

THE POPULAR SCIENCE MONTHLY.

DECEMBER, 1905.

FRESH-WATER SPRINGS IN THE OCEAN.

BY PROFESSOR C. H. HITCHCOCK,
DARTMOUTH COLLEGE.

THE ancient Greeks tell of a river of the Peloponnesus called Alpheus, rising in Mt. Stymphalus, flowing through Arcadia and Elis, and then making its way beneath the Mediterranean as far as Sicily, where it united with the fountain Arethusa near Syracuse. It was the love of a swain for a nymph which led to this movement, and this emotion seems to have been able to prevent the commingling of the two kinds of water where ordinarily a mixture would result. What has been narrated in fable seems to be true to-day in the existence of boiling fresh-water springs rising up persistently in the briny deep off certain shores in the Hawaiian and West India islands and elsewhere. So little is known about them that I venture to present a few facts that have fallen under my observation, in the hope that this slight contribution to hydrology may interest others and lead to important results.

The suggestion of this conclusion came from the combination of facts ascertained in different parts of the world. First of all was a study of artesian wells upon the island of Oahu.* This island has an area of about 600 square miles, an irregular four-sided figure with an extreme diametral line of 46 miles. Figure 1 represents Oahu and a few of its more general topographical features. The land rises to two mountainous ranges about 13 miles apart, parallel to each other. The Kaala or Waianae Mountains, 21 miles long, lie on the southwest side, with a culmination of 4,030 feet. The Koolau Mountains on the northeast side culminate in Konahuinui, 3,105 feet high, and a length of 37 miles; and the two parts are known as Koolaupoko and Koolaupoko.

* *Geology of Oahu, Bulletin Geol. Soc. America, Vol. XI., p. 25.*

The lowland between rises gradually to a watershed 888 feet above the sea. Each range represents an elongated dome composed of basaltic layers gently inclined outwards in every direction (quaquaversal). The Kaala dome originated first in igneous ejections outpouring at the bottom of the ocean; they were constantly renewed, and finally emerged above the waters. It was then exposed to the erosive influences of the rains brought by the trade-winds. The streams excavated cañons in the basalt upon both sides of the island, eating away more of the rock in certain portions than in others. After a

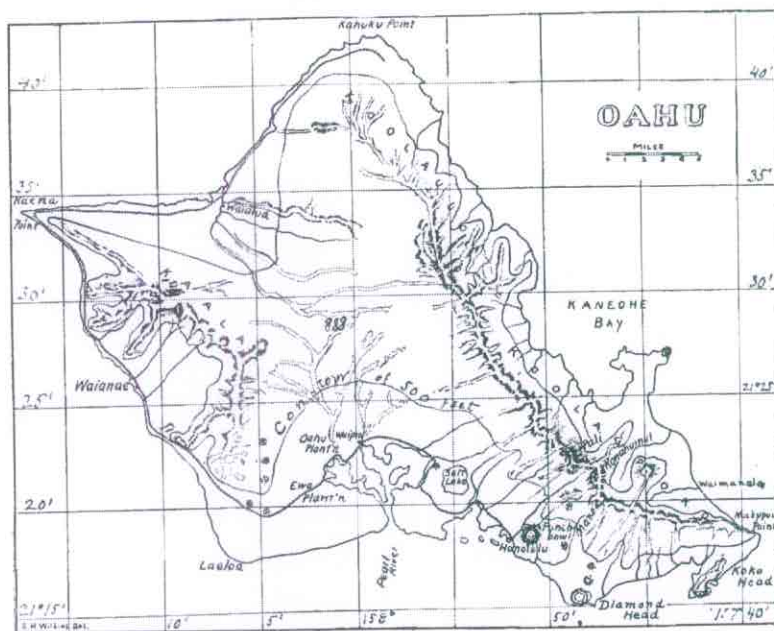


FIG 1. MAP OF OAHU.

long period a similar but longer island developed upon the eastern side, becoming the Koolau range, with more marked erosion upon the windward side, and very little upon the northern half of the leeward side. The Koolau lava poured itself out profusely, and covered up some of the earlier formed cañons upon the Kaala range.

