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# The water bore of Oranjestad 1942-1943, and its implication as to the geology and geohydrology of the island of Aruba *(Netherlands West Indies)*

I and II

BY

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GEOLOGY

# THE WATER BORE OF ORANJESTAD 1942—1943, AND ITS IMPLICATION AS TO THE GEOLOGY AND GEOHYDROLOGY OF THE ISLAND OF ARUBA *(Netherlands West Indies)* I


BY

J. H. WESTERMANN



(Communicated by Prof. G. H. R. VON KOENIGSWALD at the meeting of Jan. 27, 1951)



*Summary*

In 1942—1943 a water test well was drilled by the Government of Curaçao within the limits of Aruba's capital Oranjestad, following the "discovery" of an underground fresh water flow by two French friars operating a detector or divining rod. A depth of 927′ was reached without encountering the predicted fresh water. However, abundant salt water under pressure was struck in a sand bed at 830′. Its salt concentration proved to be twice that of sea water. It may be assumed that rain water entering the outcrop area of weathered diorite and diorite detritus further inland, percolates down through a dipping sand bed, locked in by impervious clay layers, thus constituting an artesian water system. The high salinity of this water is tentatively explained by a process of solution of salts adsorbed in the sands and clays during their deposition in a marine or coastal environment.

Practically all sediments penetrated by the bore carry salt water. A survey of ground water localities all over the island reveals a generally high salinity, coupled with a limited supply, offering unfavourable conditions for intensive ground water production.

The test well has considerably increased our knowledge of the Tertiary and Quaternary formations of the island. Clayey and sandy deposits of marine origin were encountered, so far unknown in Aruba. Quaternary coral limestones, totalling some 300 feet, overlie unconformably foraminiferal clays and sands of (presumably Lower to Middle) Miocene age, the latter series reaching down to 830′. From 830′ to 930′ a probably non-marine mica sand, carrying the above-mentioned artesian salt water, was penetrated. A Schlumberger survey, measuring electrical resistivities in rocks, has determined the depth of the basement under the drill-hole location as approximately 1610′. Most likely this basement is of a dioritic character.

Further drilling unto the basement would probably meet with more water-bearing sand beds. The prospects are that this water will be likewise salt water.

*General*

On the 1st September of the year 1941 the people of Curaçao and Aruba were greatly stirred by the newspaper announcement that two French friars from Venezuela, Frères APPOLLINAIRE and JUAN, predicted the occurrence of an underground fresh water flow in the island of Aruba. Their detection was based on a research carried out with divining rod and pendulum. According to the friars the water flow would be in easy drilling reach, just below the capital Oranjestad [1]). It was believed that this fresh water would originate in the Sierra Nevada de Santa Marta of Colombia, moving subsequently below the Caribbean Sea and rising somewhat after reaching Aruba. Its further course should be sought in the direction of Curaçao and beyond.

In view of the great need of fresh water the Government of Curaçao undertook to drill a hole at a location opposite the Roman Catholic church of Oranjestad marked carefully by the friars (550 m. NE of the coast; altitude 4.5 m). The drilling was carried out by an American contractor, with a cable tool drilling outfit, and lasted from June 29th until September 11th, 1942.

Abundant salt water was encountered below 666′ and below 830′. On September 11th, after reaching a depth of 937′ drilling work was interrupted owing to shortage of equipment and pending the arrival of new material. It was resumed on 18th January 1943. Because of technical set-backs and taking into account geological advice, it was finally decided to abandon the project (17th April 1943). There had been practically no progress since the depth of 937′ was reached.

*Outline of the geology of Aruba, with particular reference to the subsoil of Oranjestad as revealed by the water bore and the electrical sounding survey.*

The oldest rocks of Aruba are found in the centre; they consist of a diabase and diabase tuff series, presumably of Cretaceous age. Orogenic processes and the simultaneous intrusion of a quartz-dioritic magma — occurring in older Tertiary time — have metamorphosed this series to a large extent. The intruding magma differentiated into a variety of igneous rocks of which in particular quartz-diorite occupies large areas of the present island surface.

These two older formations are covered unconformably by limestone of Tertiary and Quaternary age. The older beds of this limestone show

[1]) According to the friars there would be two fresh water flows below the capital, one to the Northwest of the Roman Catholic church at a depth of 902 feet (water displacement would amount to 45 cubic meters per minute), and a second flow in the neighbourhood of Companasji, not far from the R.C. school, at a depth of 738 feet (water displacement 53 cubic meters per minute). The newspaper Amigoe di Curaçao of 1st April 1942, from which the above figures are quoted, does not mention the dimensions of the transverse section of the supposed water "channels".

distinct dipping and are remnants of a slightly arched limestone cap which in earlier times appears to have covered a great part of the island. Younger limestone beds at the periphery of the previously existing cap are present as horizontal terraces, bordering on the sea. The facies of the limestone is predominantly coralline, *Lithothamnium* being widespread.

