The factor $\frac{\text{Valence}}{\text{Atomic weight}}$ is called the reaction coefficient.[1] In any stable chemical system the acid radicles must balance the bases, and their reacting values should, therefore, be equal, and this fact is evident in most of the charts. Slight discrepancies may be explained either by the presence of small quantities of undetermined constituents or by minor errors in the analytical results.

In the charts shown in Figures 32 and 33 the large areas in which the acids are plotted against the bases are proportional in size to the quantity of mineral matter—the total dissolved solids. The scale in the two figures is different, however, as is shown by comparing the sizes of the two areas for the Sources Chaudes de Los Pozos. The height of the area shown for silica is based upon the ratio of the reacting value of silica to the sum of the reacting values of both acids and bases.

The charts bring out forcibly the features of the different types of waters described. The surface waters, represented by Rivière Artibonite and Étang de Miragoâne contain the lowest total solids, the common springs, represented by the Port-au-Prince supply, slightly more, but the character of all three is much the same, high calcium carbonate being the principal feature. The wells at La Morinière contain higher total solids, relatively less calcium, and more magnesium, as well as more silica.

The type of water in the well of the railroad company at Cap-Haïtien is unusual. Calcium is very low, magnesium is higher than calcium, and sodium and potassium are very high and are present largely as carbonate.

The similarity of the water of Étang Saumâtre to sea water and the dissimilarity between the water of Étang Bois-Neuf and sea water are very evident in the graphic comparison in Figure 33.

The remaining charts cover unusual spring waters considered under the heading "Springs" (pp. 553-566).

SPRINGS.

GENERAL FEATURES AND CLASSIFICATION.

Springs are found at many places in the Republic, both in the mountains and on the plains, although they are uncommon in certain small areas, as, for instance, in much of the Northwest Peninsula and on Gonave Island. Springs may be classified as hot or cold, highly mineralized or not, and in many other ways. A recent and useful classification, proposed by Bryan,[2] is based on the source of the water and the structural feature that brings it to the surface. The source of the water of most of the springs of the Republic is rainfall that has entered the ground and thus become ground water. Examples of nearly all the structural types of

[1] Stabler, H., The industrial application of water analyses: U. S. Geol. Survey Water Supply Paper 274, p. 167, 1911.

[2] Bryan, Kirk, Classification of springs: Jour. Geol., vol. 27, pp. 522-561, 1919.

springs could probably be found, but only the commonest and most useful types are here described, and appropriate examples of each type are given. A few of the more noted or unusual springs are described in detail.

SPRINGS EMERGING FROM SOLUTION CHANNELS IN LIMESTONE.

One of the commonest and most useful types of springs includes those that form the outlets of underground streams that follow solution channels in limestone. Most of these springs issue at the base of mountains—either in valleys or at the border of plains—or on the sea shore. Some of them give rise to large streams, such as the Rivière Salée, near Baradères. The openings from which some of them come are visible. A good example is the Source Moreau, at the northern edge of the Cayes Plain, which issues directly from a limestone cliff and gives rise to the Rivière de Torbeck. The opening, however, is generally obscured by a mass of soil and débris, through which the water must force its way. Source Diquini (p. 571) of the Port-au-Prince supply and Source Cinq Carreaux (p. 583) of the Cap-Haïtien supply are springs of this kind; before they were cleared out and utilized they issued from a mass of soil in ravines, but the removal of this mass exposed the open channels in the rock from which the water issues. One of the largest springs of this type is the big spring at Maneville, on the edge of Étang Saumâtre. Although its opening is filled with soil it is no doubt the outlet of an underground stream that comes from the limestone mountains to the north. Sources Le Clerc and Chaudeau (p. 571), of the Port-au-Prince water supply, and Source la Pierre, which furnishes the water of Gonaïves, are other springs of this type. In fact, nearly all the springs in limestone regions are of this type, although many of them could also be classified as contact springs.

CONTACT SPRINGS.

Contact springs are of several different kinds, but all of them occur along the contact of a porous rock with a less porous or impervious rock, usually at places where the porous rock is on top. Water absorbed by the porous rock passes downward until its movement is checked by the impervious rock, and then moves laterally down the slope of the impervious rock until it finds an outlet on some hillside or in a ravine or valley. Many such springs occur along the contact of porous limestone with underlying impervious igneous rock, slate, or compact chalky limestone. Such springs also belong in the class of springs that emerge from solution channels in limestone, the solution channel having been localized along the contact with the impervious rock. A very good example is Source Cinq Carreaux, of the Cap-Haïtien water supply (p. 583), already mentioned. This spring issues at a contact between limestone and underlying metamorphic clayey chert. The springs on Gonave Island (p. 541), occur at the contact of porous limestone with compact chalky limestone, and the springs of La Vallée on Tortue Island occur at the contact of limestone with impervious metamorphic rocks.

In regions underlain by igneous rock small springs or seeps on hillsides are rather common. Most of them are fed by water that slowly seeps from accumulations of residual soil and débris and that moves down the hillside above or upon the surface of the denser, less pervious unweathered rock beneath. Few such springs are large. An exceptionally large spring of this type is Source Belair, of the Cap-Haïtien supply (p. 584).

