have an aggregate flow of about 300 gallons a minute. Approximately 7 miles south of Tejutla in the valley of the Río de Salitre and beside the San Salvador-Tejutla road is a dug well about 30 feet deep which obtains a small supply for domestic use from dense volcanic tuff.

Along the southern margin of the plains of Chalatenango in the valley of the Río Lempa, ground-water supplies are obtained in several places from alluvial deposits of sand and gravel by means of wells a few tens of feet deep. Farther north on the plains shallow dug wells obtain small supplies from late Tertiary (?) pyroclastic rocks or Pleistocene lake-bed deposits. For example, there is a dug well 40 feet deep beside the San Salvador-Tejutla road, about a mile north of the Río Lempa, that apparently obtains water from late Tertiary (?) volcanic tuff.

DEPARTAMENTO DE CUSCATLÁN

GENERAL FEATURES

The Departamento de Cuscutlán, in the central part of El Salvador, covers an area of about 626 square miles and has approximately 100,000 inhabitants. It includes the southwest part of the Cojutepeque highland, the extreme western part of the San Salvador highland, the volcano, Volcán Guazapa, with its surrounding eruptive field, and the northeastern part of the plain of Aguilares. (See pl. 3.) Pleistocene and late Tertiary (?) lavas and pyroclastic rocks form most of the Cojutepeque highland, Volcán Guazapa and nearby parts of the San Salvador highland. The plain of Aguilares is underlain chiefly by Pleistocene and Recent lacustrine and alluvial deposits, which in turn are underlain by late Tertiary (?) volcanic rocks.

GROUND-WATER CONDITIONS

The rocks that compose the Cojutepeque and San Salvador highland region of the department include irregular beds of volcanic ash, cinders, and pumice, interbedded with andesitic and basaltic agglomerate and lava flows. The pumice and cinder beds and the interflow zones in the lavas are usually quite permeable and, where present in the zone of saturation, yield small to moderate supplies of water to wells and springs. In this part of the department, springs are the principal source of domestic and municipal water supplies, but wells are used to a limited extent in favorable localities.

The permanence of a spring depends principally on the size and extent of the ground-water intake area contributory to the spring. The high-level springs on the upper slopes generally fail completely or decline in flow markedly during the season. Numerous springs of this type are found in the vicinity of Cojutepeque, El Carmen, and San Rafael Cedros. Inhabitants of the area and travelers on the Pan American Highway are dependent on such springs for water supplies. During the dry season the shortage of water is acute, and water must be hauled considerable distances from more permanent sources. The low-level springs in the deeper canyons and valleys usually persist throughout the dry season and are therefore the most reliable sources of water supply in the region. A typical example is La Cangreja spring in the valley of the Río Cacahuatl, about 3½ miles south of Cojutepeque. This spring issues from scoriaceous and fragmental zones at the base of a lava flow and has an average discharge of about 150 gallons a minute. Other springs in this vicinity have similar characteristics, though few have so large a flow.

Most of the northern half of Departamento de Cojutepeque is occupied by a segment of the plain of Aguilares. This area is underlain chiefly by alluvial and lacustrine deposits of water-laid tuffaceous silts with interbedded pumice, cinders, and occasional sand and fine gravel. Older volcanic agglomerates and tuffs occur in the deeper canyons and valleys. The position of the water table in this area is controlled largely by the drainage level of the principal streams tributary to the Río Lempa and Río Acelhuate. In their lower courses these streams are perennial, being fed in the dry season by springs that rise along the channels. Spring lines, some several hundred feet long, are commonly developed where a stream valley cuts through a pervious bed of pumice or cinders overlying an impermeable bed of tuff or agglomerate. Such spring lines are generally outcrops of the regional water table and indicate the approximate position of the water table in the interstream areas. Usually wells in these areas must be dug to or below the level of these spring lines to obtain adequate supplies for domestic and stock use.

LOCAL SUPPLIES

COJUTEPEQUE

The city of Cojutepeque (population about 7,000) has a water supply of approximately 56,000 gallons a day, or about 8 gallons per capita. All the municipal supply is obtained from spring developments on the Río Cacahuatl about 3½ miles south of the city. The springs issue from soft volcanic materials at the edge of a small alluvial valley about 2,000 feet below Cojutepeque. The water is delivered to the city by a reciprocating pump, through a 5-inch steel pipeline. The supply is inadequate for the needs of the city and plans have been made to drill a well 300 to 600 feet deep near the Pan American Highway just north of the city. Such a well should encounter one or more water-bearing zones in the Pleistocene or late Tertiary (?) volcanic rocks of the area.

EL CARMEN

The village of El Carmen (population about 200) obtains its principal water supply from the municipal spring about a quarter of a mile west of the town, on the Pan American Highway. The spring issues from a thin bed of sand in tuffaceous agglomerate. It has been developed by three short trenches which feed into a concrete collecting box and ultimately to a pila (watering trough) equipped with a spring valve. The discharge of the spring is about 6 gallons a minute in the wet season and 4 gallons a minute in the dry season. The supply is considered adequate for the village.

SAN RAFAEL CEDROS

The town of San Rafael Cedros (population about 1,800) has a public water supply of approximately 75,000 gallons a day in the wet season, but only about 7,000 gallons a day in the dry season. The public supply is obtained by gravity through a 2½-inch pipeline from San Rafael spring, about a mile west of town. The spring issues from permeable zones in a ledge of tuffaceous agglomerate. The discharge is approximately 100 gallons a minute in the wet season but dwindles to about 5 gallons a minute in the dry season.

In the vicinity of the town there are several small undeveloped springs which are used for supplemental water supply, especially in the dry season. These springs issue from thin pumiceous zones in volcanic tuff and usually flow no more than a few gallons a minute.

The present water supply of San Rafael Cedros is not adequate. The best solution to the problem would seem to be a drilled well, perhaps 200 to 300 feet deep, that would tap one or more perennial water-bearing zones in Pleistocene or late Tertiary (?) volcanic rocks.

DEPARTAMENTO DE LA LIBERTAD

GENERAL FEATURES

The Departamento de La Libertad is located in the west-central part of El Salvador. It covers an area of about 830 square miles and has approximately 135,000 inhabitants. It includes the western part of the San Salvador highland, parts of the western plateau and most of the Zapotitán basin, and a part of the coastal plain. (See pl. 3.)

Within the department the San Salvador highland is underlain by Recent, Pleistocene, and late Tertiary (?) pyroclastics and lavas. The Zapotitán basin is underlain by Pleistocene alluvial, lacustrine, and pyroclastic deposits. The western plateau south of the San Salvador highland is underlain by Pleistocene and late Tertiary (?) lavas and pyroclastic rocks. The part of the coastal plain within La Libertad department is very narrow and is underlain by rocks similar to those of the western plateau, covered in part by a thin veneer of alluvial silt, sand, and gravel.

GROUND-WATER CONDITIONS

In the San Salvador highland of La Libertad, springs occur extensively in the stream canyons and valleys draining the slopes of Volcán de San Salvador and the northern and southern slopes of the Cadena Costera. Springs are the principal source of water for domestic and municipal use in this area, but wells are important sources of water in favorable localities.

As in other parts of the republic, the permanence of a spring in this area depends on the size and storage capacity of the contributory ground-water catchment area. The high-level springs issuing from Recent rocks on the upper slopes of Volcán de San Salvador and in other parts of the highland usually fail during the dry season. Springs rising from older rocks at a lower elevation generally persist through the dry season, though usually with diminished discharge.

Most of the large springs in this highland area rise from pervious beds of coarse volcanic scoria or cinders and to lesser extent from Pleistocene andesite or basalt lava flows. Usually these rocks are interbedded with impermeable tuff or tuffaceous agglomerate. About 2½ miles west of Nueva San Salvador on the Pan American Highway are the springs of Los Chorros, which issue from a 5-foot stratum of coarse volcanic cinders lying between two massive beds of volcanic tuff. By sapping action, a spring alcove has been cut almost 1,000 feet back from the canyon of the Río Guaramal. The discharge in November 1943 was estimated at about 3 cubic feet per second or 1,350 gallons a minute. Other springs issue from the same geologic horizon at several points on the highway between Los Chorros and the village of Colón. They flow at rates ranging from a few tens to a few hundred gallons a minute and are perennial.

