the limestone lie metamorphic rocks, which are exposed in some of the valleys, particularly near La Vallée and along the coast. Springs issue along the contact of the limestone with the metamorphic rocks at the head of the valley north of La Vallée and give rise to a short stream. The largest spring seen is about 2 kilometers north-northwest of La Vallée at an altitude of 170 meters above level, where a concrete basin to impound the water was constructed by the company that proposed to exploit the forests of the island. Similar but smaller springs were seen farther east along the south coast, between La Vallée and Pointe des Oiseaux.

Moreau de St. Méry,[1] with his usual care, gives full descriptions of all the known sources of fresh water on the island. On the south coast there are spring-fed streams similar to those of La Vallée at Cayonne, about 2,000 meters west of Basse Terre and just west of Pointe des Oiseaux, as well as two smaller ones between Pointe des Oiseaux and La Vallée. There is said to be a stream on either side of Pointe Tête de Chien on the north coast. Both streams flow for only short distances in deep gorges, and disappear before reaching the sea. On the south coast at Pointe Masson, about 2,400 meters east of Basse Terre, a spring issues from a steep sea cliff. Its outlet is covered at high tide but exposed at low tide, when fresh water is obtainable.

Well water probably could be obtained by shallow wells at places in the ravines where the metamorphic rocks are exposed. There is not much hope of obtaining water easily in the interior of the island.

QUALITY OF WATER.

GENERAL FEATURES.

Most of the waters of the Republic are of good quality for domestic use when not polluted by sewage or waste. They are also generally good for irrigation and for many industrial uses. There are, however, notable exceptions to this general rule, particularly for the water from a few salt lakes and certain springs. As the rocks of a large part of the Republic are calcareous the characteristic feature of most of its waters is hardness, chiefly in the form of calcium bicarbonate. Twenty samples of water from the Republic were recently analyzed in the United States Geological Survey. These samples probably represent most of the available types.

STREAMS, FRESH LAKES, AND COMMON SPRINGS.

The following analyses cover the waters of two large rivers, the largest fresh-water lake, and five springs of the more common type. They represent by far the greater part of the water in use.

The total solids in all these waters are moderately high. The main difference between the spring waters and the surface waters is that the spring waters are generally a little more highly mineralized. Hardness

[1] Op. cit., vol. 1, pp. 733-739.

Analyses of waters from streams, fresh lakes, and common springs.

[C. S. Howard, analyst, except for Port-au-Prince supply.]
[Parts per million.]

	R. Cul-de-Sac at Bassin Général.	R. Artibonite at Pont Sondé.	Étang de Miragoâne at Pont de Miragoâne.	Gonaïves supply, home of B. F. Knighton.	Cap-Haïtien supply, Justinien Reservoir.	Port-au-Prince.		Source Maneville.
						Source Turgeau.	Source Plaisance.	
Total dissolved solids	180	218	253	225	271	278	282	370
Silica (SiO_2)	34	37	34	22	44	15	21	119
Iron (Fe)	.11	.09	.19	.15	.13	.13	.08	.14
Calcium (Ca)	23	53	51	58	39	80	92	38
Magnesium (Mg)	7.2	7.2	11	2.9	19	6.4	3.7	21
Sodium and potassium (Na+K)	26	7.6	10	18	31	[a]8.6	[a]5.4	37
Carbonate radicle (CO_3)	9.6	11	.0	.0	12	.0	.0	19
Bicarbonate radicle (HCO_3)	127	176	185	188	214	280	287	209
Sulphate radicle (SO_4)	8.6	8.4	10	5.3	10	5.5	4.9	13
Chloride radicle (Cl)	4.0	5.0	24	19	22	6.5	6.2	34
Nitrate radicle (NO_3)	.50	.38	.58	3.8	.66	Trace	9.0	Trace
Total hardness as $CaCO_3$[a]	87	162	173	157	175	226	245	181
Date of collection	Apr. 12, 1921	Dec. 8, 1920	Apr. 10, 1921	Mar. 30, 1921	Feb. 21, 1921	Jan. 31, 1919	Jan. 31, 1919	Apr. 3, 1921

[a] Calculated.

in the form of calcium bicarbonate is preponderant. The remaining mineral content consists chiefly of silica and alkali chloride and sulphate, all of which are rather low except in the Source Maneville, which, from causes not determined, is somewhat divergent from the type. All the waters are pleasant to the taste and suitable for domestic use or for irrigation. They readily form incrustations of precipitated $CaCO_3$ in pipes and conduits and in steam boilers, and so give some trouble in city supplies and in certain industrial operations. The treatment of water for the removal of hardness is considered on pages 575-576.