Contact springs of another class occur in the beds of ravines or stream courses that are dry almost throughout the year. They are commonest in semiarid regions. Most of these stream beds contain deposits of porous gravel and sand. Water absorbed by these deposits at times of flood continues to seep downstream after the surface water has disappeared. Here and there the water may meet obstructions, such as outcropping ledges of underlying impervious rock or beds of impervious clay. These obstructions force the water to rise to the surface and suggest the name "rock-dam springs," which is frequently applied to springs of this type. A good example is the spring at Terre-Neuve that supplies most of the water used in the town. This water rises from gravel that lies upon impervious igneous rock and sinks away again in the gravel farther downstream. The water reappears about 2 kilometers west of Terre-Neuve, where igneous rock and limestone are exposed in the stream bed, and flows for a considerable distance. Another example is Source Plaisance (p. 572), of the Port-au-Prince supply, which rises at a place where the alluvial gravel of the stream bed is interrupted by beds of impervious Miocene marl.

Another type of contact spring, somewhat more difficult to recognize, probably occurs on the alluvial plains and valleys, about the perimeters of artesian areas. We have seen (p. 519) how artesian water receives its head by passing downward along a porous bed beneath a confining impervious bed. When the porous bed is fully saturated the excess water absorbed at the intake area must escape, and it frequently does so through springs at outcrops of the impervious confining bed. The springs at the north side of the town of Léogane are probably an example of this type of spring, and perhaps also some of the springs on the Cul-de-Sac Plain, the Cayes Plain, and the North Plain.

ARTESIAN SPRINGS.

The type of spring last described is difficult to distinguish from the artesian spring that is due to artesian pressure and that emerges through some break or weak spot in the confining bed above. Many such breaks are produced by faulting, the water under pressure finding its way to the surface along the fault plane. Springs of this class may perhaps be found at some places in the Republic, especially on the Cul-de-Sac Plain. Earthquakes are frequent in the plain (see pp. 338-350), and they may produce lines of weakness that permit the escape of artesian water. Earthquakes also cause sudden large flows of water due to the slumping and compression of water-bearing rocks. Such flows of water are generally temporary, but some may continue as permanent springs. Several reports indicate that flows of this kind in the plain have been produced by earthquakes.

SPRINGS IN FRACTURES IN IMPERVIOUS ROCKS.

Another type of spring is that due to fractures or fissures in relatively impervious rocks. To this type probably belong a number of small springs whose water circulates through joints, simple or complex, entering them at high altitudes and issuing at lower. Of this type also are springs that issue along fault zones that probably extend to considerable depth in the earth. Some of the more noted warm springs of the Republic are doubtless of this class. (See p. 565.)

UNUSUAL TYPES OF SPRINGS.

Many springs in the Republic that can be referred to the above types so far as the attendant rock structure is concerned, have distinctive features of other kinds, such as highly mineralized water, included gases (particularly hydrogen sulphide), or a temperature markedly above the general average of the atmosphere. The larger ones noted can be classified as salty springs (contaminated by sea water), sulphur springs, and warm springs.

Salty Springs Contaminated by Sea Water.

Salty springs appear to be rather common, particularly on the limestone coasts. Among the best examples of the type are two springs southwest of Miragoâne, where the coast is high and steep. The larger spring is on the shore about a kilometer from the town. The spring (Pl. XL, *B*) issues from large open solution channels in a low bluff of Eocene limestone very close to the sea. The water level in the large basin-like pool at the outlet rises and falls with the tides, which enter beneath the bridge to the north. The flow of the spring is probably at least 100 liters per second. The water is very salty, quite unfit for drinking. The smaller spring, which is nearer the town, is much like the larger one, but its flow is less and its water is more salty. Analyses of the water of these two springs, compared to sea water, are given in the table on page 554.

Graphic comparisons of these waters with sea water are given in Figure 33. The ratios of all the significant bases and radicles in the spring waters to the total solids and to each other is virtually the same as in sea water, so that the only notable difference is the degree of concentration. Of course a part of the calcium and most of the silica and bicarbonate in the spring waters are derived from normal meteoric ground water, but nearly all the chloride, sulphate, carbonate, sodium and potassium, and magnesium is derived from sea water, probably in part by diffusion, in part by the infiltration of sea water into open crevices at high tide, and perhaps in part by displacement of fresh water by sea water, particularly at high tide, because of the greater specific gravity of the sea water. The sea water, probably affects only the water at and near the outlet of the springs.

Other springs of this type are not uncommon. The Source Salée between Léogane and Port-au-Prince, the springs at Grand-Gosier, and the Source Baie de Henne (p. 590) are examples.

Analyses of water of salty springs near Miragoâne and of sea water.
[Parts per million.]

	Larger salty spring.[a]	Smaller salty spring.[a]	Sea water.[b]
Total dissolved solids	10,476	20,928	35,000
Silica (SiO_2)	77	79	....
Iron (Fe)	.25	.45	....
Calcium (Ca)	178	183	419
Magnesium (Mg)	387	675	1,304
Sodium and potassium (Na+K)	3,224	6,752	[c]11,094
Carbonate radicle (CO_3)	34	48	72
Bicarbonate radicle (HCO_3)	272	220	....
Sulphate radicle (SO_4)	763	1,551	2,693
Chloride radicle (Cl)	5,559	11,376	19,352
Nitrate radicle (NO_3)	Trace	Trace	....
Date of collection	Apr. 10, 1921	Apr. 10, 1921	1873-1876

[a] C. S. Howard, analyst.
[b] From U. S. Geol. Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.
[c] Sodium (Na) 10,707, and potassium (K) 387 parts.

SULPHUR SPRINGS (SOURCES PUANTES).