South of the San Salvador highland, in the western plateau and coastal-plain districts of the department, springs most commonly rise from permeable zones in tongues of Pleistocene andesitic or basaltic lava. The pyroclastic volcanic materials in these districts apparently are generally less permeable to ground water than elsewhere in the department. The spring of Ayagualo, about 3½ miles south of Nueva San Salvador on the highway to La Libertad, is typical. It issues from a ledge of jointed and fractured andesite above a mass of impermeable volcanic agglomerate. The discharge is estimated at about 150 gallons a minute. Approximately a mile north of La Libertad on the highway to Nueva San Salvador, a well 105 feet deep encountered permeable water-bearing zones in andesitic lava. It is reported that the water is under some artesian pressure and rises to a static level 52 feet below the surface. The well yields 50 gallons a minute with only a few inches of drawdown.

The part of Departamento de La Libertad north and west of the San Salvador highland is occupied by the Zapotitán basin. This area is underlain chiefly by alluvial and lacustrine materials derived from the neighboring highlands. They include deposits of water-laid tuffaceous silt, pumice, and cinders with interbedded sand and occasionally fine gravel. The pumice, cinder, sand, and gravel beds are generally quite permeable and are water bearing over a large part of the area.

In most places the water table is not deep and in some places it intersects the land surface, giving rise to springs, spring-fed lakes, and swampy tracts. Laguna de Zapotitán, at the head of the Río Sucio, is a feature of this type. Approximately 2 miles southeast of the Río Sucio bridge on the Pan American Highway, the water table is only about 10 feet below the land surface. In the well at El Recreo finca, approximately 2½ miles northwest of the bridge, it was 25 feet below the land surface in December 1943.

In and near Quezaltepeque many wells 20 to 60 feet deep tap beds of water-bearing volcanic cinders interbedded with impermeable tuffaceous silt. The depth to water in these wells ranges from about 15 to 55 feet, and water levels fluctuate 5 to 10 feet with the wet and dry seasons. The same water-bearing beds supply the springs of Poluncuilo, which rise on the side of a shallow ravine just west of

Quezaltepeque. These springs flow at the rate of about 100 gallons a minute.

LOCAL SUPPLIES

ANTIGUO CUSCATLÁN

The municipal water supplies of the village of Antiguo Cuscatlán (population 1,000) and the neighboring cantons of La Ceiba (population 1,600) and La Puerta de La Laguna (population 1,300) are obtained from a development of the springs of La Montaña. The cantons of La Ceiba and La Puerta de La Laguna receive their supplies by gravity pipeline. Antiguo Cuscatlán obtains its supply by gravity and a booster pump. The water supplies of these villages are more than adequate for present requirements, but the development needs extensive sanitary improvements.

Directly west of Antiguo Cuscatlán is an almost circular volcanic sink or crater about 1,500 feet wide and 150 feet deep. The rocks forming the crater walls are composed of interbedded layers of highly permeable volcanic scoria with explosion breccia and impervious fine-grained tuff. All along the south rim of the crater is an extensive water-bearing bed from which the springs of La Montaña issue in permeable zones in volcanic cinders at levels ranging from the crater floor to about 50 feet above it. The total spring discharge from this bed may amount to several thousand gallons a minute.

QUEZALTEPEQUE

The city of Quezaltpeque (population 7,000) has a municipal water supply of approximately 32,000 gallons a day, or about 4½ gallons per capita. Water from private wells and the springs of Poluncuilo is used to supplement the municipal supply, which comes from a well in the southern part of the city. The well is 169 feet deep and penetrates seven water-bearing beds in Pleistocene cinders or pumice interbedded with tuff. The water-bearing beds above 130 feet were cased off so that the horizons now supplying the well are below that depth. The static water level is approximately 52 feet below the surface, and the well yields 30 gallons a minute with very little drawdown.

NUEVA SAN SALVADOR (SANTA TECLA)

The city of Nueva San Salvador, formerly called Santa Tecla (estimated population about 21,000), is supplied with approximately 400,000 gallons of water daily, or about 19 gallons per capita. The supplies are obtained from a series of nine small spring developments, a pumping plant at the springs of Ayagualo, and a deep well near the northern edge of the city.

Of the total supply approximately 100,000 gallons a day is delivered by gravity through pipelines from the nine spring developments located in the hills southwest of Nueva San Salvador. Two of the springs, San Andres and Loma Larga, issue from tabular partings in Pleistocene or late Tertiary (?) andesite lava flows interbedded in massive tuff. These springs contribute most of the gravity supply of the city. The remaining seven springs contribute almost negligible flows. They issue at relatively high elevation from thin permeable lenses of pumice in massive impermeable tuff. In the dry season four of the springs fail completely, and the remaining three supply less than 3 gallons a minute to the gravity system.

A pumping plant at the spring of Ayagualo supplies approximately 170,000 gallons a day to Nueva San Salvador. The water is raised by pumping some 670 feet above the spring development to a 300,000-gallon storage tank, and from there it is delivered by gravity pipeline to the city.

A deep well on the Larreynaga finca at the northern outskirts of Nueva San Salvador furnishes about 130,000 gallons a day to the city supply. The well was completed in May 1942 at a depth of 630 feet. The static water level is reported to be about 513 feet below the land surface. An 11-stage, 8-inch turbine pump set in the well produces 330 gallons a minute with a drawdown of 26 feet in the water level. The water-bearing beds supplying the well lie between 545 and 572 feet below the surface. These beds appear to be in volcanic scoria or sand interbedded with basaltic lava flows, tuff, and ash beds of Pleistocene or late Tertiary (?) age. The well was improperly constructed and poorly developed when completed; as a result the pumping equipment has operated inefficiently and the withdrawal is much less than the potential yield.

The present water supply of Nueva San Salvador is inadequate for the needs and future growth of the city. It has been recommended that a new well be drilled in the lower part of the city to obtain additional water. Such a well would need to be between 500 and 600 feet deep in order to tap the water-bearing beds that supply the Larreynaga well. If the well is properly alined, constructed, developed, and equipped, an adequate supply for the present and immediate future needs of the city can be obtained.

DEPARTAMENTO DE LA PAZ

GENERAL FEATURES

The Departamento de La Paz is in the south-central part of El Salvador. It has an area of approximately 895 square miles and has a population of about 99,000. The department includes the eastern extension of the San Salvador highland south of Laguna de Ilopango, the southern half of the San Vicente highland, a part of the western plateau south of the highland areas, and a broad segment of the coastal plain. (See pl. 3.)

Within the department the San Salvador highland is coextensive with the Cadena Costera of El Salvador. Together with the western plateau and the inland margin of the coastal plain, it is made up largely of late Tertiary (?) pyroclastic rocks and lava flows. The San Vicente highland is underlain principally by Recent and Pleistocene volcanic rocks. The seaward margin of the coastal plain is underlain chiefly by Recent and Pleistocene alluvial deposits, but in places late Tertiary (?) rocks crop out from beneath the alluvial cover.

GROUND-WATER CONDITIONS

The rocks that compose the San Salvador highland and the western plateau with adjacent parts of the coastal plain include late Tertiary (?) tuffs, tuffaceous clays, and compact andesitic agglomerates with occasional intercalated basalt and andesite lava flows.

The tuffs and clays are largely impermeable and hence yield little water to wells and springs. The agglomerates are somewhat more permeable, and where present in the zone of saturation they furnish small to moderate quantities of water to wells and springs from joints and other secondary partings in the rock. Shallow dug domestic wells in and near Santiago and Zacatecoluca obtain water supplies from this source.

Permeable zones in lava flows interbedded with the pyroclastic materials yield moderate to abundant supplies to wells and springs where present in the zone of saturation. In the vicinity of Zacatecoluca are several small springs and two large spring groups that apparently rise from bouldery deposits, probably formed from broken or highly jointed andesite lava flows that are interbedded with volcanic agglomerate and tuff. One of the spring groups, Santa Irene, about 1½ miles southwest of Zacatecoluca discharges at a rate of approximately 3,000 gallons a minute. The group includes one major and three minor springs that rise within a few score feet of one another. About a mile south of the city is the spring group of Inchanmichen, quite similar to that of Santa Irene. The Inchanmichen springs discharge roughly 2,500 gallons a minute and are used to generate power at a small hydroelectric plant.