WELLS.

Four samples of water from comparatively deep wells, three of them belonging to the Haytian-American Sugar Co. on the Cul-de-Sac Plain, were analyzed and the results are given in the following table.

Analyses of well waters.

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

	Group of drilled wells at La Morinière. (See p. 521.)	Group of drilled wells at Dessources. (See p. 523.)	Drilled well at Vaudreuil. (See p. 524.)	Well of Railroad Co. at Cap-Haïtien. (See p. 588.)
Total dissolved solids	468	423	1027	875
Silica (SiO_2)	57	69	102	41
Iron (Fe)	.07	.07	.13	.08
Calcium (Ca)	62	56	14	22
Magnesium (Mg)	27	32	26	31
Sodium and Potassium (Na+K)	60	41	325	279
Carbonate radicle (CO_3)	6.0	14	58	26
Bicarbonate radicle (HCO_3)	339	292	220	531
Sulphate radicle (SO_4)	39	54	123	13
Chloride radicle (Cl)	47	32	328	175
Nitrate radicle (NO_3)	1.5	1.3	Trace	.57
Total hardness as $CaCO_3$ (calculated)	266	272	142	182
Date of collection	Oct. 15, 1920	Oct. 13, 1920	Apr. 11, 1921	Feb. 23, 1921

The first two analyses represent normal ground water of the Cul-de-Sac Plain. They do not differ greatly from the waters of streams and springs described above except that they are a little more highly mineralized. Bicarbonates of calcium and magnesium, producing hardness, are the chief features of these waters, and probably would be the chief features of most well waters, deep or shallow, in the Republic, except those found in areas of igneous rock or at places near the shore line.

The last two waters are very different. The total solids are much higher—high enough to impart a slight taste to the water—although both waters are regarded as good for drinking. The predominant salts are alkali chlorides and sulphates, and the water from the well at Cap-Haïtien apparently contains considerable alkali carbonate. Calcium is quite low and magnesium is in excess of calcium, a relation very unusual in normal ground waters and suggestive of sea water. Both these wells are near the sea and the high salinity is probably due to a small amount of sea water. In the well at Vaudreuil this sea water may be connate water that escapes from buried marine beds in which it was included, rather than sea water that has entered by infiltration, for the shore is a kilometer or more away, but it might also come by diffusion from underlying salt water, which may extend back a considerable distance beneath coasts.[1] In the well at Cap-Haïtien the presence of marine salts is probably due to direct infiltration or diffusion, as the well is on a sandy beach only a few meters from the sea. Ground waters of this type, contaminated by sea water, are probably not uncommon in a narrow zone along the whole coast.

SALT LAKES.

The largest saline lake is Étang Saumâtre, at the eastern border of the Cul-de-Sac Plain. Besides this lake there are a few small salt lakes of the desert playa type. The only one for which analysis is available is Étang Bois-Neuf, between St.-Marc and Mont-Rouis. The salinity of Étang Saumâtre closely resembles that of sea water, and for purposes of comparison an average analysis of sea water is given. An analysis of water from Lago de Enriquillo, Dominican Republic, which is of the same type, is also given.

Analyses of water from salt lakes and comparison with sea water and with water of Lago de Enriquillo, Dominican Republic.

[Parts per million.]

	Étang Bois-Neuf.[a]	Étang Saumâtre.[a] [b]	Sea water.[c]	Lago de Enriquillo Dom. Rep.[d]
Total dissolved solids	29,464	7,432	35,000	48,902
Silica (SiO_2)	48	26	....	....
Iron (Fe)	.07	.48	....	....
Calcium (Ca)	446	94	419	1,649
Magnesium (Mg)	589	279	1,304	378
Sodium (Na)	8,349	2,159 (Na + K)	10,707	15,973
Potassium (K)	80		387	503
Carbonate radicle (CO_3)	40	46	72	.0
Bicarbonate radicle (HCO_3)	98	161	....	512
Sulphate radicle (SO_4)	14,580	711	2,693	3,833
Chloride radicle (Cl)	4,582	3,660	19,352	25,547
Nitrate radicle (NO_3)	Trace	Trace	....	....
Date of collection	Dec. 8, 1920	Apr. 3, 1921	1873-1876	May 29, 1919

[a] C. S. Howard, analyst.
[b] Collected about 500 meters offshore near Maneville.
[c] From U. S. Geological Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.
[d] A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921. Analyzed by A. T. Geiger.