The character of the erosion is shown in Figure 2 upon the Waianae side of the Kaala range. The cañon has been enlarged to an alcove and the precipitous side—called a *Pali* by the Hawaiians—presents a curious scalloped surface, or what might almost be called the ribs of the mountain side. Precisely similar waves appear upon the pali at the eastern side of the Koolau range. The most interesting point is at a wind-gap, 1,205 feet above the sea, the only place in the whole range where a road has been cut through from Honolulu by way of Nuuanu Valley to Kaneohe Bay. Up this valley for about eight miles about a hundred years ago King Kamehameha drove an army of his enemies,

who were crowded forward so furiously that they were precipitated down this pali of a thousand feet, where their bones could be seen till quite recently. This pali is one of the most interesting sights visited by modern tourists.

The Pliocene Tertiary.

These are quite extensive plains near the sea level composed partly of sediments derived from the decay of the basalts and other igneous products, and partly of calcareous marine deposits. Without attempting precision of delimitation, our map presents an approximate contour line of 500 feet altitude, which may represent the upper border of the terrane, which is clearly proved by its fossils to belong to the Pliocene



FIG. 2. EROSION ON THE WAIANAE SIDE OF KAALA.

Tertiary.* This band has a very variable width, dependent upon the amount of subaerial erosion, being the most extensive in valleys like those of Waianae and Waimanalo and in the more open area between the two mountain ranges. It is upon these plains that several large sugar plantations have been installed, for whose benefit numerous artesian wells have been sunk. In the southern part of Oahu there is a continuous belt of cane-fields eighteen miles in length, and averaging two in breadth to the west of the city of Honolulu. Others are near Waianae and Waialua.

The sugar plantations were at first located upon other islands of the group, as on Kauai, Hawaii and Maui, where plenty of streams of water afford plentiful supplies for moistening the soil, or to trans-

* W. H. Dall, *Bulletin Geol. Soc. America*, Vol. XI., p. 57.

port the cane from the uplands to the mills in flumes. Oahu was neglected because it is comparatively arid. Near Hilo, upon Hawaii, the rainfall amounts to 175 inches annually; in East Maui to 230 inches annually; while about Honolulu it varies from 24 to 38 inches; at Ewa and vicinity from 16 to 40 inches, and is quite variable by years, and insufficient for the growth of the cane. At first, attempts were made to supply water by irrigation. Like other cities, Honolulu receives much water from mountain streams brought by pipes for household and manufacturing purposes, as well as for the flowage of extensive tracts of rice land. The great need of water led to suggestions of an artesian supply. In 1879 James Campbell sank the first artesian well upon the island, near the Pearl River lagoon. Water commenced to flow from the depth of 240 feet, and the auger penetrated 33 feet more. The next one was sunk the following year at the mouth of Manoa Valley, where the discharge proved to be abundant from the depth of 298 feet. In the same year Judge McCully obtained a still greater supply from the depth of 418 feet. This last well was within the city limits, where it was easily seen by the public, who thoroughly appreciated its value. Many other persons followed the example of these pioneers, till now there are 195 wells upon the five leading plantations, yielding daily 287 million of gallons, and there are many more within the city limits of Honolulu.*

The Artesian Conditions.

Oahu presents two series of diversified sheets of rock dipping gently toward the sea from high central points; but the material is volcanic. In the early days successful artesian wells had been sunk through sedimentary strata, whence it was inferred that it would be useless to attempt borings in the so-called unstratified rocks. Many were dissuaded from such attempts by that consideration, yet any geologist would quickly observe the resemblance between these volcanic sheets and a nearly horizontal stratification. Nowhere is the succession of varied igneous layers better seen than on Kauai. This land is to be compared with either one of the Oahu or Maui domes; so that these latter islands may be termed *doublets*. The highest land on Kauai is at its center, Mt. Waialeale, over 5,000 feet in altitude. So far as is known no scientific explorer has yet penetrated this central point which is also commonly obscured by clouds. On the flanks of this central elevation are extensive plains gently inclined seaward and reminding one of a sedimentary fan, covered by a fertile soil. Streams have cut through these plains, displaying perhaps 200 feet thickness of alternating volcanic clays, earths or laterites and hard basalts. The diversity of the sheets is such as to give the conditions necessary for the de-

* Since this statement was made the number of wells and the consequent yield have considerably increased.

velopment of underground currents, but these are all clearly of volcanic origin, and here and there may be seen the remnants of the secondary craters whence came the ejections.