The alluvial deposits that mantle much of the coastal plain thicken toward the coast and finally merge with estuarine clay, silt, and beach sand near the shore line. Along the lower reaches of the Río Jiboa, the Río Amate, and other smaller streams that flow southwest across the coastal plain to the ocean, there are extensive deposits of sand and fine gravel that yield moderate to large supplies of water to wells at shallow depth. On a narrow barrier beach that extends along the shore of La Paz for about 10 miles near Estero Grande de Jaltepeque, small fishing communities and beach resorts obtain small domestic water supplies from shallow wells dug in beach sand. The water becomes somewhat saline in the dry season because of insufficient fresh-water recharge from rain to replace ground water dissipated by springs at the shore.

LOCAL SUPPLIES

ZACATECOLUCA

The city of Zacatecoluca, with a population of approximately 10,000, has a public water supply of approximately 70,000 gallons a day or 7 gallons per capita. About half the city supply is delivered through a gravity pipeline from four collecting boxes at the springs of Apantes. The rest of the city supply is obtained from a well in the northern outskirts of the city. The springs of Apantes are about 5 miles northeast of the city. They issue from tabular partings in tuffaceous agglomerate and thin lenses of cinders interbedded with volcanic tuff. The discharge has declined since the spring developments were made in 1940, a condition which probably has been brought about by a cycle of dry years.

The municipal well of Zacatecoluca is approximately 400 feet deep and is cased to the bottom with 8-inch casing. The water level is about 325 feet below the land surface. The well is equipped with a reciprocating pump powered by a Diesel engine that delivers 60 gallons a minute for 9 hours a day.

The existing water supply of Zacatecoluca is inadequate, and a new source of water is needed. An adequate supply could be obtained from a well drilled near the present storage tanks to a depth of about 400 feet. The necessary depth of a well drilled down the slope near the center of town would be considerably less. The springs of Inchanmichen and Santa Irene and the municipal well indicate that there is an extensive water-bearing bed beneath the city. One or two properly constructed wells completed in this bed and fitted with modern pumping equipment could adequately supply water for the city.

DEPARTAMENTO DE LA UNIÓN

GENERAL FEATURES

The Departamento de La Unión includes all of the extreme eastern part of El Salvador. It covers about 860 square miles and has approximately 94,500 inhabitants. The northern half of the department is included in the eastern upland and the southern part in the coastal plain. (See pl. 3.)

Most of the eastern upland in Departamento de La Unión is a moderately dissected hilly region with a well-integrated drainage pattern. The area is underlain principally by lava and pyroclastic rocks probably of early (?) Tertiary age, with thin alluvial deposits of sand and gravel in the principal stream valleys.

The coastal plain in the department is underlain by late Tertiary (?)

volcanic rocks that are mantled by Pleistocene and Recent alluvial deposits of silt, sand, and gravel derived from the upland areas. Rising above the coastal plain south of the city of La Unión is Volcán Conchagua (elevation 4,100 feet). The volcano and the immediate surrounding area are composed of Recent and Pleistocene pyroclastic materials and lava flows.

GROUND-WATER CONDITIONS

The rocks that underlie the eastern upland and adjacent areas of the coastal plain include weathered lavas of andesite and basalt with associated siliceous lavas of Tertiary age. These rocks are intercalated with pyroclastic tuffs and agglomerates and, occasionally, detrital sandstones and conglomerates. The permeability of the volcanic rocks is generally lower than that of similar rocks of younger age. In many areas their initial permeability has been reduced by weathering and induration. However, in many areas water stored in tabular openings and fragmental zones sustains small springs and supplies wells of small to moderate yield.

About 3 miles west of Santa Rosa on the highway to San Miguel are the springs of El Jícaro. They issue from fractures and tabular partings in dense, altered tuffaceous agglomerate in a zone about 75 feet long. The spring has been improved through development by a covered cut-off trench and collecting box, which delivers about 30 gallons a minute to a roadside watering place for travelers.

In the vicinity of the canton of Albornoz on the highway about 4½ miles west of Santa Rosa, dug wells 30 to 50 feet deep obtain small domestic supplies from joint or fracture partings in volcanic tuff or andesite. The water table at these wells is reported to fluctuate annually through a range of 15 to 20 feet with seasonal variations in rainfall.

Over much of the coastal plain, alluvial sand and gravel deposits yield moderate to large supplies to shallow wells. The water table is not deep in most of the area and in places is at the land surface, giving rise to swampy tracts and springs such as those near Laguna del Camalotal. Where the alluvial deposits are above the zone of saturation, small to moderate supplies of water are obtained from wells in the underlying Tertiary volcanic rocks.

LOCAL SUPPLIES

SANTA ROSA

The town of Santa Rosa (estimated population 5,500) has a public water supply of approximately 30,000 gallons a day or about 6 gallons per capita. The town supply is delivered by gravity pipeline from two springs, La Chorrera and Las Anonas, about 2 miles southwest of town.

The springs are about a quarter of a mile apart on the flank of a ridge. The water issues from tabular partings in fractured andesite lava overlying tuffaceous agglomerate. The discharge of La Chorrera is about 20 gallons a minute and that of Las Anonas about 5 gallons a minute.

In Santa Rosa and vicinity are numerous dug wells ranging in depth from 25 to 55 feet. The water-bearing bed is in volcanic tuff or tuffaceous agglomerate, which yields only small to moderate supplies of water to wells. Water levels in these wells are reported to fluctuate 10 to 15 feet through the annual wet-dry cycle.

DEPARTAMENTO DE MORAZÁN

GENERAL FEATURES

The Departamento de Morazán, in the northeastern part of El Salvador, covers an area of approximately 895 square miles and has about 88,000 inhabitants. With the exception of a small segment of the northern highlands, all of the department is included in the eastern upland. (See pl. 3.)

GROUND-WATER CONDITIONS

Most of Morazán is a moderately dissected hilly to mountainous upland whose relief increases gradually from south to north. The surface drainage is well integrated in the Río Torola, the Río San Miguel, and their tributaries. The principal rocks of the upland area are interbedded pyroclastic and flow rocks of probable early (?) Tertiary age. Andesites with basalt are common rock types but siliceous rocks occur locally. Rhyolite and dacite lava flows interbedded with pyroclastic rocks were observed by the writers at various points along the highway 3 to 4 miles northeast of Jocoro, as well as in other scattered localities in the department.

Generally the early (?) Tertiary rocks in the department yield only small or moderate supplies of water to wells and springs. At Jocoro and in the vicinity several domestic dug wells 15 to 25 feet deep yield small supplies from a water-bearing zone in dense tuff or tuffaceous agglomerate. The water table at these wells is reported to fluctuate only a few feet through the annual wet-dry cycle.

In San Carlos moderate water supplies are obtained from dug wells 30 to 35 feet deep. The water-bearing bed is apparently in tabular openings in dense tuff or tuff breccia. About half a mile west of the village on a low ridge two small springs issue from crevices in an andesitic lava flow overlying dense tuff. Each of the springs discharges about 4 gallons a minute and is reported to flow throughout the year.

In the northern highland area of Morazán sedimentary rocks of probable Jurassic and Cretaceous age are reported to occur. This area was not examined by the writers, and no comment can be made regarding the water-bearing properties of the rocks in that area.

LOCAL SUPPLIES

JOCORO

The town of Jocoro (population approximately 2,000) has a public water supply of approximately 86,000 gallons a day or 43 gallons per capita. The supply is delivered by gravity pipeline from the springs of El Pital. The springs are in a deep canyon about 1½ miles southeast of the town. They issue from fractures in a ledge of volcanic breccia. The combined flow from the three springs was estimated to be 60 gallons a minute.

The present supply is entirely adequate for the needs of the town, but the sanitary quality of the water could be greatly improved by a few small repairs in the spring-development structures.

SAN FRANCISCO

The city of San Francisco (population 6,000) obtains its water from two sources: Chilanga spring, about 3 miles north-northwest of the town, and a subsurface diversion of underflow in the channel of the Río Agua Fría, about 1½ miles north-northeast.

The existing supply is inadequate for the present and immediate future needs of the city. The supply furnished by the Agua Friá system could perhaps be doubled by developing the springs that feed the Río Agua Fría.

Supplemental water supplies in and near the city are obtained from dug wells 25 to 35 feet deep. The water in these wells appears to issue from crevices in dense volcanic tuff. Water levels are reported to fluctuate 10 to 15 feet through the annual wet-dry cycle.