A number of springs in the Republic contain hydrogen sulphide (H_2S) in solution. Most of this gas escapes when the water reaches the surface and pressure on it is released. The unpleasant odor of the gas suggested the name sources puantes, which is frequently applied to these springs. The most famous are the Sources Puantes at the northwestern corner of the Cul-de-Sac Plain. (See Pl. XXXIX.) The odor of these springs is very strong and can be detected for some hundreds of meters. A view of the springs is given in Plate XL, *C*.

The Sources Puantes are on a very narrow extension of the Cul-de-Sac Plain, not more than 100 to 200 meters from the sea, at the base of low foothills that border the higher mountains north of the plain. The foothills consist of Miocene rocks, but near the springs they are surfaced with gravel and conglomeratic débris. The plain is alluvial. It stands virtually at sea level and becomes a mangrove swamp only about 50 meters from the outlet of the springs.

The original outlet of the springs has apparently been disturbed a little by the building of a railroad embankment and highway crossing. The present flows issue from two small basins at the lower side of the embankment. Some water also seems to seep out over a marshy area that is at least 100 meters in diameter. Bubbles of gas rise almost continuously both at the larger openings and at many places in the adjacent marsh. Presumably most of it is hydrogen sulphide (H_2S). The total flow of the two springs at the railroad embankment amounts, probably, to at least 30 liters per second. The water had a temperature of 32.7° C. on December 6, 1920, with the atmospheric temperature at 29° C. The mean annual temperature at Port-au-Prince is 27° C. and is probably nearly the same at the springs. The water is clear, but very salty and rather nauseating to the taste.

The water probably rises along a fault that borders the north side of the Cul-de-Sac Plain, as faulting doubtless had some share in the formation of the greatly depressed region of the plain and faults were discovered on the south side of it. (See p. 335.) If there is no fault at this locality the water may possibly escape because the alluvial sediments at the margin of the plain are coarser and more porous here than they are to the south and east. The water probably rises because of artesian pressure, such as accounts for other springs and for flowing wells in the lower part of the Cul-de-Sac Plain.

The high temperature of the water is believed to be due to the considerable depth from which it comes, for, as is well known, the temperature of the earth increases with depth. An average figure for the rate of this increase of temperature with depth near the surface of the earth probably is about 1° C. for each 35 meters of depth. A figure very commonly used by English and American writers is 1° F. for each 50 to 60 feet in depth, equivalent to 1° C. for each 27 to 33 meters.[1] Some recent and very careful measurements by C. E. Van Orstrand, in West Virginia, indicate that the rate is somewhat less, particularly in very deep wells. An average increment of 1° C. for each 43 meters in depth was obtained from measurements in 6 wells ranging in depth from 2,000 feet to 7,310 feet (610 to 2,228 meters).[2] The rate of increase varies considerably in different parts of the world and even in nearby localities, so that at best only an approximation is possible. The figure used here of 1° C. for each 35 meters of depth is believed to be conservative, and the water of the Sources Puantes would therefore need to circulate only about 5×35 meters or 175 meters, beneath the surface to attain a temperature of 5° above the mean atmospheric temperature. Allowance must be made for the loss of heat along its path to the surface, but probably not enough to increase the depth unreasonably. The depth given is no greater than that of some

[1] See Chamberlain and Salisbury, Textbook of geology, vol. 1, p. 569, 1905.
[2] See Darton, N. H., Geothermal data of the United States: U. S. Geol. Survey Bull. 701, pp. 90-95, 1920.

of the artesian wells on the plain. The temperature of the water in these wells is slightly higher than atmospheric temperature.

The salinity of the water appears from the analysis to be due to sea water, as is shown by a comparison of analyses in the table below and in the charts in Figure 33.

Analysis of water of Sources Puantes compared to sea water.
[Parts per million.]

	Water of Sources Puantes.[a]	Sea water.[b]
Total dissolved solids	12,684	35,000
Silica (SiO_2)	36	....
Iron (Fe)	.08	....
Calcium (Ca)	397	419
Magnesium (Mg)	299	1,304
Sodium and potassium (Na+K)	3,930	[c]11,094
Carbonate radicle (CO_3)	.0	72
Bicarbonate radicle (HCO_3)	610	....
Sulphate radicle (SO_4)	872	2,693
Chloride radicle (Cl)	6,627	19,352
Nitrate radicle (NO_3)	Trace	....
Hydrogen sulphide (H_2S)	136	....
Date of collection	Dec. 6, 1920	1873-1876

[a] C. S. Howard, analyst.
[b] From U. S. Geol. Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.
[c] Sodium (Na) 10,707 and potassium (K) 387 parts.

The close resemblance to sea water is striking. The total solids, magnesium, sodium and potassium, sulphate, and chloride—the significant factors—all bear a ratio of about one-third to the concentration of sea water. Most of the calcium and the bicarbonate may be derived from normal meteoric ground water. The presence of sea water seems unquestionable; though the question how it comes to be present is not easily answered. It might enter by direct seepage into the upper strata near the outlet of the springs, by infiltration along a fissure or fault zone opening beneath the sea, or as connate water that was imprisoned in marine beds beneath the plain at the time of their deposition and that is now being gradually replaced by fresh meteoric ground water, which is seeping seaward under pressure. The first two assumptions are not regarded as very probable. Observations made elsewhere show that salt water seldom invades uniformly textured alluvial or sedimentary rocks that are exposed at the surface along beaches, especially when the escaping ground water has a considerable head forcing it seaward, as at the Sources Puantes.[1] This head of fresh water also probably would prevent the salt water from entering fissures in the sea bottom and would tend to form submarine fresh water springs instead. The assumption that this is connate sea

[1] Brown, John S., A study of coastal ground water: U. S. Geol. Survey Water-Supply Paper. (Awaiting publication.)

water, coming either from the young marine beds beneath the alluvium of the plain or from the buried Miocene beds, therefore seems reasonable, and accords also with the theory that the hydrogen sulphide is derived from sea water that ascends from considerable depths.