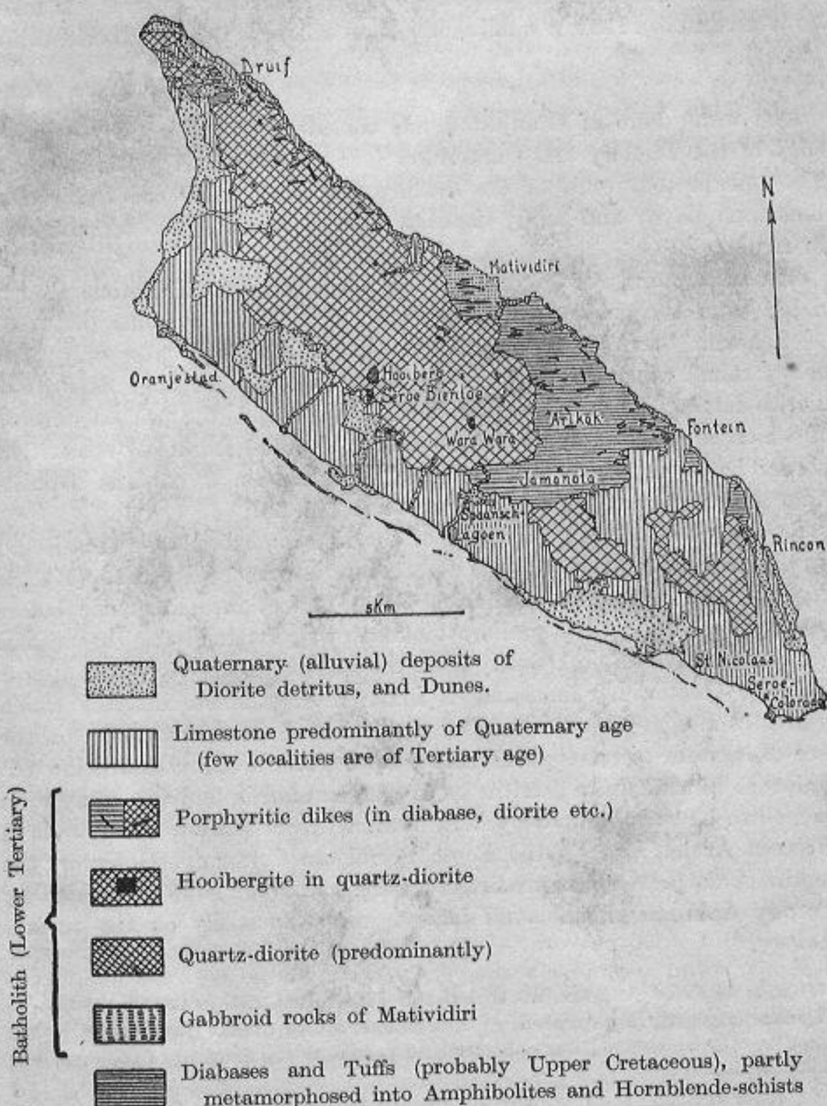


Fig. 1. Geological sketch-map of Aruba.

Large deposits of diorite detritus occur along the South and West coast. Their deposition was begun as soon as the magmatic rock series reached the erosion level, and is still in force. Hence, this material is found both underlying and overlying the limestone beds; the Quaternary limestone itself also contains a fair amount of diorite minerals, indicating that only part of the island was submerged during that period.

For a full description of the geology and petrography reference is made to WESTERMANN 1932. A small sketch-map will serve for general orientation (fig. 1).

The water bore of Oranjestad has considerably increased our knowledge of the Tertiary and Quaternary formations in that particular area. The unexpected result of the drilling was that under the Quaternary limestone clayey and sandy deposits were encountered, so far unknown in Aruba.

The surroundings of the capital show a low-lying, flat limestone plateau rising from the coast to some 65 feet. The "rooi" systems (a "rooi" — Spanish: "arroyo" — is a water course carrying water only after heavy rains) which cut through the limestone, contain large deposits of diorite detritus derived from the dioritic hinterland, the nearest outcrop of which is situated some 2 kilometers ($1\frac{1}{4}$ mile) from the coast. The border between diorite and the younger limestone & detritus deposits runs somewhat parallel to the shore line (fig. 2).

Previous to 1942 the thickness of the limestone bed near Oranjestad was unknown. In the extreme Southeastern corner of Aruba (Mangle Corá) a bore had penetrated from 50 to 70 feet into limestone before reaching diorite, and a similar thickness was assumed for the coastal plain around the capital. Solely from the surface geology it would appear that the Quaternary limestone is underlain by diorite detritus which gradually merges into diorite. The prediction of the friars would, on the face of it, seem to relate to normal ground water accumulated below the limestone in the diorite detritus or weathered diorite, and this conception seemed to be corroborated by data obtained from shallow water wells in Western Aruba, dug by the Eagle Petroleum Company. However, the depths of the water flow predicted by the friars (902′, 738′) exceeded by far any estimate which could have been based solely on the surface geology.

Thanks to Frère ANTOON, in Aruba, and Frater REALINO in Curaçao — whose diligence is greatly appreciated — a complete set of "bailer" samples [2]) of the water bore, down to 930′, was collected and placed at the disposal of the author of

[2]) After crushing the rock with the drilling bit (cable tool drilling), the crushed material is pulled up by means of a "bailer", a metal cylinder fitted with a valve. It is obvious that such "bailer" samples could be easily contaminated with rock material derived from beds slightly higher in the drilling hole and not yet cased off by casing.