Oahu resembles Kauai in the dispersal of friable material in layers alternating with hard basalts, and adds marine accumulations to the igneous. The meteorological conditions explain the source and spread of the waters. Rain is profusely abundant on the highlands. The trade-winds, laden with moisture, drop their burdens on coming in contact with the land surfaces. The maximum rainfall is at the altitude of about 1,200 feet. The preponderance of the discharge, being upon the windward side, determines the place of the most copious streams and the more effective erosion. Hence the domes have been worn away unequally. One side may be entirely removed, and the other be scarcely affected at the surface. If the ridge is narrow at the altitude of greatest precipitation both sides will be extensively worn down. This is well shown on the Koolau upland, where the southeast end has been greatly denuded upon both sides from Mokapu point to the pali, while to the north, at a greater height, the cañons are less conspicuous on the west side.

The laying bare of the interior of the dome allows the water to sink into the pervious layers, and to flow beneath the surface towards Kaala and the southwest. Only the needful alternation of pervious and impervious strata is necessary to give rise to the subterraneous streams which will send water to the surface when pierced by the artesian wells.

The borings upon Oahu prove the alternation of basalt, clay, earth and limestone to the depth of several hundred feet. The principal water-bearing stratum is a very porous basalt, from 300 to 400 feet below the sea level by the shore. It has a hard, impervious cover, sufficiently tight to prevent the passage of water through it. The following general statements concerning the artesian conditions seem to be well established:

1. The presence of a porous water-bearing stratum beneath an impervious cover.
2. Water is reached usually at the depth of from 300 to 500 feet.
3. The water flows freely without pumping only in a narrow belt of territory adjacent to the coast line, where the surface is but slightly elevated; which is 42 feet at Honolulu, 32 feet at Ewa and 26 feet at Kahuku, at the northeast angle of the island. Wells sunk in higher ground show the water rising to the level indicated. Thus at the height of 100 feet the water will rise to the level of 42 feet at Honolulu, above which it will discharge only by the application of a pump.
4. For convenience in obtaining a proper supply several wells are sunk adjacent to each other. Naturally, as development takes place, the number of the wells increases. Thus the Ewa plantation had at first six ten-inch wells about thirty feet apart connected to a single pump,

which lifted the water about sixty feet. Later the wells are a foot in diameter in groups of ten for each pump. The water is forced through steel pipes twenty-four and thirty inches in diameter to a maximum elevation of four hundred feet. From various points ditches are dug which carry the water to every field of the plantation. The photograph, Figure 3, shows one of these pumping stations where there are twenty wells, each a foot in diameter. Though the pumps act without cessation, the water never fails; 5,000 acres of land are irrigated from these wells. The water here rises to the height of 22 feet above sea level.

5. These wells at Ewa are found to be slightly affected by the brine

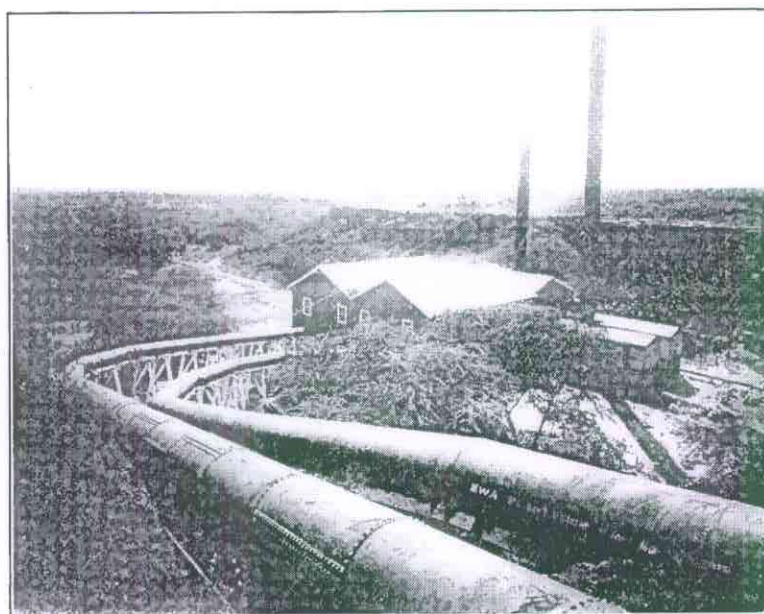


FIG. 3. EWA PLANTATION PUMPING STATION.