The hydrogen sulphide is probably produced from the sulphate that was originally in the sea water by chemical reactions due to the agency of organic matter in the rocks traversed by the rising water, particularly near the surface. The ground around the spring, especially the mangrove swamp nearby, is full of organic matter, which doubtless occurs also in considerable amount in lower beds, as the shore line probably has been near the same place for a long time. Clarke[1] says "The sulphates of a water, by accession of organic matter, can be partly or entirely reduced to sulphides, and carbonic acid, acting upon the latter, may expel sulphureted hydrogen and produce carbonates." This is apparently the type of change that has occurred here. The necessary carbonic acid is abundantly present in all the normal meteoric ground water of the Republic, such as must constitute the two-thirds of the water not derived from the sea. Additional support is lent to this theory by the fact that the sulphate in the spring water is slightly less than one-third that in normal sea water, but the chloride and sodium and potassium are slightly greater than one-third, indicating perhaps the reduction of a small amount of sulphate.

The Sources Puantes are regarded by many people as having therapeutic value. A basin for bathing has been sunk in the mud of the marshy area, flush with the surface of the ground. It is about 2 meters in length and somewhat less in depth and width and appears to be walled with either brick or stone. It has no roof, and does not appear to be much used. There are no houses near the springs.

Nearly all the warm springs of the Republic contain slight traces of hydrogen sulphide, particularly those at Los Pozos. (See p. 564.) Moreau de St.-Méry[2] describes what apparently is a notable sulphur spring at the foot of the mountains southwest of Port-de-Paix near the boundary between Bas Moustique and Haut Moustique. The hydrogen sulphide in some of these springs may be derived from other sources than those suggested for the Sources Puantes.

WARM SPRINGS.

The Republic contains no boiling springs, but a few springs are distinctly warm and exhibit unusual features. Nearly all these springs are known by the generic name of Sources Chaudes, and local geographical names are added to distinguish them from one another.

[1] Clark, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, p. 204, 4th edition, 1920.

[2] Op. cit., vol. 1, p. 715.

SOURCES CHAUDES OR EAUX BOYNES.

The Sources Chaudes on the southern side of the Northwest Peninsula, also known as Eaux Boynes, are the most celebrated warm springs in the Republic. They are about 12 kilometers west of Terre-Neuve and 30 kilometers northwest of Gonaïves. The springs have long enjoyed the reputation of having great curative properties, particularly for skin diseases and rheumatism, and they have been frequented a great deal by invalids. Moreau de St. Méry[1] gives a lengthy description of the springs and of their utilization by the colonists. They were discovered and their curative properties were first tested by a negro named Capois in 1725. Their fame spread until they came to be frequented by invalids of many classes, and they are credited with some remarkable cures. In 1772 the owner of the springs, M. de Rameur, made a gift of them to the Crown in order that they might be used more fully for the public good. Under governmental direction a public bath-house with sixteen masonry baths and a sanitarium, open to the public at reasonable rates, were erected. A military hospital, with separate baths for soldiers, was also maintained. A passenger boat made regular bi-monthly trips between Cap-Haïtien and the landing at Port-à-Piment. Beautiful avenues of trees were planted and the place must have had a prosperous appearance, strongly in contrast with its present dilapidated condition.

Only the ruins of 8 of the masonry baths now remain. There is a small agricultural settlement at the springs, but no attempt is made to exploit them either by public or private enterprise, although many invalids still frequent the place on their own initiative. The water from the springs still makes the place a green and pleasant oasis in the surrounding semiarid region and permits the irrigation of garden spots in a small area. The ownership of the springs is still vested in the Government.

The Sources Chaudes are about 8 kilometers from the coast, at the interior edge of the Arbre Plain. Behind them, to the north and east, is a narrow belt of low foothills, which borders the steep southern escarpment of the easternmost range of the Montagnes du Nord-ouest. This range rises more than 1,000 meters above sea level. The altitude of the springs is less than 100 meters above sea level.[2] The relative position of the springs and the surrounding surface features are shown in Figure 34. Of the six distinct springs now visible, five are ranged along a remarkably straight line trending about N. 55° W. across a low divide between two shallow ravines. The distance between the springs at the extremities of the line is about 235 meters. The sixth spring is offset considerably to the south of the easternmost spring. The line of springs plainly occupies a position at the break in the slope from the foothills to the plain. Geologically it also appears to occupy a well-defined contact. Only alluvium and

[1] Idem, vol. 2, pp. 62-75.
[2] Given as 70 meters by Tippenhauer.

residual soil are visible near the springs, but the plain is underlain by Miocene rocks, which are exposed not far to the south, and the surface features suggest that the whole plain is formed on the soft marly beds of