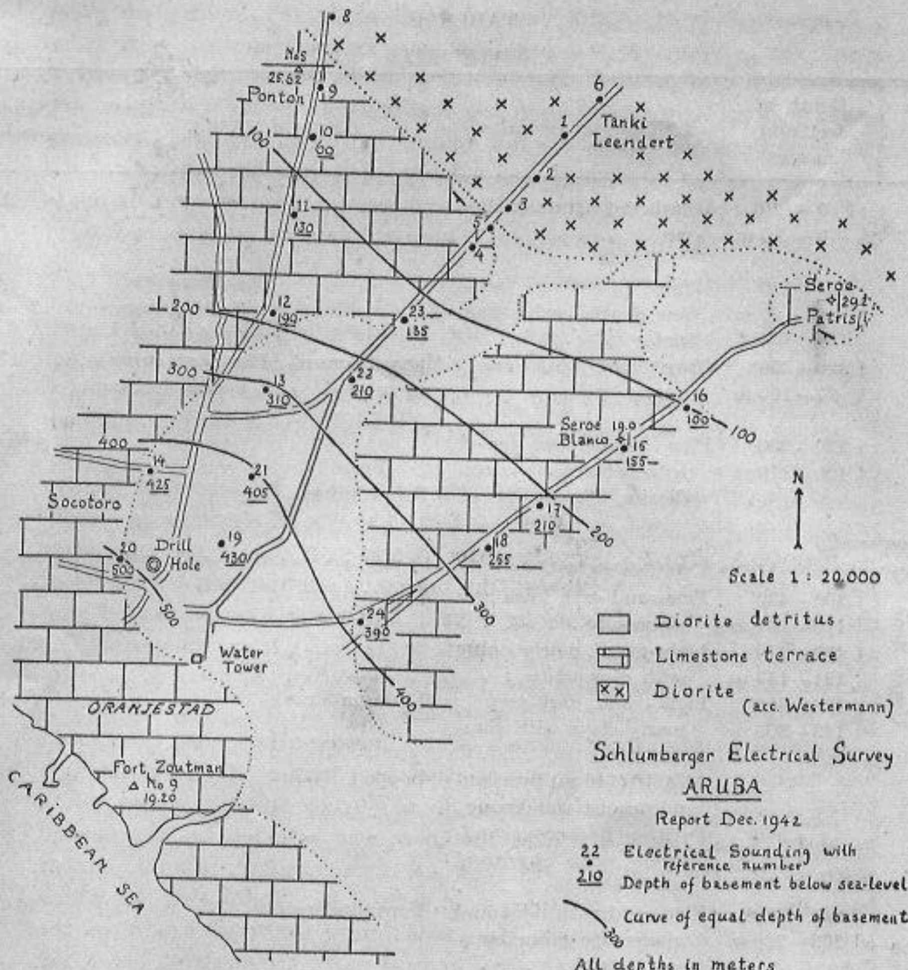


Fig. 2

this article, at that time working with the Caribbean Petroleum Company at Maracaibo, Venezuela. The geological investigation of the samples was carried out with the approval of the said Company and of the Government of Curaçao. A preliminary article was published in the Weekly Periodical "Curaçao" (WESTERMANN 1943).

In 1949—1950 the foraminifera were investigated by C. W. DROOGER (Lit), at the Mineralogical-Geological Institute of the University of Utrecht, Holland.

Fairly complete sample collections of the water bore are being kept at three places: *a*) St. Dominicus College at Oranjestad, Aruba, under the care of Frère ANTOON; *b*) St. Thomas College at Willemstad, Curaçao, under the care of Frater REALINO; *c*) Mineralogical-Geological Institute of the University of Utrecht, Holland.

The geological and palaeontological evidence of the 49 "bailer" samples is shown in table 1. Data of the driller's report have been added (H. SMITH).

From the stratigraphical column it is evident that below the subrecent

TABLE 1

Stratigraphy

| | Depth in feet and meters | Lithological remarks | Faunal remarks | | Sample numbers |
|---|---|---|---|---|---|
| Holocene | 0–20′ / 0–6 m | Weathered debris of diorite . . . . . . . . . | | | 1 |
| Holocene | 20–320′ / 6–97 m | White limestones with few quartz grains (salt water) . . . . . . . | | Coral remains, *Lithothamnium*, *Amphistegina* | 2–16 |
| Pleistocene | 320–330′ / 97–100 m | Grey marl with few quartz grains . . . . | Many Foraminifera and other fossils | *Planulina ariminensis*, dominant species | 17 |
| Pleistocene | 330–390′ / 100–119 m | Fine calcareous gravel with pebbles of quartz, diorite, etc. . . . . . | Few Foraminifera | | 18–20 |
| *Unconformity* | | | | | |
| Miocene, Upper Zone | 390–430′ / 119–131 m | Fine sand with mica and glauconite . . . . . . | Foraminifera | | 21–22 |
| Miocene, Upper Zone | 430–470′ / 131–143 m | Light-grey marly clay with glauconite . . . | Many Foraminifera | | 23–24 |
| Miocene, Upper Zone | 470–666′ / 143–203 m | Light- and dark-grey marly clays with glauconite . . . . . . . | | | 25–34 |
| Miocene | | At 480′ (146 m) pyritised micaceous sandstone. | | | 26 |
| Miocene | 666′ / 203 m | Pyritised micaceous sandstone with pyritised wood remains . . . . | | | 35 |
| Miocene, Lower Zone | 666–720′ / 203–220 m | Fine sand with mica and glauconite (abundant salt water) . . . . . | Foraminifera | | 36–38 |
| Miocene, Lower Zone | 720–830′ / 220–253 m | Light- and dark-grey marly clays with glauconite . . . . . . . | Many Foraminifera | | 39–44 |
| Miocene, Lower Zone | 800–830′ / 244–253 m | Semi-carbonized wood remains . . . . . . . | | Shallow? water fauna | 44 |
| ? | 830–930′ / 253–284 m | Fine sand rich in mica; small lignitic fragments (abundant salt water under high pressure) | No Foraminifera or other fossils | | 45–49 |

detritus deposits of Oranjestad, measuring some 20 feet, the bore has penetrated into 300 feet of coralline *Lithothamnium* limestone and has subsequently struck beds of marl and conglomeratic limestone (calcareous gravel). At 390′ a true marine series is reached, beginning with fine grained foraminiferal sands rich in mica and glauconite. From 430′ down to 830′ this series consists of marine clays, with marine sands interbedded. The latter formation rests on a mica sand of presumably non-marine character: 830′—930′.

Although there is no strict palaeontological evidence it may be assumed that the upper diorite detritus and the underlying limestone series belong to the Quaternary. No distinction, however, can be made between Holocene and Pleistocene. It should be noted, that we have no data on dips, and that, as a consequence, the stratigraphical thickness remains uncertain for the time being. Most probably the dip does not exceed 30° in the lower limestones and may be nearly horizontal in the higher beds.

For the interval between 390′ and 830′, consisting of typical foraminiferal sands and clays, DROOGER (Lit. in press) — after careful correlation with similar strata in Northern South-America and the Caribbean area — has determined a Miocene age; the faunal evidence points with about equal strength to both Lower and Middle Miocene, whereas no conclusion can be drawn as to the presence of Upper Miocene. Attention is also drawn to the determination of the Ostracod *Cytheromorpha minuta* from the same formation, by VAN DEN BOLD (1946); this species was found earlier in the Miocene of Cuba.

The Miocene sands are largely composed of terrigenous material derived in all likelihood from the diorite massif to the Northeast: quartz-mica-sands. Quartz and mica are also found in the clays; whether these minerals have been washed in exclusively by natural processes or are to be considered partly as contaminated material (due to the "bailer" sampling method) remains questionable.

The mica sands of 830′—930′ prove to be devoid of fossils, and no particular age can be attached to them. There is no sign of a stratigraphical gap at 830′ and for the time being they may be included in the Miocene. A stratigraphical gap should be assumed, however, between the Miocene series and the overlying Pleistocene beds of predominantly calcareous facies.