DEPARTAMENTO DE SAN MIGUEL

GENERAL FEATURES

The Departamento de San Miguel is in the eastern part of El Salvador and covers an area of approximately 1,325 square miles. It has about 150,000 inhabitants. Within the boundaries of the department are Volcán de San Miguel, a part of the eastern upland, a part of the coastal plain, and the Colinas de Jucuarán. (See pl. 3.)

The eastern upland areas are underlain chiefly by sedimentary and volcanic rocks of probable early (?) Tertiary age. Volcán de San Miguel and the area immediately surrounding it are underlain by Recent and Pleistocene volcanic rocks. The coastal plain is mantled by Recent and Pleistocene alluvial deposits but is underlain by late Tertiary (?) volcanic rocks, which also make up most of the Colinas de Jucuarán.

GROUND-WATER CONDITIONS

The rocks underlying the eastern upland region in the northern part of the department include a somewhat heterogeneous assemblage of pyroclastic materials interbedded with andesitic and siliceous lava flows, conglomerates, laminated clays, and carbonaceous beds. Most of these rocks are well indurated or altered by weathering. As a result, initial openings in the rocks have been largely destroyed and their capacity to transmit water has been considerably reduced. However, numerous small springs in this area, especially in the valleys of the tributaries of the Río Chapeltique, issue principally from joint partings or fracture zones in dense pryoclastic rocks or lava flows.

In Chapeltique and vicinity fracture and joint openings in dense tuffaceous agglomerate yield small domestic supplies to dug wells 20 to 30 feet deep. Water levels in these wells fluctuate as much as 10 to 15 feet with seasonal rainfall distribution. Similar ground-water conditions are found in the lowland areas between Chapeltique and Moncagua.

Near San Miguel the coastal plain merges gradually with the eastern upland. Much of the coastal plain is mantled by alluvial deposits of silt, sand, and gravel derived from adjacent higher areas of volcanic rock. The water table is fairly shallow and water is found in saturated sand and gravel of the alluvial deposits over much of the coastal plain. In places the water table intersects the land surface, giving rise to swampy tracts and shallow spring-fed lakes. In the vicinity of San Miguel many large springs rise in swampy tracts from the water-bearing beds of sand or water-laid cinders. Numerous dug wells 20 to 40 feet deep obtain domestic supplies from this source.

The Colinas de Jucuarán, which parallel the coast line of Departamento de San Miguel, are composed chiefly of clayey agglomerates intercalated with basalt and andesite lava flows. Most of the springs observed in this area issue from joint partings in the lava flows.

In Chirilagua all domestic water supplies are obtained from dug wells 35 to 45 feet deep. The wells, on the west side of the town, obtain supplies from water-bearing zones in tuffaceous agglomerate. Water levels in the wells are reported to fluctuate 10 to 15 feet annually. In the center of the town is an andesitic lava flow overlain by the tuffaceous agglomerate. The water-bearing zone in the agglomerate on the west side of town apparently does not extend eastward, as a hole dug in the plaza to a depth of 155 feet penetrated andesitic lava for its entire depth.

DEPARTAMENTO DE SAN SALVADOR

GENERAL FEATURES

The Departamento de San Salvador lies in the central part of El Salvador. It covers about 780 square miles and has 207,000 inhabitants. Within the department are included the central part of the San Salvador highland, part of the plain of Aguilares and the contiguous Zapotitán basin, and a small part of the western plateau. (See pl. 3.)

The San Salvador highland and the western plateau to the south are underlain chiefly by Pleistocene and late Tertiary (?) pyroclastic rocks and lava flows. The plain of Aguilares and the Zapotitán basin are mantled by Pleistocene alluvial and lacustrine deposits which rest on late Tertiary (?) volcanic rocks.

GROUND-WATER CONDITIONS

The San Salvador highland and the western plateau are made up of a heterogeneous assemblage of volcanic rocks formed by both explosive and liquid eruptions. The explosive rock types include extensive beds of tuff, pumice, cinders, agglomerate, and breccia. Intercalated with these are scattered flows of basalt and andesite lava.

The pumice and cinder beds are productive water bearers where present in the zone of saturation. The scoriaceous and fragmental facies of the lava flows are quite permeable and supply many wells and springs in the department. Typical examples of such wells and springs occur near Panchimalco, Mejicanos, San Martín, and Prusia.

About half a mile southeast of Panchimalco are Cataracta springs, which issue near the bottom of an alcove or box canyon formed by the recession of a waterfall of the Río Cuitapán. The springs issue from joints and fractures in an andesite lava flow above impermeable volcanic tuff, in a zone about 50 feet long. The discharge of the springs, estimated at 1,200 gallons a minute, is sustained throughout the year. About half a mile west of Panchimalco are San Román springs, which issue on a hill slope to form a small stream that flows south toward the Pacific. The springs issue from volcanic sand or cinders overlying agglomerate in two adjacent cup-shaped depressions. The combined flow of the two springs was estimated to be 500 gallons a minute.

About half a mile southeast of Mejicanos (a suburb of San Salvador) are the springs of El Borbollón which rise in the ravine of Río Borbollón, a tributary of Río Acelhuate. The springs issue from a permeable zone in broken and fragmental basaltic lava beneath a bed of tuffaceous agglomerate. The discharge is estimated to be about 1,500 gallons a minute.

In the vicinity of San Martín an extensive water-bearing horizon occurs at the base of a highly permeable pumice stratum that overlies an impermeable stratum of volcanic tuff. Numerous spring lines occur where canyons and valleys of the areas are cut below this contact. Typical examples in the vicinity of San Martín are Don José springs, 2 miles northeast, Ayalapa spring, 2 miles north, and numerous small springs along the Arenal Colochos. It has been estimated that this water-bearing bed is about 250 to 300 feet below the surface at San Martín.

In the vicinity of Prusia one or more water-bearing beds occur from 60 to 200 feet below the surface in strata of highly permeable volcanic sand or pumice interbedded with tuff. These beds are tapped by the well of the San Salvador municipal slaughterhouse, that of the Prusia mill, and other wells. Yields ranging from 75 to 200 gallons a minute are obtained from wells drawing upon these water-bearing strata.

The plain of Aguilares and the adjacent Zapotitán basin in the northern part of the department are underlain by alluvial and lacustrine deposits of water-laid tuffaceous clay, silt, and sand, with some gravel. These deposits are in turn underlain by late Tertiary (?) volcanic rocks.

In the vicinity of Guazapa dug wells less than 100 feet deep obtain domestic supplies from alluvial or lacustrine deposits and the underlying volcanic rocks. Small springs that issue from permeable beds in the alluvial deposits occur at several points near the San Salvador-Tejutla road 4 to 5 miles south of the Río Lempa.

LOCAL SUPPLIES

SAN SALVADOR

The city of San Salvador (population 104,000) has a water supply of approximately 9 million gallons a day, or 86 gallons per capita. These supplies are obtained from five wells widely spaced throughout the city, from a pumping plant at El Coro springs, and from four pipelines that deliver by gravity the flow of 20 developed springs. Of the total daily supply about 2,640,000 gallons is obtained from the five wells, about 3,170,000 gallons from the pumping plant at El Coro, and about 3,195,000 gallons by gravity from the 20 springs.

The municipal wells and numerous private wells obtain supplies from water-bearing zones in an extensive bed of basaltic lava that underlies most of San Salvador. Just east of the city this bed crops out along the canyon of the Río Acelhuate in the vicinity of El Coro and La Chacra. Beneath the city the lava bed is overlain by younger pyroclastic materials that include tuff, agglomerate, cinders, and explosion breccia. These materials range in thickness from about 30 feet in the eastern part of the city to about 250 feet at the west end of the city.

The principal water-bearing bed tapped by wells in the city is apparently in the upper part of the lava bed. This stratum is full of cavernous openings, contraction partings, and scoriaceous material, which in the aggregate contain a considerable volume of water. The municipal wells, which are 205 to 370 feet deep, yield 300 to 600 gallons a minute each from this stratum. Several springs that issue from the lava bed in its line of outcrop along the Río Acelhuate yield several hundred gallons a minute. La Chacra and El Coro, from which part of the municipal water supply is pumped, are the largest and most important of these springs.