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

The water of Étang Bois-Neuf is of a type unusual in the Republic. Although nearly as concentrated as sea-water, it differs from it greatly, especially in possessing much higher sulphate and much lower chloride. Apparently its mineralization is due to concentration by evaporation. The high sulphate may be due to the presence of gypsum in the surrounding Miocene rocks (see p. 512), but if so, the calcium salt has in some way been converted into an alkali sulphate.

The water of Étang Saumâtre has about one-fifth the concentration of sea water, in striking contrast to that of Lago de Enriquillo, which is 40 per cent more concentrated than sea water. The resemblance of type is better illustrated by the following comparison of mineral constituents in terms of percentage of their sum.

Comparative percentage composition of water of Étang Saumâtre, water of Lago de Enriquillo, and average sea water.

	Étang Saumâtre.	Lago de Enriquillo.[a]	Average sea water.[b]
Calcium (Ca)	1.3	3.4	1.2
Magnesium (Mg)	4.0	.8	3.7
Sodium and potassium (Na+K)	30.6	34.2	31.8
Carbonate radicle (CO_3)	1.8	.5	.2
Sulphate radicle (SO_4)	10.1	8.0	7.7
Chloride radicle (Cl)	51.9	53.1	55.4
Total	99.7	100.0	100.0

[a] From A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921.
[b] From Clarke, F. W., Data of Geochemistry, U. S. Geol. Survey Bull. 695, p. 123, 1920.

Both these waters closely resemble sea water, although they differ from it in some details. The water of Lago de Enriquillo corresponds with sea water more closely in respect to sodium and potassium, chloride and sulphate, but that of Étang Saumâtre corresponds much more closely with sea water in respect to calcium and magnesium.

During early Quaternary time the sea occupied all the trough from Port-au-Prince Bay to Neiba Bay, separating the island of Haiti into two major parts and covering the region that is now occupied by both salt lakes. The salt water of these lakes may be residual sea water, or it may be derived from residual sea water that was held in the depressions when the land emerged. Condit and Ross[1] suggest this explanation for the salinity of Lago de Enriquillo and cite evidence to show that the shrinking of that lake in historical times by evaporation has been sufficient to account for much of its concentration. Dilution rather than concentration would have to be inferred to account for the composition of

[1] Condit, D. D., and Ross, C. P., in A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921.

Étang Saumâtre. Dilution might have actually occurred either by flooding until the lake overflowed or by an increase in the size of the basin after its emergence, as, for instance, by the building up of the alluvial barrier in the Cul-de-Sac Plain, to the west. The concentration of Étang Saumâtre could hardly have been diminished by the precipitation of material, for the ratio of mineral constituents could not have been preserved in that process. Again, it must be observed that high salinity in both lakes could probably be due to the leaching of salt beds in the rocks about their borders. Such beds of salt crop out along the southern border of Lago de Enriquillo and may occur in the vicinity of Étang Saumâtre. Finally, it is well known that many interior lakes have a mineral content which closely resembles that of sea water, although there is no possibility that they have been recently connected with the sea.[1] On the whole, it seems best not to render a verdict regarding this interesting problem until better data on the surface features and geologic history of the region are available.

MINERAL SPRINGS.

Several springs of the Republic yield water that is divergent from the more common types either in mineral content or in origin. Those for which analyses are available are considered under individual descriptions of the springs.

GRAPHIC COMPARISONS OF ANALYSES.

The relative concentration and composition of the mineral constituents in waters may be shown more effectively by charts than by mere comparisons of figures. A number of charts covering all the types of water previously described are given in Figures 32 and 33.

In constructing these charts the mineral constituents are separated into bases and acid radicles. The principal bases are calcium (Ca), Magnesium (Mg), sodium (Na), and potassium (K). Iron (Fe) and aluminum (Al) may occasionally act as bases, but are commonly regarded as present in colloidal form. Moreover, the quantity is usually insignificant and they are ignored in the charts. The principal acid radicles are carbonate (CO_3) and bicarbonate (HCO_3), sulphate (SO_4) and chloride (Cl). Silica, which may sometimes act as an acid radicle, is generally present in water in colloidal form. Its quantity, however, may be large, and it is accordingly plotted separately, as an inert constituent.