Thanks to the diligence of R. J. BEAUJON, former Chief of 's Lands Watervoorzienings Dienst (Government Water Supply Service), the Schlumberger Surenco S.A. at Caracas was contracted to carry out an electrical investigation which had for sole aim the study of the structure of the Oranjestad "basin" and an approximation of the depth of the basement. The prospect was conducted by the engineers R. LELEU and C. AYNARD, and lasted from 9th to 28th November, 1942 (SCHLUMBERGER 1942).

As the Schlumberger report has only a very limited distribution it is deemed advisable to reprint the most important parts of it, thus giving the reader an idea of the general principles and the results of this "electrical sounding" survey.

„Numerous measurements taken during the last twenty years inside drill-holes as well as on outcrops have shown that the different rocks, considered as electrical conductors, behave very unequally. It has been proven too that the conductivity of rocks derives from their water content, whether the water is saturating a porous medium such as in a sand or held by capillarity as in a clay. Consequently the various rocks present widely separated electrical resistivities, the lowest corresponding to a high amount of water together with a high percentage of salts in solution. It must be noticed that, as long as a given geological formation keeps the same composition, its electrical resistivity remains approximately constant. As an example the following values were observed in Curaçao and Aruba:

| | |
|---|---|
| Igneous rocks: quartz-diorite Aruba . . . . . . . . . . . | 100—200 ohms/m²/m |
| diabase Curaçao . . . . . . . . . . . . . | 70—300 |
| Metamorphic rocks . . . . . . . . . . . . . . . . . . . . | 70—300 |
| Weathered zone covering the igneous rocks: | |
| quartz-diorite Aruba . . . . . . . . . . . | 20—30 |
| diabase of Curaçao. . . . . . . . . . . . | 10—40 |
| Blue clay (found in drill-hole Aruba) . . . . . . . . . . | I |
| Salt water sands (id) . . . . . . . . . . . . . . . . . . | I |
| Superficial beds of Quaternary limestone, not impregnated with sea-water . . . . . . . . . . . . . . . . . . . . | 50—300 |
| Quaternary limestone impregnated with sea-water . . . . | I |

A physical parameter of the rocks showing such important variations lends itself readily to underground prospection by means of a simple technique".

After presenting a cursory outline of the geological problem of the bore the report continues: "To remain within a practical point of view the question which is of immediate importance is that of the total thickness of these formations, because the original idea is that the fresh water is to be found in the basement not far from the contact between the sedimentary deposits and the igneous or metamorphic rocks.

It must be understood that the electrical investigation has for sole aim the study of the structure of the basin and cannot give direct indication concerning the wateryielding capacity of the different formations involved. In the whole area which has been prospected we can foretell with a fairly good approximation the depth at which lies the basement, at the drilling location we predict how many hundred meters of hole must be dug before striking the basement. Whether potable water would be finally obtainable when the hole is completed can no more be ascertained by the resistivity method than by any other scientific geophysical process.

Before taking any measurements it could be assumed that the igneous and metamorphic rocks would act as a basement of resistivity practically infinite compared to that of the sedimentary formations above. This was confirmed by the field observations".

The observations are subject to the general limitations of the resistivity method. After indicating these limitations the authors expressed as their opinion: "Altogether, we estimate that our determinations of depth are obtained with an approximation of 10 %.

The results are represented essentially by a map (fig. 2) in which each center of electrical sounding has been marked down with its reference number. The denseness of the observations could not be exactly as great as we desired in the very vicinity and to the south of the drill-hole, because of the impossibility of extending the cables amidst the houses of Oranjestad. Consequently the drill-hole itself is on the edge of the surveyed area. However, the disposition of the stations along profiles converging towards the drill-hole enables us to check the final results on different cross-sections.

The electrical measurements clearly indicate that salted water is impregnating the limestone everywhere below sea-level. This phenomenon is already known in the water-wells dug close to the shore in certain parts of this island; it was observed at the time the upper section of the hole in Oranjestad was drilled; we can state that it persists even to a distance of two kilometers from the sea.

On the map, besides each electrical sounding the calculated depth below sea-level of the basement is plotted. Curves of equal depth have been construed with an interval of 100 meters. They give, inside a strip about one kilometer wide, a picture of the sedimentary basin which lies along the South-West coast of the island. The basement has roughly the shape of a plane dipping towards the sea under an average angle of 18 degrees.

A cross-section (fig. 3) has been drawn along a line following a North-East to South-West direction in the central part of the surveyed area. It runs from Tanki Leendert to Oranjestad and includes the location of the drill-hole. From a point located between station 3 and 5 the contact plunges gradually to reach its greatest recorded depth under station 20 [8]).

On this section, *the depth of the basement under the location of the drill-hole is found to be* 490 *meters* (1610 *feet*). It should be borne in mind that an approximation of 10 % is attached to the above figures".

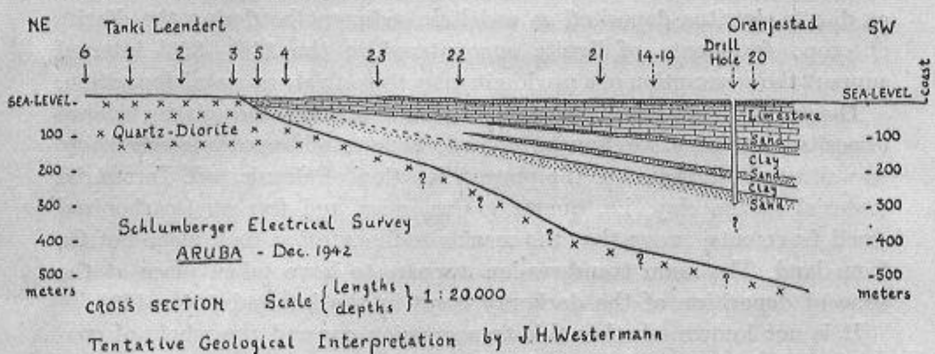


Fig. 3

From the Schlumberger survey described above it is apparent that no conclusion can be drawn as to the character of the sediments above the basement, nor can the kind of basement rock be ascertained. In fig. 3 we have assumed a dioritic basement rather than a (metamorphosed) diabase & diabase tuff formation, owing to the relative proximity of outcropping diorite. This of course remains conjectural. Although we have no indication as to the kind of sediments in the interval between the bottom of the well (937′) and the basement (measured by the Schlumberger engineers at approximately 1610′) it may be surmised that here too an alternation of sandy and clayey beds obtains: the water-bearing sands below 830′ supposedly are confined above and below by clay beds.