of the sea. The natural waters of the island contain .0073 per cent. of salt according to Dr. Walter Maxwell;* Pacific water holds 2.921 per cent. of the same. One hundred grains to the gallon of water represents 0.14 per cent. The analyst of the Ewa company found that the chlorine present (sodium chloride) was more abundant in the wells nearest the ocean. At station No. 1 the chlorine amounted to 17.61 grains in a gallon. At stations Nos. 2 and 3, farther inland, the chlorine had diminished to 8.18 and 11.97 grains to the gallon. By experiment at several localities it has been found that the salinity increases when the pumping becomes excessive. At Ewa it is stated that vegetation is not at all affected when the number of grains per

* 'Lavas and Soils of the Hawaiian Islands,' 1898.

gallon is less than sixty. At Molokai, where the salinity is greater, it is stated that the cane is not affected unless the number of grains per gallon exceeds one hundred.

From all the facts available, the conclusion seems warranted that the underground waters descend to the seas from the highlands and remain free from admixture till the pressure of the ocean exceeds that of the descending stream, when a commingling of the two liquids results. When the ocean pressure becomes greater, because of excessive pumping, the brine will increase in amount. In a small island the ocean water will force itself inland quite conspicuously. Molokai illustrates this proposition. Our information is derived from a report of Waldemar Lindgren in the Water Supply and Irrigation Papers No. 77. The springs there are of three classes, of which only the first calls for consideration here, (1) those very near the shore, (2) those breaking forth up to the height of 2,000 feet, (3) running streams still higher.

Shallow wells near the shore show the following degrees of salinity or number of grains per gallon, 238, 403, 150, 126, 109, 86, 102, 86; of deeper wells the first gave 86 grains at the surface and became ocean water at 50 feet. The second became ocean water at 125 feet. At Naiwa there are 90 grains of salinity at 70 feet. At Kalamaula several deep wells gave 102 and 104 grains and pure ocean water. The American Sugar Company sank several deep wells at Kaunakakai, of which the first five had 150 grains per gallon; others ranged from 270 to 485 grains. The Risdon wells yielded 70 to 79 grains per gallon. Better results appeared in nine wells sunk at Kawela, many of them showing less than 50 grains of salinity. The fresh water is contaminated up to four or five feet above the sea level. None of the underground streams can be more than eight miles in length, and many do not exceed three. It is also probable that no impervious layer protects the underground water as in Oahu.

6. There are springs of fresh water near the sea-shore in Oahu which may correspond to the artesian fountains. One is the famous Kamehameha Bath near Punahou, a second is near the railroad station at Honolulu, and a third gladdens the thirsty soul at Waialua near the Haleiwa Hotel. Another is at Niu, west of Koko Head. It would seem that the underground water finds its way to the surface through some crevice, after the usual manner of springs, and that it is powerful enough to prevent the commingling of the ocean water with it.

The theory of the subterranean stream from the summits to sea level has been further tested practically by the driving of tunnels to reach the water near its source. Thus derived the water is free from any possible saline contamination, and being delivered by means of a ditch sloping downwards, the expense of sinking artesian wells and the subsequent pumping is saved. In this way a copious daily flow has

been obtained from the Waianae side of Kaala, utilized to run a dynamo, besides irrigating several plantations. On Maui near Lahaina, a six-million-gallon daily flow is derived from the altitude of 2,600 feet through a tunnel of the same length. There are no springs nor other signs of underground water along the route. It must be permanent, as the flow has been constant for the past two years. Other examples could be cited.

Springs in the Ocean.

7. After so many introductory statements it is possible now to postulate the central idea of this paper: springs of fresh water arise in the midst of the ocean at some distance from the shore. The facts are not numerous, but are stated upon the best authority. Professor Joseph Le Conte, in his 'Geology,'* says that fresh-water springs arise in the ocean in the Hawaiian Islands. In reply to my inquiry as to details, he wrote that he had not preserved the memoranda relating to these phenomena, and that they had escaped his memory. No one can doubt the correctness of the statement in view of the existence of the proved underground waters. Powerful streams discharge millions of gallons of water through the artificial openings very near the sea-shore. If not intercepted, they must continue a considerable distance out to sea, and hence must well up to the surface amid saline billows.