The values plotted in Figures 32 and 33 are reacting values, which are obtained by the following formula:

$$\text{Reacting value} = \frac{\text{Parts per million} \times \text{Valence}}{\text{Atomic weight}}$$

[1] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, pp. 152-174, Washington, 1920.

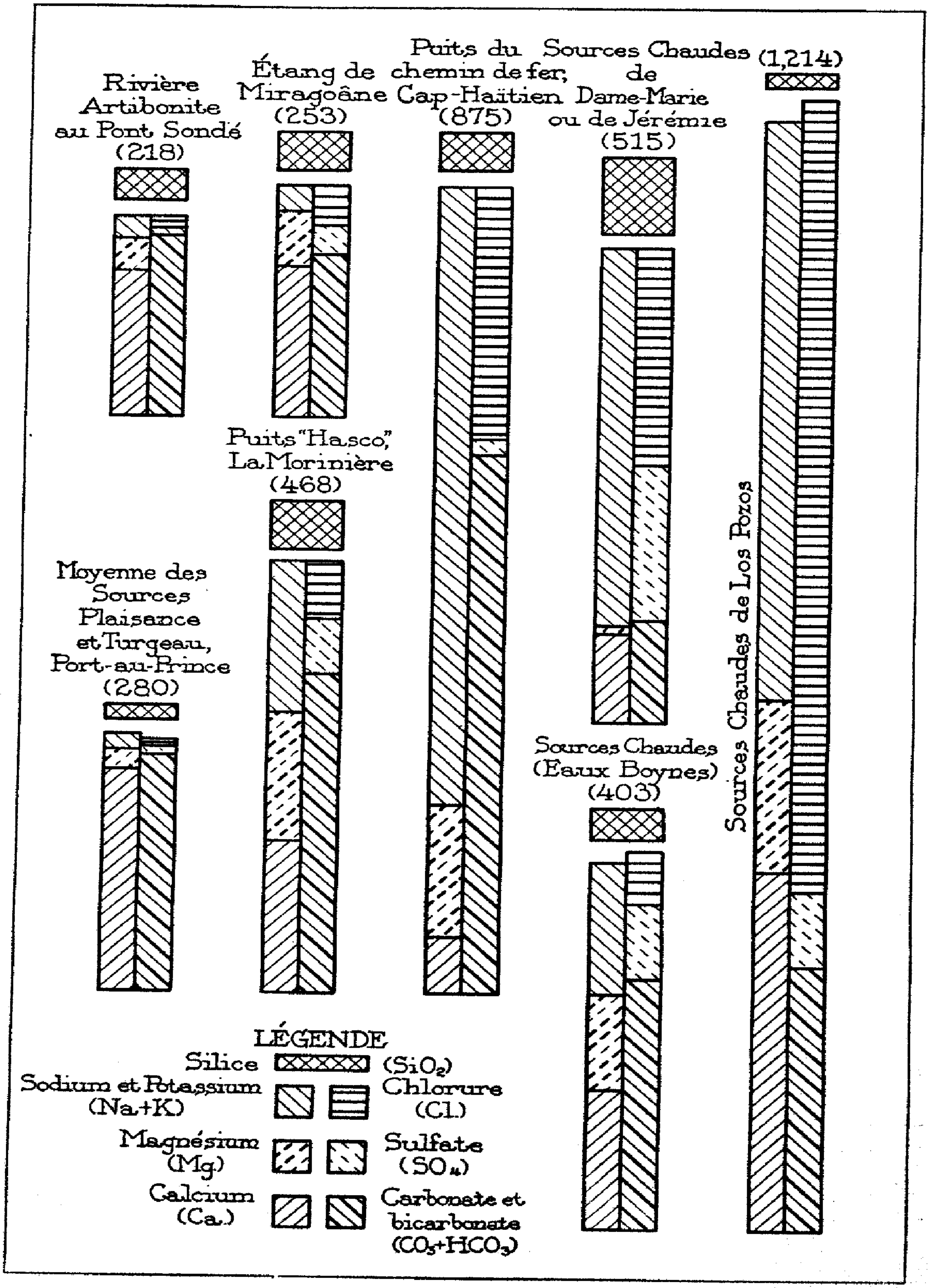

FIGURE 32.—Graphic representation of analyses of some waters of the Republic.