The gravity water supply of San Salvador is obtained from developed springs that rise in the ravines of headwater tributaries of the Río Acelhuate south of the city. The springs of Ilohuapa, about 3 miles south of the city, rise in three adjacent spring heads from a stratum of pumice or cinders interbedded with volcanic tuff. The total flow of these springs is about 200 gallons a minute.

In a canyon on the southern outskirts of San Salvador is the spring of Monserrat, which issues from crevices and cavities in the upper part of a lava flow and contributes about 30 gallons a minute to the city supply.

Las Dantas springs are located along the canyon of the Río Acelhuate from 1 to 2 miles south of San Salvador. In all, three groups of springs, which in successive order upstream are Danta Vieja, Fuentes Intermedias, and Danta Nueva, have been developed.

The springs of Danta Vieja issue from crevices in a fractured, blocky bed of andesitic or basaltic lava at the base of a gentle slope adjacent to the Río Acelhuate. About a quarter of a mile upstream from Danta Vieja are the springs Fuentes Intermedias. Several small springs in the group issue from scoriaceous or fragmental zones in one or more flows of andesitic lava at levels 20 to 150 feet above the channel of the river. The springs of Danta Nueva also issue from an extensive fractured zone in an andesitic lava flow. These springs rise along the channel of the river about a mile upstream from Danta Vieja. The total contribution of the spring developments of Las Dantas to the water supply of San Salvador is approximately 2,000 gallons a minute.

MEJICANOS

The city of Mejicanos, about 1½ miles north of San Salvador, has an estimated population of 8,000. The municipal water supply is about 17,300 gallons a day or an average of only 2 gallons per capita. The supply is obtained from La Bomba spring, in a small ravine about a quarter of a mile northeast of the city hall. The spring issues from a thin stratum of scoria or pumice interbedded with dense volcanic tuff. It flows at a rate of about 18 gallons a minute. During part of the day this flow is delivered direct to the city distribution system by a small reciprocating pump. During the rest of the day the spring flows to waste for lack of storage facilities at the spring or in the city.

Within Mejicanos numerous private dug wells furnish small domestic water supplies that supplement the inadequate municipal supply.

These wells range in depth from about 75 feet in the central part to about 125 feet in the higher western part of the city. Most of the wells in the central and northern parts of the city tap a water-bearing bed of volcanic pumice or cinders 75 to 95 feet below the surface. The springs of La Bomba apparently rise from the same water-bearing zone. The Chacón well in the western part of the city taps a deeper water-bearing zone at a depth of 125 feet in scoriaceous basalt, apparently in the upper part of a lava flow. This may be the same zone as that supplying the springs of El Borbollón southeast of Mejicanos.

The existing wells and springs indicate the presence of one or more extensive water-bearing zones at depths of less than 200 feet beneath the city. An adequate water supply for Mejicanos could be obtained from one or two drilled wells finished and properly developed in these zones and furnished with efficient pumping equipment.

VILLA DELGADO

The city of Villa Delgado, about 2 miles east of San Salvador, has a population of about 10,000. It has a public water supply of approximately 70,000 gallons a day or about 7 gallons per capita. An infiltration tunnel at the springs of La Bomba is the source of the municipal supply. Two small reciprocating pumps raise water from the springs to a 7,000-gallon distribution tank, in the higher part of the city. The springs of La Bomba issue from a bed of pumice above a layer of volcanic tuff in a tributary ravine of the Río Urbina in the northern outskirts of the city. The springs discharge at a rate of about 100 gallons a minute. In the suburb of Paleca are many dug wells that obtain small domestic supplies from water-bearing volcanic sand or pumice at depths ranging from 100 to 125 feet below the surface.

The springs along the Río Urbina and the wells in Paleca indicate that one or more water-bearing beds occur beneath much of Villa Delgado at depths of less than 200 feet. One or two drilled wells finished and properly developed in these beds and equipped with efficient pumps could furnish the present and immediate future water requirements of the city.

SAN MARTIN

The town of San Martín (estimated population 5,000) has a public water supply of about 30,000 gallons daily, or about 6 gallons per capita. The supply is obtained by gravity pipeline from captations on three springs about 5 miles west of the town. The springs issue from a short lens of pumice interbedded with massive, impermeable volcanic tuff. They have a total flow in the wet season of about 20 gallons a minute but in the dry season perhaps only half that amount. As mentioned in the general discussion on ground-water conditions in the Departamento de San Salvador, there is believed to be an extensive water-bearing zone about 250 to 300 feet below the surface at San Martín. One well properly developed and finished in this zone and equipped with an efficient pump could furnish the town with an adequate water supply.

TONACATEPEQUE

The town of Tonacatepeque (population about 3,000) has a public water supply of about 43,000 gallons a day, or about 14 gallons per capita. The supply is delivered by gravity pipeline to the town from La Fuente spring, which is about 2½ miles southeast of the town on a hill slope adjacent to a waterfall of the Río Izmatapa. The spring issues from the base of a platy flow of andesitic lava that is overlain by flow breccia and underlain by volcanic tuff with lenses of pumice. The flow is about 30 gallons a minute in the wet season and somewhat less in the dry season.

About 1½ miles south of Tonacatepeque are the springs of Los Chorros, which discharge about 75 gallons a minute. Additional water supplies for the town could be obtained through gravity pipeline by development of these springs.

DEPARTAMENTO DE SAN VICENTE

GENERAL FEATURES

The Departamento de San Vicente lies in the central part of El Salvador. It has an area of about 870 square miles and a population of about 90,000. The department covers a part of the western plateau with a contiguous segment of the Cojutepeque highland, the northern part of the San Vicente highland, and a part of the coastal plain including the lower valley of the Río Lempa. (See pl. 3.)

Within the department the western plateau is underlain chiefly by late Tertiary (?) pyroclastic rocks with interbedded lava flows. Pleistocene volcanic rocks underlie much of the Cojutepeque highland and limited areas of the western plateau. The San Vicente highland is underlain by Pleistocene and Recent volcanic rocks. The seaward margin of the coastal plain and the lower valley of the Río Lempa are underlain chiefly by Recent and Pleistocene alluvial deposits, but in many places late Tertiary (?) rocks crop out from beneath the alluvial cover.

GROUND-WATER CONDITIONS

The late Tertiary (?) rocks that constitute the western plateau of Departamento de San Vicente include a heterogeneous assortment of volcanic breccias, agglomerates, and tuffs with occasional interbedded lava flows. In the Cojutepeque highland and limited areas of the western plateau, these rocks are overlain by soft or semiconsolidated ash and pumice deposits of probable Pleistocene age.

The tuffs, agglomerates, and breccias are not generally permeable and hence yield only meager supplies of water to wells and springs. The strata of pumice and cinders and the scoriaceous and fragmental zones in the lava flows are important aquifers where present in the zone of saturation.

As in other parts of the republic, most of the high-level springs issuing from these rocks fail in the dry season, but most springs at lower elevation have greater catchment areas and are perennial. In the vicinity of Santo Domingo, for example, numerous small springs issue from thin lenses of pumice interbedded with volcanic ash. Most of these fail in the dry season, but a few, such as Encuentras spring about half a mile north-northeast of town, flow throughout the dry season. This spring discharges about 2 gallons a minute and is the principal source of drinking water for the people of Santo Domingo.

Southeastward along the Pan American Highway from kilometer 45 at Santo Domingo to kilometer 60, perennial springs are rare, and those that persist through the dry season become increasingly important despite their small yields and relative inaccessibility. A typical example is La Leona spring, which issues on a steep slope about 600 feet north of the highway at kilometer 54 and about 2 miles southwest of San Esteban. The spring issues from a fractured zone in a flow of vitreous lava that is interbedded with volcanic agglomerate and tuff. A flow of about 3 gallons a minute is sustained throughout the dry season and provides water for rural inhabitants of the area and travelers on the highway. Another example is Petaca spring, about 600 feet north of the highway at kilometer 56½. This spring issues from tabular partings in a ledge of dense volcanic agglomerate and discharges about 2 gallons a minute.

Between kilometer 60 and kilometer 62 the Pan American Highway crosses the basin of Laguna Apastepeque. In this area the water table is generally less than 50 feet below the surface, and numerous small springs feed into Laguna Apastepeque, Laguna Ciego, Río Izmatapa, and other small streams of the area. The water-bearing beds beneath this basin occur in beds of volcanic sand or cinders interbedded with ash or tuff.