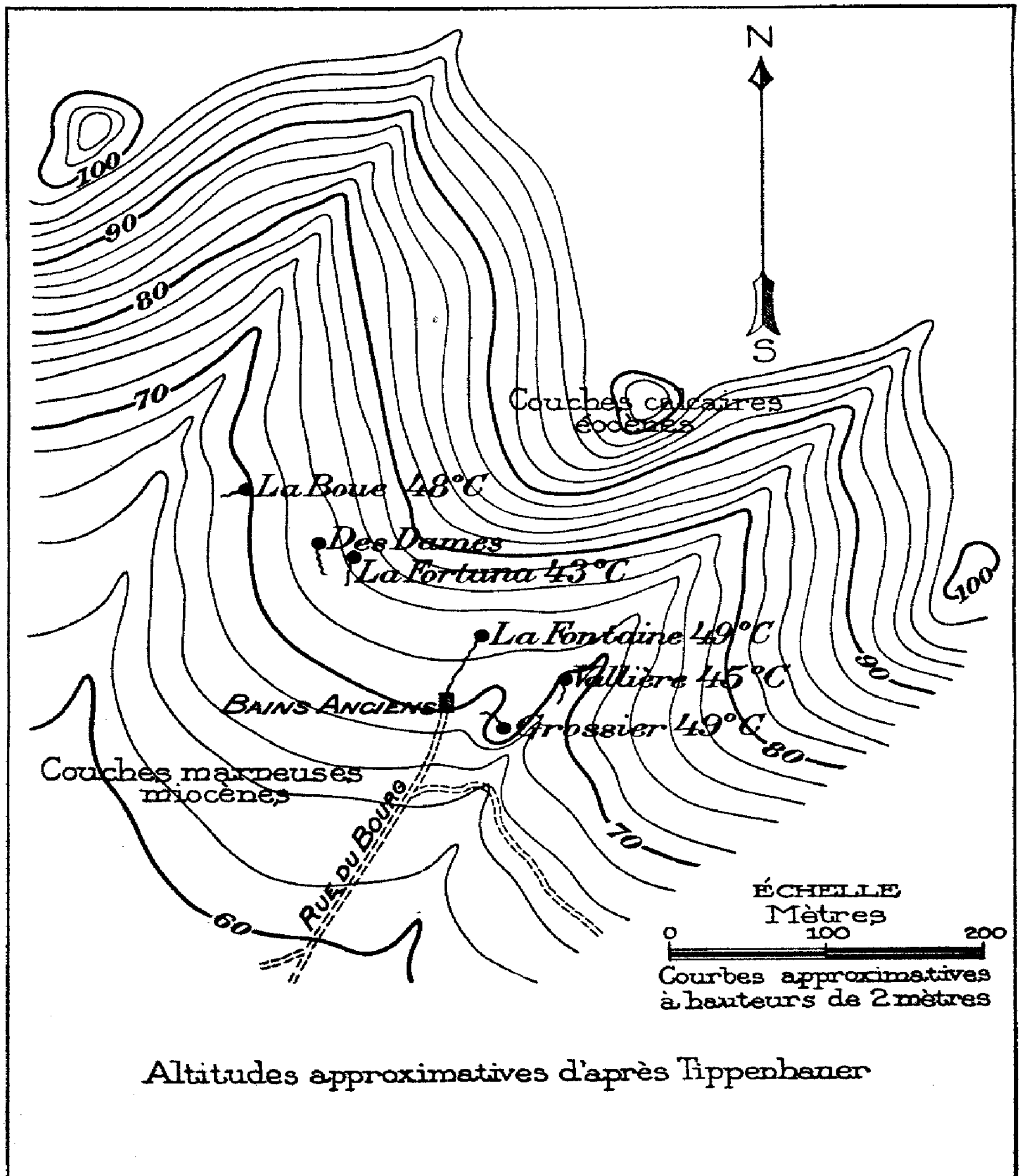

FIGURE 34.—Sketch map of the Sources Chaudes or Eaux Boynes.

Miocene age. On the other hand, the foothills are generally composed of limestone, which is exposed on the hill about 200 meters northeast of the springs. The limestone is hard, yellowish-white, and unfossiliferous, and generally resembles a facies of the upper Eocene limestone. The exposure is poor, however, and the bedding is indeterminable.

Only six springs can now be found, although it is said there were once seven. Some of the springs, particularly Des Dames and La Fortuna, appear to have been developed by excavating at seeps, and the lost spring is probably one of this type, which has become covered with débris and ceased to flow.

Source Grossier is 50 or 60 meters south of the east end of the main line of springs. It is on a distinct knoll that rises from a little ridge on the bank of a ravine about 3 meters in depth. Black soil full of plant humus forms the mound, which is covered by a thick tangle of trees, chiefly bayahonde. The water does not flow from the crest of the knoll but mainly from an outlet on its western side, away from the ravine. A little water also issues on the side nearest the ravine. The temperature in the little pool at the main outlet is 49° C. The flow probably does not exceed 10 liters a minute. No use is made of the water.

Source Vallière is in the bed of a shallow ravine and issues from a small basin in soft soil. It yields perhaps 20 liters a minute, and the water has a temperature of 45° C. It is not used much, if any.

Source la Fontaine rises from a bowl-shaped basin about half a meter in diameter in soft black soil. It is probably the largest of the springs, flowing perhaps 40 or 50 liters a minute. The temperature of the water in the outlet is 49° C. Bubbles of gas rise very slowly, at intervals of several seconds, with the water. There is little if any odor, however, and only a trace of H_2S could be found, so that it is apparently some other gas. The water flows through a canal for 50 or 60 meters to the ruins of eight masonry baths. It also feeds a fountain at the baths and a trough for watering stock. Virtually all the water for domestic use and drinking in the village is carried from this fountain. The water is clear, and although it has a slightly peculiar taste is neither unpleasant nor harmful, even when taken warm.

Source la Fortuna and Source des Dames are covered and issue through short aqueducts. They are used for laundry work and probably to a small extent for irrigation. No temperature reading could be obtained near the outlet of Des Dames, and that given for La Fortuna (43° C), was taken at a seep from a break in one side of the cover and is perhaps too low. The flow of each spring is probably less than that of La Fontaine.