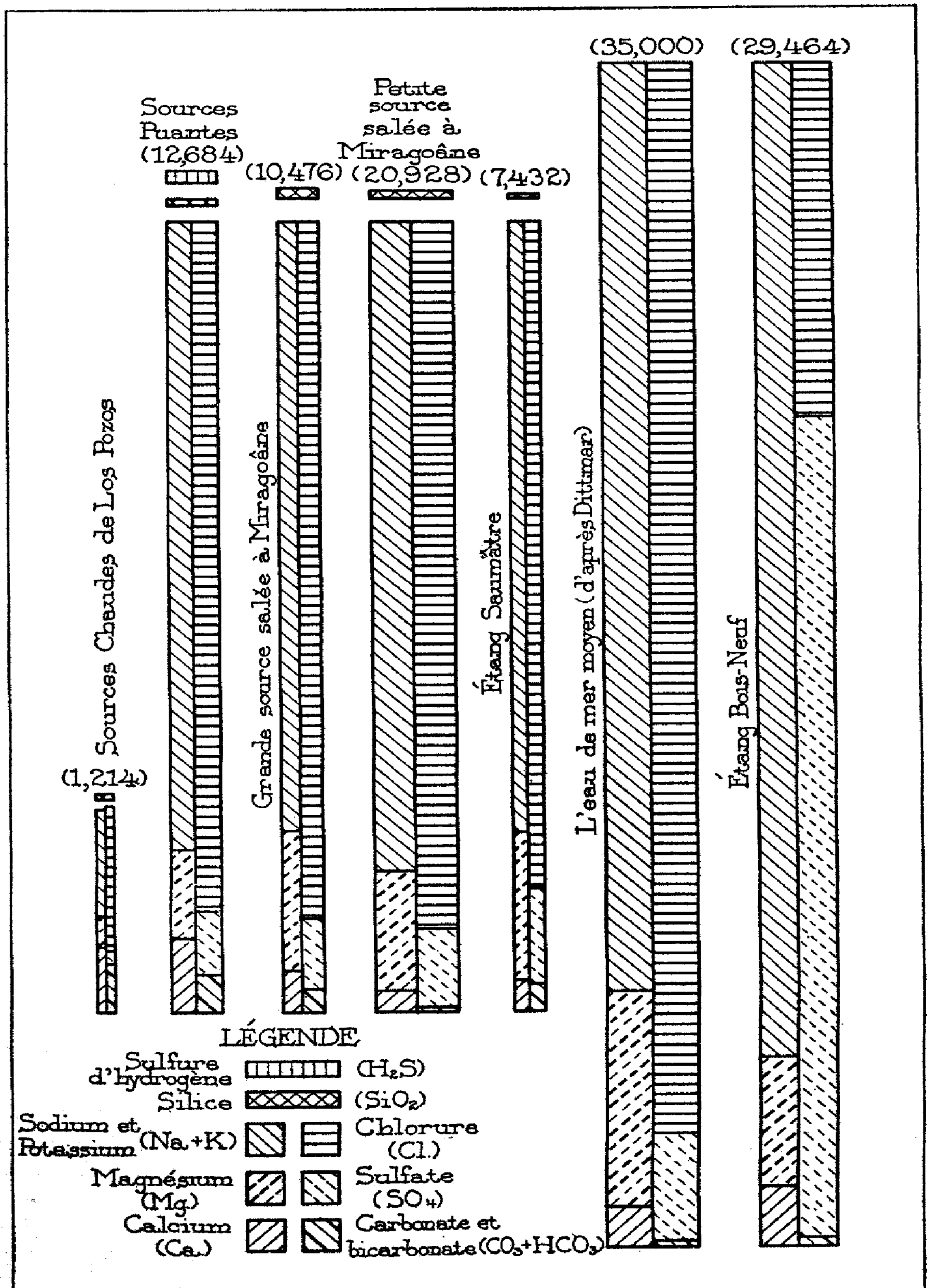

FIGURE 33.—Graphic representation of analyses of some waters of the Republic.

Scale greatly reduced as compared to Figure 32; for relative scale compare representation of the Sources Chaudes de los Pozos in both figures.

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.