Between kilometer 62 and kilometer 80 along the highway perennial springs occur only infrequently. Near kilometer 65½ is the spring of El Carrizo, which issues from a blocky andesitic lava flow overlying a bed of dense clayey tuff. The dry-season flow is about 5 gallons a minute. At kilometer 78½ the highway crosses the Quebrada Seca. About a quarter of a mile upstream from this crossing several springs issue from permeable zones in an extensive flow of andesite lava. These springs flow at rates ranging from about 5 to 15 gallons a minute and persist throughout the dry season.

In most of the coastal plain and the lower Río Lempa valley the water table is not far below the surface. Near the coast and along the Río Lempa extensive swampy tracts are fed by ground-water discharge, and in the adjoining areas the water table occurs at depths of a few feet to a few tens of feet. Shallow dug wells are the principal source of domestic and public water supplies in this region. The wells tap water-bearing zones in alluvial deposits of sand and gravel or, where these are thin or absent, in the underlying late Tertiary (?) volcanic rocks.

The San Vicente highland is made up of pyroclastic tuffs, agglomerates, and breccias interbedded with andesitic and basaltic lava flows. The pumice and cinder beds in the pyroclastic materials and the fragmental and scoriaceous zones in the lava flows are quite permeable and yield moderate supplies of water to wells and springs. Locally permeable sand and gravel deposits are found in alluvial fans around the base of Volcán Chichontepec. Where these are in the zone of saturation, they yield small to moderate supplies to wells and springs.

About a quarter of a mile north of Tepetitán numerous small springs issue from a saturated zone in sand and gravel in the channel of the Quebrada del Blanco, a tributary of Río Acahuapa. The aggregate discharge of the springs is about 100 gallons a minute a few hundred feet below the uppermost spring head. In this same vicinity are the springs of El Almendro, which issue from a thin bed of pumice between beds of volcanic ash. The springs flow at the rate of about 25 gallons a minute.

Just west of the town of Verapaz are the springs of Verapaz. The springs issue from an extensive saturated zone a few hundred feet long on the east bank of the stream channel. The saturated zone occurs in a bed of sand and gravel lying between beds of volcanic ash. The aggregate flow of the springs about 200 feet below the uppermost spring head is approximately 150 gallons a minute. In the town of Verapaz dug domestic wells 60 to 75 feet deep obtain supplies from beds of pumice or volcanic sand interbedded with ash or agglomerate.

The springs of San Cayetano, about 2 miles west of San Vicente, rise in a small spring basin from a bed of cinders or sand interbedded with ash. The flow of the springs is about 100 gallons a minute in the wet season but diminishes to about 50 gallons a minute in the dry season. Near the village of Ixtepeque are the springs of El Zapote, whose origin and occurrence are similar to those of San Cayetano. These springs discharge about 150 gallons a minute.

LOCAL SUPPLIES

GUADALUPE

The town of Guadalupe (population 4,000) has a public water supply of approximately 14,000 gallons a day in the wet season and about

3,500 gallons a day in the dry season. This is equivalent to an available supply of about 3 gallons per capita in the wet season and less than 1 gallon per capita in the dry season. The public supply is delivered by gravity pipeline from El Pinar spring, about 2 miles east of town on the slope of San Vicente volcano.

This supply is hardly sufficient in the wet season and almost fails entirely in the dry season. To alleviate the water shortage a well 315 feet deep has recently been dug by the Department of Public Works. The water-bearing zone, at the bottom of the well, consists of scoriaceous material about 6 feet thick beneath a dense basaltic lava flow 30 feet thick. The materials removed from the well above the lava flow are chiefly volcanic tuff, agglomerate, and pumice. This well will furnish an adequate water supply for Guadalupe if it is properly developed, completed, and fitted with an efficient pump.

SAN VICENTE

The city of San Vicente (population 12,500) has a water supply of approximately 280,000 gallons a day or about 22 gallons a day per capita. The supply is delivered by gravity pipelines from the springs of El Cubo, La Quinta, and Agua Caliente. The spring of El Cubo, about 2 miles southwest of San Vicente, issues from tabular partings in tuffaceous agglomerate. The flow is estimated to be about 25 gallons a minute. La Quinta springs, about 1½ miles west of the city, issue from two orifices in tabular partings in volcanic flow breccia. These springs discharge about 75 gallons a minute. The principal source of municipal water is Agua Caliente spring, about half a mile south of the city. The spring issues from tabular partings in a bed of platy lava and discharges about 100 gallons a minute.

DEPARTAMENTO DE SANTA ANA

GENERAL FEATURES

The Departamento de Santa Ana, in the northwestern part of El Salvador (pl. 3), covers an area of about 1,350 square miles and has a population of approximately 180,000. Within the department are included the central and eastern parts of the Apaneca-Santa Ana highland, a part of the northern highlands, a part of the western plateau with adjacent sections of the Zapotitán basin, and the plain of Candelaria. (See pl. 3.)

The rocks of the Apaneca-Santa Ana highland are chiefly Recent, Pleistocene, and late Tertiary (?) pyroclastic materials and lava flows. The area near Lago de Güija, the plain of Candelaria, and the Zapotitán basin are underlain chiefly by alluvial and lacustrine deposits of silt, sand, and clay of Pleistocene age. In many places, however, they are underlain by late Tertiary (?) volcanics or interbedded with Pleistocene volcanic rocks. The rocks of the northern highland belong to the Metapán formation and early (?) Tertiary volcanic and sedimentary rocks.

GROUND-WATER CONDITIONS

In the Apaneca-Santa Ana highland springs are the principal source of domestic and municipal water supplies. The springs, issuing from Recent rocks on the upper slopes of the volcanoes, are generally temporary and fail in the dry season. Most of the permanent springs in the highland issue from Pleistocene or late Tertiary (?) rocks. Many of the larger ones issue from tongues of jointed and fractured lava of Pleistocene age interbedded with impermeable tuff and agglomerate. The smaller springs issue from thin beds of pumice or cinders in late Tertiary (?) tuff and agglomerate.

Underlying the plain of Candelaria and much of the area near Lago de Güija are water-laid tuffaceous silts with interbedded strata of pumiceous and cindery sand and gravel. Pyroclastic materials of similar physical character are interbedded with these deposits along the margins of the lowland areas. The silts, clays, and fine sands that comprise most of the water-laid deposits are rather impermeable, but interbedded sand and gravel yield small to moderate supplies of water to dug wells and springs. The position of the regional water table beneath most of the lowland areas is controlled chiefly by the drainage level of the larger streams tributary to the Río de Paz and Río Lempa. Commonly springs rise along the stream channels in seepage lines from beds of pumiceous or cindery sand and gravel overlying impermeable strata of tuffaceous silt or sand. The yield of individual springs is small, but the aggregate discharge of a seepage line may be 50 to 100 gallons a minute or more. These spring lines represent outcrops of the water table. In the interstream areas wells for domestic and stock supplies must be dug approximately to the level of the spring lines to obtain adequate water supplies.

In the vicinity of kilometer 72 on the Pan American Highway, about 3½ miles northwest of Santa Ana, the water table in December 1943 was 78 feet below the land surface at two dug wells that are 85 feet deep. These wells tap a stratum of water-bearing cindery sand interbedded with tuffaceous silt. The same stratum apparently crops out in a ravine near the crossing with the highway at kilometer 71. In this vicinity small springs issue along a line several hundred feet long and discharge in the aggregate about 100 gallons a minute. At kilometer 73 the water table is only 40 feet below the surface, but from this point westward to kilometer 77 on the highway the depth to the water table increases to 60 or 70 feet. Near kilometer 80, 4½ miles southeast of Candelaria, water-bearing strata occur from about 110 to 120 feet below the surface, and the water level in wells is at a depth of 105 to 115 feet.

In the section of the western plateau lying between Santa Ana and Coatepeque most of the wells and springs are supplied by water-bearing beds in Pleistocene pyroclastic rocks. About 650 feet north of the Pan American Highway, between kilometer 60 and 61 on the Arrara coffee plantation, is a dug well 52 feet deep. The well is reported to have penetrated several feet of water-bearing pumice underlying volcanic ash or tuff. The water level in the well was 48 feet below the surface in December 1943. The well yields a moderate supply of water throughout the year. At kilometer 61½ a dug well on the farm of José Manuel Siguenza encountered a stratum of water-bearing cinders at a depth of 194 feet. The water level was 190 feet below the land surface in December 1943.