*Tentative reconstruction of the geological history of Aruba during Tertiary and Quaternary.*

The surface geology, the examination of the sediments of the water bore and the electrical survey throw some light on the geological processes prevailing in Caenozoic time.

[8]) The fairly steep slope of the basement below the stretch 22—21 may indicate faulting, more or less parallel to the Southwest coast (note by the author).

After the period of orogenesis and magmatic intrusion in Old Tertiary time the older volcanic and magmatic formations became subjected to a relatively high tectonical uplift and subsequent denudation.

A *Lepidocyclina* limestone whose age may range from Upper Eocene to Upper Oligocene, collected in Southeast Aruba (Butucoe) testifies of the occurrence of at least one marine ingression in Middle Tertiary time. Besides, a number of fossils of questionable Tertiary age has been found in various places (WESTERMANN 1932, 1949).

More definite data on marine transgressions are presented by the clay and sand sediments of the Oranjestad water bore whose age has been determined as (probably Lower to Middle) Miocene. The non-marine mica-sands below the foraminiferal series (830′—930′) may be considered as diorite detritus deposited as a deltaic sediment bordering the diorite outcrop; fragments of lignite encountered in the 830′—850′ interval support the assumption of a predominantly terrestrial or coastal deposition.

The overlying alternating series of marine clays and sands gives evidence of positive and negative changes in level, while to all appearance the shore was situated Northeast of the present location of Oranjestad. Terrestrial material in the clay, i.e. quartz grains, mica and few semi-carbonized wood fragments, prove that the marine sedimentation took place not far from land. The main transgression appears to have taken place at the time of deposition of the darkgray clays in the interval 666′—470′.

It is not known whether this transgression covered the whole of contemporary Aruba or only part of it. According to WAGENAAR HUMMELINCK (1940) zoögeographical data indicate partial submergence, and this would seem to be corroborated by the fact that elsewhere in Aruba Miocene sediments are found to be absent between the "basement" formations and the overlying Quaternary limestones. Although there is always the possibility that such Miocene beds have been removed in a later period, it is equally possible that the Miocene transgression has been confined entirely to the SW portion of Aruba.

The beds between 470′ and 390′ are indicative of regression, a Southwestward movement of the shoreline and increased transport of terrestrial material into the sea at the location of Oranjestad, which was getting shallower continuously.

As far as can be determined there is a definite stratigraphical gap between the Miocene clay & sand series below 390′ and the overlying calcareous beds which are to be classed as probably Pleistocene. Therefore, during Pliocene time Southwest Aruba seems to have been marked by a strong regression causing a gap in the sedimentation. This regression was followed by a transgression in the Pleistocene period. On top of the Miocene beds a conglomeratic limestone, with pebbles of quartz and diorite, was deposited and subsequently covered by a thin marl and thick coral reef deposits. The thickness of the coralline limestone of maximum 300 feet indicates a gradual subsidence of the island.

It was pointed out before, that elsewhere in Aruba the limestone has been deposited directly upon the old volcanic and magmatic formations. It is very likely that during the Pleistocene transgression not all of Aruba was submerged since the limestone contains quartz material throughout the section; this conception is supported by zoögeographical data.

The coral limestones of the water bore cannot be subdivided into a Pleistocene and Holocene section. The surface geology of Aruba gives evidence of a slight upwarping of the Pleistocene limestone. During the Holocene this limestone cap was covered at its periphery by younger reef limestones. Subsequently diorite detritus was deposited on top of these limestones. A subrecent lowering of the sea level caused renewed erosion of outcropping formations; there is a possibility that at the location and in the surroundings of the bore the younger limestone has been (partly) removed by erosion and replaced by "rooi" deposits of diorite detritus (compare fig. 2).

For a more detailed account of the Quaternary history of Aruba and the influence of the Glacial oscillation of the ocean level, reference is made to WESTERMANN 1932 and 1949.

*(To be continued.)*

GEOLOGY

# THE WATER BORE OF ORANJESTAD 1942—1943, AND ITS IMPLICATION AS TO THE GEOLOGY AND GEOHYDROLOGY OF THE ISLAND OF ARUBA (*Netherlands West Indies*) II

BY

J. H. WESTERMANN

(Communicated by Prof. G. H. R. VON KOENIGSWALD at the meeting of March 31, 1951)

## *Geohydrological Data*

The outcome of the bore viewed with respect to fresh water supply, proved to be disappointing. No fresh water was encountered at the depth of 902′, where it had been predicted by the friars. However, an abundant supply of salt water was struck by the drill at a depth of 830′ when penetrating the non-marine mica sand. Considerable pressure, suddenly released by the drill, converted the sand bed into quick sand which ascended into the drilling hole over a distance of some 200 feet, at the same time dislocating the heavy drilling outfit and dragging it along over more than 50 feet.

The drilling work below 830′ was greatly hampered on account of the drilling hole being choked continuously by ascending quick sand.

The salt water at 858′ was tested by the chemical laboratories of the "Openbare Gezondheids Dienst", Curaçao, the Eagle Petroleum Co. and the Lago Oil & Transport Cy, Aruba. It proved to contain 6.3 % of salts, and the total hardness was measured at 501.2 D° (i.e. equivalent to 5012 milligrams of CaO per Liter). The temperature was about 90° F, density 1.039 [1]). A more detailed chemical analysis of the salt water obtained from the bore, is not available.

Another salt water horizon was penetrated in the marine sands between 666′ and 720′. For some unknown reason abnormal pressure was not observed at this particular occurrence. In the driller's report this interval is marked down as "quick sand".

As to the salt water below the depth of 830′ three points need some explanation, i.e. the high pressure, the medium temperature, and high salt content.

The general impression is gained that the water bore at Oranjestad can be viewed as an artesian well. Studying the geological section, tentatively drawn on the basis of the lithology of the well and the data of the

[1]) The approximate figures of sea water are given for comparison: 3.5 % of salts, 370 D°, density 1.0223 at 76.6° F.