Inquiry about these springs during the past summer in the territory of Hawaii has resulted in the discovery of several upon Oahu, there is one off Diamond Head; a second off Waialae. At the east end of Maui, in Hana, there was a fortress named Kaimuke, occupied by soldiers in the ancient times. As it was almost an island communication with the mainland was not feasible in the time of a siege, and for the lack of water it could not have been held except for the presence of submarine springs. The natives would dive down to collect water in their calabashes, which supplied all the wants of the garrison. Other springs were known in the harbor of Hana, and at low tide at Lahaina. Upon Hawadi I found there were fresh-water springs off Kawadahae and Punaluu. Further inquiry would doubtless discover many other examples.

Underground Waters in Florida.

A later residence of a few weeks in Florida proved that the characteristic fluvial phenomena cited above were even better developed there than in Hawaii. If there is anything peculiar about drinking-water one discovers it very soon, as was the case in Florida. The first feature to be noted along the eastern coast of Florida is the presence of hundreds of driven and artesian wells. Every cottage of importance derives its water for culinary and irrigating purposes from them.

* 'Elements of Geology,' p. 74.

In the Water Supply and Irrigation Papers, No. 102, Mr. M. L. Fuller, of the U. S. Geological Survey, has brought together all sorts of information about the natural and artificial sources of water of Florida, as well as of the whole eastern United States. Mr. Fuller has kindly answered my inquiries about these fresh-water springs in the ocean, stating important facts supplementary to this Water Supply Paper.

The peninsula of Florida is underlaid by Tertiary deposits of all ages, the older portions lying along the central axis, and are flanked upon both sides by the Oligocene, Miocene and Pliocene. Artesian wells are successfully operated upon both the Atlantic and Gulf coasts. The strata dip gently from the central axis towards both shores, and where there is the proper diversity of hard, soft, pervious and impervious strata the water comes to the surface without pumping. A few statements about the better known wells partly derived from original observations and partly taken from Mr. Fuller's report will be pertinent. At Jacksonville the visitors to the subtropical exposition in 1888 saw water flowing in a stream from a well several hundred feet deep, supplying the various needs of the management. Flowing wells have since then been sunk to the depths of 616, 708, 740, 800, 850, 3,000 and 5,000 feet.

At St. Augustine a well 1,500 feet deep furnishes the East Coast Hotel system with plenty of water, including a spacious swimming tank. It has a temperature of 70° F., so that bathing in it is agreeable in the coldest weather.

At Ormond there are numerous wells at comparatively shallow depths, the deepest one reaching 200 feet. At Daytona, close by, there are 400 wells from 100 to 220 feet deep. There are many others at nearly every town along the coast. At Palm Beach, close to the seashore, a well 1,200 feet deep is quite saline.

On the west coast the wells in the more northern section yield water by pumping. In Manatee County and at Fort Myers the fluid discharges in the normal way from depths exceeding 400 feet. One on the premises of T. A. Edison, the distinguished inventor, yields most abundantly from the 350-foot level, and will discharge from the height of twenty feet.

Most of these waters are characterized by the presence of sulphur, besides being warm. Chemical analyses show the presence of the following compounds: calcium sulphate, sodium chloride, sodium carbonate, calcium and magnesium carbonates, and occasionally potassium chloride and sulphate. Commonly these ingredients are so abundant as to make the water disagreeable to the taste, and when used for bathing the tubs are easily soiled, and cleansed with difficulty. When used for the table it is found expedient to allow the water to stand for

several hours before using, so that the sulphur may be volatilized and the temperature reduced.

Florida is a well watered country. Lakes, streams and springs are extremely numerous. The underlying limestone is full of caverns containing water. Every one knows about the Silver Spring in Marion County. It starts as a full-grown river from a spring 25 to 30 feet deep, perfectly clear, with an outlet 60 feet wide, 10 to 14 feet deep. It is the Oclawaha River, navigable for steamers from its very source. The water is probably the rainfall of the region filtering through miles of sand, with a temperature of 72° and perceptibly calcareous to the taste.