Approximately 1 mile northwest of Coatepeque, near kilometer 55 on the Pan American Highway, is the spring of El Milagro. It rises in a semicircular spring-sapped alcove about 50 feet wide. The water-bearing bed is a 4-foot stratum of volcanic cinders that lies between massive beds of tuff. The flow is approximately 75 gallons a minute and is perennial.

Southwest of Coatepeque the regional water table in the upland areas is generally deep, and small springs fed by perched ground-water bodies are the chief sources of water. Typical are the springs on the Los Angeles plantation near Potosí. These springs issue from thin stringers of pumice in volcanic tuff. The dry-season flow is less than 2 gallons a minute. At kilometer 48½ on the highway a well 137 feet deep obtains a small domestic supply from a stratum of volcanic sand. The depth to water is reported to fluctuate between 123 and 129 feet below the land surface. At one time the owner attempted to deepen the well to obtain a greater yield, unsaturated permeable material was encountered and water from the sand stratum started to leak away. the well to obtain a greater yield; unsaturated permeable material was low the sand stratum. These conditions suggest that in this vicinity the water-bearing sand stratum is perched with respect to the regional water table.

Near the western edge of the Zapotitán basin, in the vicinity of Chilamatal, the low-lying springs that issue from the pyroclastic rocks are generally outcrops of the regional water table. In the valley of the Río La Joya west and northwest of Chilamatal are several springs of considerable size. Nearly all of them issue from permeable beds of volcanic cinders or sand interbedded with volcanic tuff, agglomerate, and lava flows. The uppermost springs of the Río La Joya rise along the stream channel about 1¼ miles northwest of Chilamatal. A few hundred feet below the highest spring head the discharge of the stream is perhaps 5 cubic feet per second. Downstream the flow is augmented from place to place by smaller springs. Directly west of Chilamatal at the base of a steep bluff is the spring of El Jute, which furnishes most of the domestic requirements of the townspeople. This spring issues from a thin bed of volcanic cinders overlying tuff in a small spring-sapped recess. The flow of approximately 50 gallons a minute finds its way to the Río La Joya, a few hundred feet below the spring orifice.

In the Metapán region and the adjacent northern highland areas of Departamento de Santa Ana, sandstone, shale, conglomerate, marl, and limestone of Upper Jurassic and Lower Cretaceous age are reported. These rocks belong to the Metapán formation. They are in part overlain by weathered porphyries, andesites, and phonolites with intercalated pyroclastic rocks and detrital sediments, including sandstone and conglomerate of probable early (?) Tertiary age. The ground-water conditions of this region are not well known, but it is probable that the rocks generally have low permeability, owing to cementation and induration of sedimentary beds and alteration of volcanic materials. Locally the fragmental and scoriaceous facies of the lava flows may yield moderate to large supplies of water to wells and springs.

DEPARTAMENTO DE SONSONATE

GENERAL FEATURES

The Departamento de Sonsonate lies in the western part of El Salvador. It covers an area of approximately 740 square miles and has a population of 110,550. Within the department are parts of the coastal plain and the western plateau with adjacent sections of the Apaneca-Santa Ana highland and Zapotitán basin. (See pl. 3.)

The rocks underlying the western plateau are chiefly Pleistocene and late Tertiary (?) pyroclastic materials with interbedded lava flows. Similar rocks underlie the coastal plain, but they are veneered in part by stream deposits of the Río Grande and neighboring streams. The Zapotitán basin is underlain chiefly by lacustrine and alluvial materials derived from pyroclastic rocks in the neighboring highlands.

GROUND-WATER CONDITIONS

The rocks underlying the western plateau and much of the coastal plain include large masses of volcanic tuff, agglomerate, pumice, and cinders interbedded with andesite lava flows. The beds of pumice and cinders and the fragmental and scoriaceous zones of the lava flows are generally permeable. Where they lie in the zone of saturation they supply many of the wells and springs in the department. For example, Chilata springs, which furnish the water supply of San Julián, rise from fragmental zones in andesite lava flow that lies above a mass of dense volcanic tuff. The springs issue from three closely adjacent orifices, and the discharges are united at a central collecting box. The flow is delivered by gravity through a pipeline to the town. The total discharge of the springs is about 100 gallons a minute. In San Julián and the surrounding valley area the water table is at relatively shallow depth, and domestic dug wells tap water-bearing beds of pumice or cinders interbedded with volcanic tuff 15 to 25 feet below the surface in and near the town.

In the vicinity of Armenia, along the courses of the Río Agua Caliente and the Río Teguaya, numerous small perennial springs issue from beds of pumice overlying tuff. A typical example is Totonilco spring, 1½ miles east of Armenia near the track of Salvador Railway. The spring issues from a thick bed of pumice in a steep bluff overlooking the Río Teguaya. It discharges about 25 gallons a minute. A well dug along the Nueva San Salvador-Armenia road about half a mile northeast of Armenia, at the Plan del Coco farm, encountered a stratum of water-bearing pumice interbedded with volcanic ash at a depth of 17 feet. The well is reported to furnish an adequate water supply for domestic use throughout the year. In the vicinity of Sonsonate near Nahulingo a number of large springs in a swampy tract rise from Pleistocene or late Tertiary (?) volcanic rocks. The discharge from these springs is several cubic feet per second. Other large springs that issue from permeable zones in late Tertiary (?) volcanic rocks in the western plateau and coastal-plain areas contribute most of the low-water flow of the tributaries of the Río Grande, the Río Chiquihuatl, and the Río Tazulate. Along the lower reaches of these streams near the coast the thickness of the alluvial deposits increases and the basal parts are in the zone of saturation. In limited areas they are tapped for domestic water supplies by dug wells a few tens of feet deep.

The ground-water conditions in the Apaneca-Santa Ana highland have not been studied in Sonsonate, but it is probable that they are quite similar to conditions in the highland in neighboring Santa Ana and Ahuachapán.

LOCAL SUPPLIES

ARMENIA

The city of Armenia (population 8,500) has an inadequate public water supply of doubtful sanitary quality. It is obtained from two spring developments and a small surface-water dam on the San Eugenio plantation 1 to 1½ miles south-southwest of the city. The spring nearest the city is on a hillside in the narrow valley of the Río Teguaya. It issues from fractures or small openings in tuffaceous agglomerate. About a quarter of a mile upstream a smaller spring, which also issues from volcanic agglomerate, discharges about 15 gallons a minute.

Along the Río Agua Caliente and the Río Teguaya, which border Armenia on two sides, numerous small perennial springs issue from a bed of pumice overlying impermeable tuff. These springs are fed by a water-bearing bed that underlies the city and the adjacent area. The position and location of the springs suggest that in the vicinity of the plaza the water table should be approximately 200 feet below the surface, and that one or more water-bearing beds would be encountered by a well drilled 250 feet deep. One or two wells of this depth, if properly developed, completed, and fitted with efficient pumping equipment, should furnish an adequate water supply for Armenia.

SAN JULIÁN

The town of San Julián (population 1,500) has a water supply of about 144,000 gallons a day, or 96 gallons per capita. The supply is obtained by gravity pipeline from the springs of Chilata, about 1¼ miles south of the town, and is more than adequate for the present needs.

DEPARTAMENTO DE USULATÁN

GENERAL FEATURES

The department of Usulatán lies in the east-central part of El Salvador. It has an area of approximately 1,270 square miles and a population of 150,000. The area includes most of the Tecapa-San Miguel highland, with bordering sections of the western plateau, and a part of the coastal plain with the lower valley of the Río Lempa. (See pl. 3.)

Within the department the Tecapa-San Miguel highland is underlain chiefly by pyroclastic rocks and lava flows of Recent and Pleistocene age. The western plateau and the inland margin of the coastal plain are underlain chiefly by late Tertiary (?) volcanic rocks. Along the seaward margin of the coastal plain the late Tertiary (?) rocks are veneered by Pleistocene and Recent alluvial deposits.