Schlumberger Electrical Survey (fig. 3), it seems quite feasible to interpret the sedimentary basin of Oranjestad as an artesian basin. Porous sands carrying water alternate with impervious clay beds, and this series is covered by limestones and marls. As far as we can ascertain the strata dip gently seaward, and it may be assumed that there exists a direct connection between the deep-lying sands and the diorite in the interior. Owing to this configuration rain water entering the outcrop area of weathered diorite and detritus, will percolate down through the dipping permeable sand beds locked in above and underneath by impermeable clay layers. Meanwhile the hydrostatic pressure is increasing with the depth, and it seems quite feasible — even considering internal and external friction — that a pressure of some tens atmospheres was released when the waterbody at 830′ was struck.

It is interesting to remind the reader of MARTIN's statement as to the impossibility of artesian wells on the islands of Curaçao, Aruba and Bonaire (1888, p. 115): „Zur Anlage von artesischen Brunnen, welche auf den Inseln so sehr gewünscht wird, liefert die Kreideformation — die einzige, welche überhaupt in Betracht kommen könnte — jedenfalls keine Handhabe; ihre zusammengestauchten und verworfenen Schichten, welche mit complicirter Lagerung tiefe Zerklüftung verbinden, müssen jeden Gedanken daran sofort zurückdrängen". Although this statement can be upheld without reservation as far as the Cretaceous formations are concerned, it is pointed out that on the other hand the tectonic configuration in the coastal basin of Oranjestad — made up of Tertiary and Quaternary sediments — has given sufficient evidence of artesian possibilities.

It may be remarked here that the assumption by frères APPOLLINAIRE and JUAN as regards an artesian connection between Colombia and Aruba can be dismissed without further comment. Earlier a similar thought was expressed by H. VAN KOL (*Een noodlijdende kolonie*, 1901, p. 22) who figured such a connection between the mountains of Venezuela and the Curaçao island group.

The salt water struck at 253 m. (830′) proved to be tepid. A temperature of approximately 90° F (i.e. 32.2° C) was measured in the drilling hole but we have no data on the exact depth of measurement! 32.2° C is only slightly less than the theoretical temperature expected at such a depth, taking into account an average geothermic gradient of 3° C per 100 meters, and an average temperature on the surface of 27° C.

The third item to be discussed is the high salt content of the artesian water. This water proved to have a concentration almost twice that of sea water (6.3 % : 3.5 %). According to RUSSELL (1933) brines having a higher concentration than sea water are commonly found in horizons not closely associated with salt deposits, and likewise we need not assume the nearby presence of such a salt body in the case of the Aruba bore. As a matter of fact most of the sand and clay samples obtained with the bailer contain a fair amount of salt, betraying itself by the salty taste and by typical salt precipitations covering the dried material.

Failing a chemical analysis of the water in question we can only guess at the nature and quantity of the dissolved salts. The total hardness of

501.2 D° (equivalent to 5012 mg/L CaO) indicates a high concentration of Ca and Mg salts (carbonates, sulphates, chlorides). The remainder of the 63,000 mg/L supposedly consists largely of chlorides and sulphates of Na (and perhaps K). The actual figure of Cl′ mg/L is unknown, but, judging from the taste, we may safely consider the water as a chloride brine.

RUSSELL has discussed critically the evidence regarding all the processes which may have produced chloride brines more concentrated than sea water. Of these processes concentration by hydration, osmosis or adsorption seems to be most evident. Special attention is paid here to concentration by *adsorption*. In order to get somewhat acquainted with RUSSELL's train of thought, the reader is referred to the following quotations from his contribution (p. 1225—1227):

„It has long been known that clays and very fine-grained soils will adsorb salts from solution. The amount adsorbed is probably proportional to the total surface area of all the particles in the material. Since the total surface area of very fine-grained rocks is enormously greater than that of coarse-grained rocks, it is evident that adsorption would be important only in the fine-grained rocks, and in a given sediment the finest portion would contain nearly all the adsorbed salts.

Very fine sediments laid down in sea water should contain considerable adsorbed bases, but it is not clear whether the chlorine would accompany these bases, or whether all or a portion of it would be released and escape before burial. If some or all of the chlorine remains in the marine deposits, certain agencies, such as recrystallization, cementation, and the effects of heat and pressure, may cause the liberation of the adsorbed materials as chlorides. The effect of these agencies should increase with depth. As most of the adsorbed salts or ions are held on the finest particles of the sediment, and as the finest grains are the first to recrystallize into larger masses, it is obvious that recrystallization would liberate most of the ions or chlorides held on the surfaces by adsorption. The chlorides thus released would increase the concentration of the solutions occupying the pore spaces of the rocks, and after further compaction they might be expelled into the associated water-bearing horizons.

Until more definite knowledge is available regarding the amounts of chlorides that are adsorbed during the deposition of fine sediments in sea water, it is difficult to apply a quantitative test to this theory. However, if, for example, a quantity of sodium chloride amounting to 0.1 per cent of the weight of a shale were expelled without accompanying water into a reservoir containing sea water and having a thickness of 50 feet and a porosity of 20 per cent, it would require a stratum of shale only 140 feet thick to furnish enough salt to double the concentration of the solution in the reservoir. A bed of shale 560 feet thick would furnish enough salt to raise the concentration to five times that of sea water.

If it could be shown that sufficient quantities of chlorine are entombed with the fine sediments as a result of adsorption, this theory would be very promising. Until further investigations have furnished additional information bearing on this point, it is difficult to estimate the importance of adsorption in producing concentrated chloride brines".

The sands and clays as encountered in the water bore of Aruba, are clearly of marine and deltaic origin, and — according to the above quotation — they could have adsorbed considerable amounts of salts during their deposition. Part of these adsorbed salts may have become fixed in the sediments and another part may have been released subsequently — and is still being liberated — by certain agencies, acting after sedimentation and burial, such as heat, pressure, compaction and other physical or chemical processes. As has been pointed out by RUSSELL it may be accepted that these salts are adsorbed (and partly released) by the fine clays in particular, rather than by the adjoining sands. Assuming a direct connection between the water-bearing sand beds in the bore and the diorite and detritus in the outcrop area further inland, enabling slow but steady percolation of rain water through the pore spaces of these dipping sand beds, one would logically expect this fresh water to dissolve the salts expelled from the adjacent clay beds. Thus, it would gradually change from fresh into brackish and salt water, surpassing even the salt concentration of sea water. The high hardness may be explained partly by solution of calcium carbonate from the fossiliferous beds, partly by liberation of other Ca and Mg salts.