The water in the lakes is purer than that from the springs, probably because on exposure the compounds break up, and the gases, sulphur and hydrogen, carbonic acid, oxygen and nitrogen (common air) are eliminated. The Everglades and Lake Okeechobee illustrate this fact. The steamers plying down the Kissimmee River, across Okeechobee and down the Caloosahatchee River to Fort Myers obtain their drinking-water from far out in the lake, because nowhere else can it be found so palatable, or so well fitted for use in the boilers of the steamers.

The source of the sulphuretted hydrogen must be the various sulphates decomposed by the action upon them of organic matter. The mineral compounds arise naturally from the solubility of the various salts, either from the original strata or from their dissemination through the soil.

Fresh-water Springs in the Ocean.

Many of these underground streams proved to exist by the artesian bore-holes are of great volume, and hence must pass to some distance under the ocean. This fact is further corroborated by the small degree of salinity even in the deeper wells. Statements made by residents claim the existence of fresh-water springs miles away from the land opposite St. Augustine, Matanzas and Ormond. The first of these is also mentioned by T. C. Mendenhall, formerly superintendent of the United States Coast Survey, in a letter to J. W. Gregory, in charge of Artesian Well Investigations, Department of Agriculture.

Mr. M. L. Fuller furnishes me with the following additional localities. Dr. Mendenhall mentions the reported occurrence of fresh-water springs off the mouth of the Mississippi River. In 'The Island of Cuba,' by Lieutenant A. S. Rowan and M. M. Ramsey (Henry Holt & Co., 1896), page 18, it is stated that the water is often forced by hydrostatic pressure to the surface far out at sea. Elisée Réclus remarked that 'in the Jardines (east of the Isle of Pinos), so named from the verdure-clad islets strewn like gardens amid the blue waters, springs of fresh water bubble up from the deep, flowing probably in subterranean galleries from the mainland.'

Mr. Fuller also adds the following quotation from a paper by

himself upon the 'Hydrology of Cuba,' in the Water Supply Paper No. 110, page 93: the springs "issue at all altitudes, from the higher portions of the hills down to the lowland border, or even at sea level. . . . Not all the water comes to the surface as springs, but some passes outward and emerges from the sea bottom along the coast, where in many instances the fresh water can be seen bubbling up through the salt water. Such springs occur in Havana Harbor and at many other points. The fresh water which surges as copious springs on some of the keys is probably of the same origin, coming from the mainland through subterranean passages in the limestone."

These may be an illustration of the derivation of fresh water from the mainland upon the island of Nashawena in Buzzards Bay Massachusetts. This is a large island midway between New Bedford and Marthas Vineyard, upon which it is proposed to erect a new state prison as well as a leprosarium. Near the center of the island and very high up is Menaud Pond, a splendid body of pure fresh water, capable of furnishing an ample supply to the new institutions. There is no perceptible inlet or outlet; the supply seems to be derived from springs, such as may be conceived to originate upon the mainland, to pass beneath the bay and to rise to the surface at the summit of Nashawena. Except for the accidental presence of land here this stream would have risen to the surface in the midst of salt water. People familiar with the shallows over the region between Long Island and the Great Banks of Newfoundland speak of an 'underground river' extending from Labrador to Block Island having many outlets similar to the supposed one at Menaud Pond. Our theory of a connection with the mainland through Tertiary strata is a better one.

Conclusions.

The foregoing facts warrant us in believing in the existence of fresh-water springs bubbling up through the brine of the ocean. They are known to exist among the Hawaiian and West India islands and off the coast of Florida. The necessary conditions seem to be those which will permit the existence of underground streams flowing towards the sea; such as will render the boring of artesian wells successful. Evidently there must be strata—whether of the later fossiliferous rocks or igneous sheets—dipping gently seawards; and the springs can not appear very far away from the coast. We should, therefore, look for these phenomena adjacent to islands and all coasts bordered by Tertiary and basaltic rocks. They may be seen off nearly the entire eastern coast of the United States—from Cape Cod to the Rio Grande. Possibly also fresh water may be able to accumulate beneath the submarine belt of Tertiary between Nantucket and the Great Banks of Newfoundland. It is conceivable that they might be utilized for the supply of steamships in places where the local supply is either defective or unwholesome.