GROUND-WATER CONDITIONS

The rocks that compose the Tecapa-San Miguel highland include a heterogeneous assortment of pyroclastic tuffs, agglomerates, pumice, and cinders, with interbedded tongues of andesitic and basaltic lava. The scoriaceous and fragmental zones in the lava flows and the pumice and cinder beds are highly permeable. Where they are present in the zone of saturation they yield moderate to large supplies of water to wells and springs. The volcanic tuffs and agglomerates are not generally permeable but locally they yield small supplies of water to wells and springs.

Near California, in the low area between Usulatán and Cerro del Tigre volcanoes, a local perched water-bearing zone occurs in a thin pumice bed in volcanic tuff. Numerous dug wells ending in this zone obtain small but perennial domestic supplies.

In a community well, "El Pozón," about half a mile north of California, this water-bearing zone is 52 feet below the surface and the water level is 48 feet. The well furnishes a perennial domestic water supply for several families. A well dug in the plaza of California encountered the same water-bearing zone at a depth of 50 feet. In an attempt to obtain a more abundant supply this well was deepened to 196 feet. At this depth the well was abandoned when permeable but unsaturated material in the upper part of an andesitic lava flow was encountered and the water from the higher perched zone began to leak away.

The city of Santiago de María obtains its water supply from a drilled well 272 feet deep which is located at the western outskirts. The principal water-bearing zone occurs in a scoriaceous and fragmental zone in a basaltic lava flow between 260 and 272 feet. The water from this zone rises in the well to 196 feet below the surface. The well yields 60 gallons a minute with no noticeable drawdown.

About 2½ miles northeast of Berlín on the road to Mercedes Umaña are the springs of Guallinac. They issue from tabular partings and scoriaceous zones in the base of a narrow tongue of andesitic lava overlying dense volcanic tuff. The total flow of the springs is estimated at 80 gallons a minute. They have been developed for the washing of coffee at two nearby coffee plantations.

The western plateau and the coastal plain are underlain chiefly by late Tertiary (?) pyroclastic rocks with interbedded lava flows. Similar rocks of Pleistocene age occur locally. The pyroclastic rocks are chiefly massive tuffs, and tuffaceous agglomerates with interbedded strata of cinders and pumice. Lava flows exist locally but are not as extensive in the late Tertiary (?) as in the Pleistocene rocks. The pumiceous and cindery beds and the scoriaceous and fragmental zones in the lava flows are permeable to water and where present in the zone of saturation yield small to moderate supplies to wells and springs.

In and near Jiquilisco an extensive water-bearing bed occurs in pumiceous zones and tabular partings in massive tuffaceous agglomerate. Many dug wells in the town obtain small domestic supplies from this bed at depths ranging from 25 to 35 feet below the surface. East of Jiquilisco, a quarter of a mile and half a mile, respectively, are the spring groups of El Chuchu and El Cacao, which rise in numerous minor orifices from the same water-bearing zone. The aggregate discharge of the springs of El Chuchu is perhaps 200 gallons a minute, and that of El Cacao is about 300 gallons a minute.

Just south of Usulatán are the springs of El Molino, which are among the largest in El Salvador. They rise from six adjacent orifices in a shallow spring basin. All the springs apparently issue from permeable material in a brecciated zone at the base of an extensive bed of andesitic lava overlying volcanic tuff. The total discharge of the springs is estimated to be about 50 second-feet. Directly west of Usulatán is a group of several springs which have an aggregate discharge of about 500 gallons a minute. They rise in adjacent spring-sapped alcoves from a pumice bed in massive volcanic tuff. This same water-bearing bed apparently supplies dug domestic wells 35 to 45 feet deep in Usulatán and appears to lie above the beds which supply the springs of El Molino.

Just north of Mercedes Umaña, near kilometer 101 on the Pan American Highway, are the springs of the Río Umaña. They issue from a lenticular tongue of highly permeable andesitic lava 150 feet or more wide and 40 feet thick at the maximum. Around the spring zone the lava tongue is completely enclosed by dense massive tuff and tuffaceous agglomerate so that the lava tongue acts as a conduit or ground-water artery from which the water issues with considerable force. The discharge is estimated to be 10 cubic feet per second or approximately 4,500 gallons a minute. The springs are the chief source of water for the townspeople of Mercedes Umaña and for travellers along the highway for a distance of several miles in either direction.

El Güiligüiste springs, about a quarter of a mile northeast of Nueva Granada, are the principal source of water supply for that town. The springs issue from small cavities and crevices in dense volcanic tuff in a line of small seeps about 150 feet long and have an aggregate discharge of about 15 gallons a minute. About 600 feet east of El Güiligüiste springs is the spring of El Chorro de Zapate, which rises from a ledge of andesitic or basaltic lava beneath a layer of volcanic tuff and discharges approximately 25 gallons a minute. Because neither of these springs is considered an adequate source of water supply, the Salvadorean Department of Public Works has undertaken the construction of a dug well in the town plaza. In October 1943 the well had reached a depth of 171 feet in tuff and agglomerate of late Tertiary (?) age and had encountered no important water-bearing materials. It is believed that if the construction of the well is continued to a depth of at least 325 feet one or more perennial water-bearing zones should be encountered. The well when properly developed, finished in the water-bearing zone, and fitted with an efficient pump should furnish an adequate water supply for Nueva Granada.

The townspeople of El Triunfo obtained their principal water supplies from three small springs that rise from rocks of late Tertiary (?) age in the vicinity of the town. El Ujustal spring rises in the bottom of a deep canyon about half a mile north-northwest of the town. It flows about 5 gallons a minute from a thin, short lens of pumice and cinders that lies within a mass of volcanic tuff. About a mile north of town is the spring of El Riíto, which also issues from a thin lens of cinders in dense tuff and tuffaceous agglomerate. The discharge is about 2 gallons a minute in the wet season. About 1½ miles west of town is the spring of La Cueva. It issues from a thin bed of volcanic cinders overlying tuff and discharges about 4 gallons a minute.

To alleviate the shortage of water in El Triunfo, the Salvadorean Department of Public Works has undertaken the construction of a dug well in the town plaza. In August 1943 the well had reached a depth of 232 feet, about 50 feet below the top of a flow of dense andesitic lava. One or more water-bearing zones will probably be penetrated within a depth of 325 feet. When properly finished in the water-bearing zone, developed, and fitted with an efficient pump, the well should furnish an adequate water supply for El Triunfo.

LOCAL SUPPLIES

ALEGRÍA

The town of Alegría (population about 2,000) has a public water supply of approximately 6,000 gallons daily, or 3 gallons per capita. The supply is delivered by gravity pipeline from two collection tunnels on small springs about half a mile west of the town. These springs discharge about 4 gallons a minute from tabular partings in tuffaceous agglomerate.

JUCUAPA

The city of Jucuapa (population 5,500) has a public water supply of approximately 86,000 gallons a day, equivalent to about 16 gallons per capita. The supply reaches the city by gravity through two pipelines from the springs of Los Naranjos, Pico Blanco, Chahuite, and Agua Caliente.

Los Naranjos spring, about 1¼ miles northeast of the city, rises in a ravine near the top of a hill. It issues from volcanic agglomerate and discharges approximately 30 gallons a minute. Chahuite spring, about 1¼ miles east of the city, issues from a bed of volcanic cinders. The discharge of this spring, together with that of Pico Blanco, is about 17 gallons a minute. Agua Caliente spring discharges about 13 gallons a minute, and the flow reaches the city by an independent gravity pipeline.

Near Jucuapa are two wells constructed for the supply of two coffee mills. One of these is 325 feet deep; the other, at lower elevation, is 221 feet deep and yields 15 gallons a minute. A large part of Jucuapa is underlain by beds of highly permeable pumice and volcanic cinders. A well drilled in the vicinity of Jucuapa would encounter one or more productive water-bearing beds of these materials within a depth of 400 feet. Such a well would considerably augment the existing water supply.

USULATÁN

The city of Usulatán (population 8,000) has a public water supply of approximately 100,000 gallons a day, or an average of about 12 gallons per capita. The supply is obtained from a pumping plant at one of the springs of Molino just south of the city. The water is raised to a storage tank in the upper part of the city and from there is distributed by gravity.

The present developed water supply is inadequate for the needs of the city. The additonal available supply at El Molino springs is 40 to 50 cubic feet per second. By installation of larger and more efficient pumping equipment, by increasing and enlarging storage facilities in the city, and by improvements in the delivery and distribution pipelines, the developed water supply of the city would be increased threefold or fourfold.

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