Besides the artesian salt water in the Miocene sands there is abundant saline water in the overlying coral limestone (according to the drilling report: "plenty of salt water"). The electrical measurements also clearly indicate salt water impregnation of the limestone everywhere below sea level. Generally speaking this ground water originates from rain water penetrated through the cavernous reef limestones until stopped by impervious clay beds.

Before attempting to explain the high salinity of the limestone ground water, it is useful to present some data on 40 shallow water wells drilled or dug by the Eagle Petroleum Company in the young limestone terrace of Western Aruba [2]). These water wells, situated along a line averaging 800 meters from the coast, have a depth of 15 to 20 feet; their bottom lies somewhat below sea level whereas their maximum water level is some 4 feet above the bottom. Water analyses show a chlorine content varying between about 330 and 2555 milligrams per liter, depending on the well and the time of sampling (see table 2). Thus, the average (1215 milligrams) chlorine content surpasses that of ordinary local drinking-water (200—500 milligrams) considerably. Excavating a well further below sea level incurs increasing chlorine content.

No chemical analysis is available of the limestone ground water encountered in the bore. From the driller's report one gets the impression that this water is true "salt water", having a salinity much higher than that of the average Eagle well. This would stand to reason because the limestone beds are — geologically speaking — very young and are situated largely below sea level. Leaching of the sea water salts left behind in the pores of the limestones has by no means proceeded very far, and as a consequence the water is still salt.

[2]) Data obtained in November 1942 from R. J. BEAUJON, former Chief of 's Lands Watervoorzienings Dienst, Curaçao.

At this instance it is interesting to draw the attention to the "warm mineral spring" observed by VAN KOOLWIJK (1884) which according to him flowed into the sea at the base of the limestone terrace, just South of Fort Zoutman, Oranjestad (fig. 2). No recent observations are available. If we leave the temperature out of account (there are no specific data on the socalled "warm" water), then this particular spring could be explained as just one of the places where the saline ground water of the limestone terrace drains off into the sea. On the other hand, a temperature higher than normal would suggest a deeper origin of the water (ascending along a fault plane?).

No particular problem is raised by the fresh water spring at Fontein, in Northeastern Aruba, making its appearance at the outcrop of the plain of abrasion separating the volcanic formation and the overlying Caenozoic limestone. In all probability this plain of abrasion dips in a Northerly direction, thus draining the rain water percolating through the limestone down to the said contact. The water production of the spring is small and depends entirely on the rainfall at the limestone plateau South of Fontein. The salinity of the Fontein spring varies between 200 and 460 Cl′ mg/L; total hardness is 17—19 D° (see table 2). Thus it compares favourably with the ground water in the neighbourhood of Oranjestad and in the Eagle concession. The difference is easily explained by the difference in topographical situation: the limestone plateau South of Fontein has an altitude varying between 80′ and 330′ above sea level, whereas the terrace limestone around Oranjestad reaches from a few feet above sea level to well below it.

It may be assumed that the salt content of the Fontein water — however small — is derived mainly from the tuffaceous beds of the old volcanic formation forming the plain of abrasion, rather than from the plateau limestone. This assumption is based on the theory that the salts adsorbed during marine transgressions in the finegrained tuffaceous rocks are more difficult to dissolve than those left behind in the cavernous and porous limestone. It would seem, therefore, that the leaching of the plateau limestone has made far more progress than that of the underlying volcanic rocks. Similar geohydrological conditions were met by MOLENGRAAFF (1929) around the springs of Hato, Curaçao. Quaternary limestone overlies here unconformably the shales of the Midden-Curaçao formation. Where the Northward dipping plain of abrasion, separating both rock types, is outcropping, fresh water springs are appearing. The salinity of the Hato springs is still lower than that of the Fontein spring, and varies between approximately 140 and 360 mg. Cl′ per liter, the total hardness from 12 to 22 D° (see also LIEFRINCK 1937, p. 36, enclosure 13). MOLENGRAAFF has observed that the salinity is highest in those springs situated farthest from the outcropping plain of abrasion i.e. from the limestone cliff, owing to the longer transport of the water through the shales which are relatively rich in adsorbed sea water salts.

The limestone plateau South of Fontein has been surveyed more than once with a view to increasing its water supply, so far without satisfactory results. DALLMUS (1943) paid a short visit to Aruba (16—18 November, 1942) and favoured the idea of utilizing the cavernous limestone of Fontein and Quadirikiri, along the North side of the plateau, as artificial ground water reservoirs, by constructing underground dams. The drainage areas at these localities were estimated at 10, respectively 5 square kilometers. He also reported on the water supply of the Mangle Corá well system in Southeastern Aruba: drainage area about 3 sq. kms. Its quality did not improve appreciably after the seaward side of the well had been cemented off [3]). Many years ago, in 1888, it was stated by MARTIN "dass das östliche Kalkplateau für die Wasserfrage bedeutungslos ist, da die Schichten sich hier in schwebender Lage als Hangendes der Felsenmeere von Diorit und nur in geringer Höhe über dem Meeresspiegel befinden", a rather indistinct statement to which no particular significance can be attached.

No attention is paid to this limestone area by LIEFRINCK (1937) and SANTING (in KRUL 1949).

Contrary to the poorly founded opinion expressed by the geologist WESTERMANN in 1932 (p. 127), that the rather deeply weathered diabasic and dioritic subsoil of Aruba would act as a fairly good water reservoir, the hydrologists LIEFRINCK, DALLMUS and SANTING report on this soil as having very limited permeability and thus greatly impeding infiltration of rain water. Thus, according to these specialists, precipitation would add little to the ground water reservoir [4]). Consequently there are no possibilities of an adequate ground water supply for the present dense population. If in view of changing economic conditions sea water distillation and foreign import of fresh water would of necessity be abandoned, a reduced population will have to fall back upon rain water cisterns and reservoirs besides the few wells suitable for drinking-water.