Source la Boue evidently receives its name from a large pool of dirty water, several meters in diameter, into which it flows. Like some of the other springs, it issues from a very small basin in black earth. It yields only 15 to 20 liters a minute and has a temperature of 48° C. Bubbles of gas rise at intervals, as from La Fontaine. The spring is not used.

Of the seven springs listed by Moreau de St. Méry, only two, Vallière and Des Dames, bear the same names today, and indeed it is not certain that these names still apply to the springs that were originally so designated.

The remarkable alignment of all but one of the springs and their position along a break in the surface features and a geologic contact suggest very strongly that they issue from a fault zone. The alignment, moreover, is parallel to the trend of the regional structural features, which extend northwestward. No positive evidence of faulting was obtained, however.

The most reasonable assumptions regarding the source of the water and the manner in which it becomes heated appear to be: (1) that it is meteoric water heated (a) by descending to great depth, or (b) by coming in contact with buried masses of hot igneous rock; (2) that it is juvenile or magmatic water escaping from cooling masses of igneous magma. It is an open question whether or not it is possible to distinguish meteoric from magmatic waters. Clarke,[1] following Gautier,[2] says:

Vadose waters, or waters of infiltration, are characterized by fluctuations in composition, concentration, and rate of flow, depending upon local and variable conditions such as abundant rain or drought. They also contain as a rule carbonates of lime or magnesia, chlorides, and sulphates. Virgin or juvenile waters, on the contrary, are fairly constant in all essential particulars and carry sodium bicarbonate, alkali silicates, heavy metals, etc., as chief constituents, with chlorides or sulphates only as accessories, and practically no carbonates of the alkaline earths. The vadose waters, moreover, issue from faults having no relation to the metallic veins of the surrounding territory—a lack of relation which is conspicuous as regards juvenile springs.

The terms vadose and juvenile, used here, are equivalent to meteoric and magmatic, respectively, as used by the writer. The distinction then, between meteoric and magmatic water must be sought in chemical analysis, which may or may not be conclusive. The following is an analysis of water from La Fontaine.[3] This analysis is shown in Figure 32, page 548.

Analysis of water from the Sources Chaudes, or Eaux Boynes, collected at Source La Fontaine, August, 1921.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	403
Silica (SiO_2)	35
Iron (Fe)	.3
Calcium (Ca)	51
Magnesium (Mg)	21
Sodium and potassium (Na+K)	56
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	277
Sulphate radicle (SO_4)	68
Chloride radicle (Cl)	36
Nitrate radicle (NO_3)	Trace.
Hydrogen sulphide (H_2S)	Trace.

[1] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, p. 208, 1920.
[2] Gautier, Armande, Compt. Rend., vol. 150, p. 436, 1910.
[3] Bottle containing sample collected by the writer was broken in shipment and sample analyzed was collected by Père J. J. Joliveau of Terre-Neuve, in August, 1921.

Most of the analytical criteria listed by Clarke favor the conclusion that this water is meteoric. It contains predominantly carbonate of lime and magnesia in bicarbonate form, characteristic of the meteoric waters of the Republic, although the quantities of alkali chloride and sulphate are also relatively large. Silica is low, very little above the average for normal meteoric waters. Whether the springs exhibit seasonal fluctuations in volume or concentration is not known, although Moreau de St. Méry asserts that the current opinion was that they did not. Fluctuations in water that admittedly must circulate deep within the earth probably would be small and not synchronous with the observed seasonal influences.

The water may be heated partly by a buried mass of hot intrusive igneous rock. Small bodies of igneous rock, probably not later than Miocene, are intruded into the upper Eocene rocks of Terre-Neuve, not far away. If the water is heated solely by its descent into the interior it must circulate rather deeply. The warmest springs have a temperature of 49° C., about 22° higher than the mean annual temperature, which probably is nearly the same as that of Gonaïves, 27.1° C. As the assumed increment of heat is 1° C. for each 35 meters of depth[1] this water must come from a depth of at least 880 meters, and an allowance of greater depth must be made to compensate for its cooling on the way to the surface. It is doubtful whether masses of hot intrusive rocks lie near the surface of the earth, but it is not improbable that the increment of temperature with depth at this locality may exceed the normal and thus the required depth of circulation may be considerably lessened. On the other hand if hot igneous masses really lie near enough to the surface to heat the water it might quite as reasonably be supposed to be of magmatic origin. The presence of escaping gas, probably CO_2, would seem to favor the view that the water may be of this origin.

SOURCES CHAUDES DE LOS POZOS.[2]

The Sources Chaudes de Los Pozos are on the estate of Charles Zamor, in the Section Los Pozos, about 6 kilometers southeast of Cerca-la-Source. The springs are not much used for any purpose, although they are commonly supposed to have therapeutic value, especially in the treatment of skin diseases. At two of the five springs there are crude shelters for bathers, but there is no settlement at the springs.

The springs are at the southern border of the valley of Rivière l'Océan, and at the foot of a rounded escarpment in upper Oligocene limestone. Farther northwest, near Cerca-la-Source, this escarpment becomes high and precipitous. The valley is underlain by argillite of Cretaceous (?) age. Of the five springs in the group, four are arranged along a straight line trending about N. 70° W., at the northeast side of the trail from

[1] See p. 555.
[2] The descriptions and sketch map are based entirely upon information supplied by W. P. Woodring.

Cerca-la-Source to Los Pozos. One is southwest of the trail. The relative position of the springs and the chief surface features of the locality are shown in Figure 35.

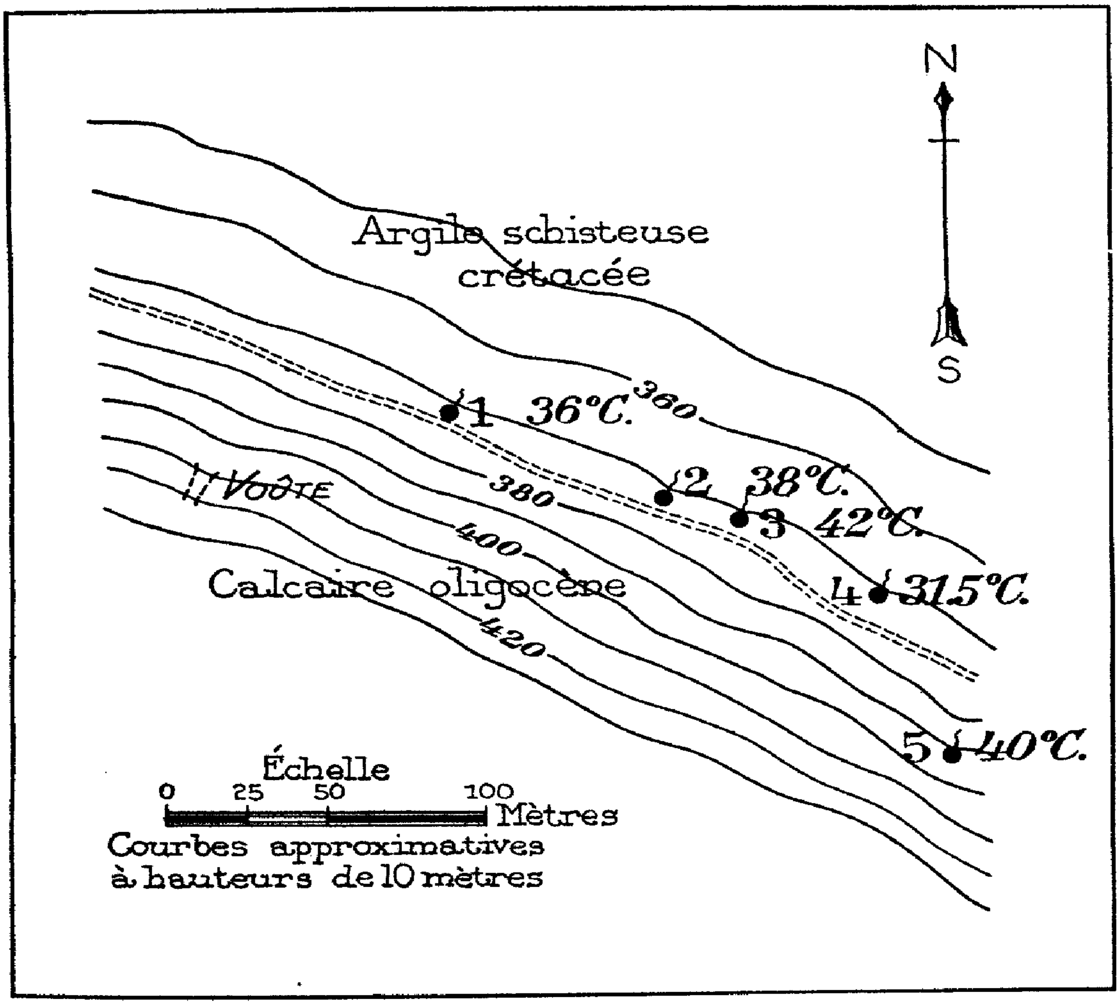

FIGURE 35.—Sketch map of the Sources Chaudes de Los Pozos.

1. Water seeps out along the trail and is conducted about 5 meters down the slope to a wooden tub, hollowed out from a log. There is a crude shelter over the tub. The temperature of the water was 36° C.
2. This is a small seep and is not cleaned out. Temperature 38° C.
3. This is the largest spring of the group; all the springs have a very small flow. It has also the highest temperature (42° C). The water issues from an opening between two large limestone boulders that have fallen from the slope above. There is a strong odor of hydrogen sulphide (H_2S), and sulphur is precipitated on the surface of the water. Bright green algae also grow in abundance. A crude shelter has been built for bathers.
4. A small spring, not cleaned out. Temperature 31.5° C.
5. This spring has been developed by digging a trench in the slope of the ridge. The opening is walled with rough limestone blocks. Temperature 40° C.

There is probably a fault at the base of the limestone escarpment that borders the long valley of Rivière l'Océan, and certainly there seems to be good reason to assume a fault at the springs, which are aligned parallel to the geologic contact and to the strike of the surrounding rocks. Presumably the water issues along the fault zone.

There seems to be less reason here than at Eaux Boynes to invoke the aid of heated igneous rock to account for the temperature of the water. The warmest spring has a temperature of 42° C., and the mean annual temperature of the air is probably about 25° C., a difference of 17° C. If the average rate of increase of temperature is 1° C. for each 35 meters the water should rise from a depth of about 600 meters, to which a little may be added to allow for some cooling on the way. This may not be an unreasonable depth for water to penetrate along fault lines, especially in regions that stand several hundred meters above sea level. The following is an analysis of the water from spring 3, Figure 35.