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[3]) Aruba Esso News Vol. 11, no. 20 of September 29, 1950, p. 4, published a popular article "Water for All Time. Mangel Cora Well", containing a photograph and a sketch map of the 2134 foot water-collecting tunnel in the coral. The concrete underground dam or "grout line" between the tunnel and the sea, acting as a barrier to water seepage from the basin to the sea, and vice versa, is also shown on the map. The article mentions an increase in the supply of fresh water from 1000 to approximately 5000 barrels a day, but does not have any record of improvement in quality.

G. SANTING informed the author that after the completion of the grout line the Cl′ content decreased from 6750 to approximately 5000 mg/L (data obtained during his visit in the year 1948).

[4]) The impermeability of the dioritic soil is reflected in the high salinity of the ground water (see table 2). This impermeability relates to the extensive areas swept barren by soil erosion, and as much to the comparatively rare places where a fairly thick soil profile has developed through weathering. In the latter case the weathered zone makes a poor reservoir in view of the fact that the already low porosity is further reduced by the fine material resulting from the decomposition of feldspar (DALLMUS 1943).

TABLE 2

| Location | Approx. Altitude in meters | Geological Formation | Cl′ mg/L | Total Hardness D° | Date of Sampling |
|---|---|---|---|---|---|
| *Northeast & North coast* | | | | | |
| Bron di Fontein . . . . | 10 | Quaternary limestone/ Diabase & Diabase-tuff formation | 210<br>400<br>460 | —<br>19<br>17 | 2 July 1930 (W.H.)<br>23 Dec. 1936 (W.H.)<br>30 Dec. 1948 (W.H.) |
| Pos di Fontein . . . . | 10 | ditto | 400 | 18 | 23 Dec. 1936 (W.H.) |
| Bron di Rooi Prins . . | 20 | Diabase-tuffs | 1300<br>1345 | 36<br>40 | 9 Jan. 1937 (W.H.)<br>26 Aug. 1949 (W.H.) |
| Cueba di Andicouri . . | sea-level | Quaternary limestone/ Diabase & Diabase-tuff formation | 780 | 4 | 26 Aug. 1949 (W.H.) |
| Bron di Andicouri . . . | 15 | Quartz-diorite | 6640 | — | 1883 (de Loos, Van Koolwijk) |
| Bron di Pos di Noord . | 10 | Quartz-diorite | 3250 | 55 | 30 Dec. 1936 (W.H.) |
| Pos di Noord . . . . . | 10 | Quartz-diorite | 3300 | 60 | 30 Dec. 1936 (W.H.) |
| *Central part of island* | | | | | |
| Rooi Juditi, SE of Seroe Kabaai (temporary) | 50−60 | Diabase-tuffs | 2260 | — | 28 Dec. 1948 (W.H.) |
| Puddle in Rooi Kabaai, SSW of Miralamar (temporary, excavated) | 55 | Diabase-tuffs, strongly metamorphosed | 1860 | — | 28 Dec. 1948 (W.H.) |
| Bron di Rooi Bringamosa | 15 | Quartz-diorite | 3150<br>4910 | 50<br>— | 6 Jan. 1937 (W.H.)<br>18 Jan. 1949 (W.H.) |
| *South & Southwest coast* | | | | | |
| Well Mangle Corá . . . | sea-level | Quaternary limestone/ Quartz-diorite | 6750 | — | Nov. 1942 (D) |
| Pos Grandi (Rooi Lamoenchi) . . . . . . | sea-level | Quaternary limestone terrace | 960 | 26 | 12 Feb. 1937 (W.H.) |
| Pos W. of Rooi Lamoenchi | sea-level | Quaternary limestone terrace | 720 | 26 | 11 Feb. 1937 (W.H.) |
| Pos di Balashi (Wesoe) | 7 | Quaternary limestone terrace | 1645<br>1595 | 53.3<br>— | July 1937 (L.)<br>10 May 1940 (S.) |
| Well in Rooi upstream of Balashi. . . . . . | ? | ? | 5106 | 87.9 | July 1937 (L.) |
| *West coast* | | | | | |
| 40 Wells of Eagle Petroleum Co's Concession | sea-level | Quaternary limestone terrace | min. 330<br>max. 2555<br>(averages 1180/1250) | — | Jan./Feb. 1942 |
| Bubali no. 1 . . . . . | sea-level | Quaternary limestone terrace | 1940/2065 | — | Jan./Feb. 1942 |
| ,, ,, 2 . . . . . | | | dry/2015 | — | Jan./Feb. 1942 |

In order to give a general idea of the composition of Aruba ground water, analyses of several springs and wells are listed in table 2. The figures are borrowed chiefly from LIEFRINCK 1937 (L), WAGENAAR HUMMELINCK 1940 (W.H.), DALLMUS 1943 (D), and SANTING (KRUL) 1949 (S), as well as from Eagle Petroleum Co's reports 1942. Dr WAGENAAR HUMMELINCK kindly supplied additional figures of samples collected during his 1948–1949 visit, and tested by F. W. KLEVE (W. H.).

*Prospects of finding potable water when drilling deeper*

The question may be raised whether fresh water would be struck by extending the water bore of Oranjestad down to the basement (calculated by the Schlumberger engineers at approximately 1610′). For the time being we cannot express any definite opinion as to the nature of the sediments between 937′ and 1610′. Either the non-fossiliferous mica sands of 830′–930′ might be found extending down to the basement, or a series of alternating marine and non-marine clays and sands (as observed in the present drilling hole) would be encountered. In all likelihood more water-bearing sand beds would be reached, at least some of them connected with the outcrop area inland and thus constituting artesian systems. Our experience with the water bodies of the present drilling does not warrant any optimistic prediction as regards the quality of water yet to be struck. There is indeed no geohydrological indication whatsoever of fresh water in the sediments below Oranjestad. Although for purely scientific purposes further drilling would be highly recommendable, this should be definitely dissuaded from an economic standpoint, notwithstanding Frère Appollinaire's confidence in ultimately finding the much desired fresh water flow.

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