No. 3, Figure 35.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	1,214
Silica (SiO_2)	15
Iron (Fe)	.13
Calcium (Ca)	118
Magnesium (Mg)	33
Sodium and potassium (Na+K)	223
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	260
Sulphate radicle (SO_4)	62
Chloride radicle (Cl)	464
Nitrate radicle (NO_3)	Trace.
Hydrogen sulphide (H_2S)	Odor.
Date of collection	Mar. 14, 1921

A graphic representation of this analysis is given in Figures 32 and 33, pages 548-549.

The outstanding feature of the water is the higher proportion of alkali chloride compared to normal spring waters and the lower proportion of calcium bicarbonate. There is little reason to attribute the salinity of this spring to sea water, or even to connate water, and the relatively high chloride is probably more explainable by supposing that the water circulated through rocks containing an unusually large amount of chloride, perhaps some of the beds in the argillites, or by supposing that it is of magmatic origin. The hydrogen sulphide may easily be produced by chemical reactions similar to those suggested on page 557.

WARM SPRINGS OF THE SOUTHERN PENINSULA.

There are a number of warm springs in the interior of the Montagnes de la Hotte, in the western part of the Southern Peninsula. According to statements made by Moreau de St. Méry[1] and other writers there are warm springs at four places, three on the Bras-à-Gauche, the eastern fork of the Grande Rivière de Jérémie, and one along the Bras-à-Droit, the western fork of the same stream. Two of these places are near the headwaters of the Bras-à-Gauche, one on a tributary ravine about 600 meters west of that stream, and one in the bed of the Bras-à-Gauche about 600 meters downstream from this ravine. These springs are variously known as the Sources Chaudes or Eaux Thermals de La Cahouane or de Tiburon. According to Moreau de St. Méry their temperatures were 34° C. and 37.5° C. About two leagues downstream from these springs are the Sources Chaudes de Dame-Marie or de Jérémie, described below. Considerably farther west on the headwaters of the Bras-à-Droit, near the bed of its deep, narrow valley, are the Sources Chaudes des Irois, or de l'Anse d'Hainault. All the springs are supposed to have medicinal virtues and are considerably frequented by persons who live near by. The region is so rough and inaccessible, however, that it is very thinly inhabited and is seldom visited by strangers.

Sources Chaudes de Dame-Marie or de Jérémie.

The springs called Sources Chaudes de Dame-Marie or de Jérémie are on the Bras-à-Gauche (east fork) of the Grande Rivière de Jérémie, about 15 kilometers by trail above its junction with the Bras-à-Droit. The trail follows the river at places but not all the way. It is very rough and rocky and difficult for horseback travel. At the springs there are about half a dozen little thatch shelters occupied by the transient visitors, but there are no permanent habitations.

The valley of the Bras-à-Gauche is deep and narrow, and is incised directly across the mountain ranges. In the vicinity of the springs the valley is narrow and V-shaped, but not so deep as it is farther north, the mountains being probably not more than 500 or 600 meters higher than the river. The aneroid barometer read 190 meters above sea level in the valley, near the springs, but the atmospheric conditions were very unstable and the instrument had not been set for two days, so that this reading is probably not very accurate.

There are two springs about 50 meters apart on the southwest bank of the stream, which flows northwestward. The most southerly spring is about 4 meters above the river bed and the other only about 1.5 meters above it. The slopes above and behind the springs are very steep. The outlet of the lower spring is best exposed. It issues from a small fracture in basalt, an inch or two in width. The other also doubtless issues from a fracture but its outlet is obscured by débris. The water bubbles up from each spring with considerable force, but no gas bubbles were seen, and there is only a faint suggestion of an odor. The temperature of the water is probably 35° or 40° C., but no thermometer was available. One can

[1] Op. cit., vol. 2, pp. 759-760.

hold the hand in either spring indefinitely without discomfort. There are no bathing facilities except a sort of earthen-walled and rock-floored basin that has been scooped out at the lower spring. A quaggy area of mud below the other spring is a favorite place for mud baths. The taste of the water is not unpleasant.

Aside from other considerations the temperature of this water is not high enough to necessitate the assumption that it is either of magmatic origin or that it has been heated by buried intrusives. All its heat might easily result from circulation along deep fractures, joints, or fault zones. The analysis shows, however, that the water is decidedly different from that of the other warm springs and in fact from that of all the other waters of the Republic for which analyses are available.

Analysis of water from the Sources Chaudes de Dame-Marie or de Jérémie.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	515
Silica (SiO_2)	68
Iron (Fe)	.07
Calcium (Ca)	26
Magnesium (Mg)	1.4
Sodium and potassium (Na+K)	135
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	93
Sulphate radicle (SO_4)	117
Chloride radicle (Cl)	121
Nitrate radicle (NO_3)	.42
Date of collection	Nov. 16, 1920

This analysis is represented graphically in Figure 32, page 548. In view of its probable circulation at considerable depth the water is not highly mineralized. The alkali sulphate and chloride are relatively very high, particularly the sulphate. Calcium and magnesium bicarbonates are very low compared to those found in the normal waters of the Republic. Silica is unusually high. The last two features might be interpreted as favoring a magmatic origin for the water. The differences between this water and other mineral waters of the Republic may arise chiefly from its circulation entirely through volcanic rocks, but the occurrence of many warm springs in this area, which is an area of volcanic rocks, might strongly suggest that this water is of magmatic origin.

PUBLIC WATER SUPPLIES.

PORT-AU-PRINCE.

Purpose of Investigation.

The water supply of Port-au-Prince has been for many years unsatisfactory and inadequate for the needs of its growing population. Owing to long-continued dry weather the shortage of water in 1919 and 1920