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# RECENT CARBONATES FROM THE NETHERLANDS ANTILLES : HYPERSALINE TO OPEN MARINE ENVIRONMENTS

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(3 figures dans le texte)

The Netherlands Antilles mainly include six islands; Aruba, Curaçao and Bonaire belonging to the Leeward Group of the Lesser Antilles, north of the Venezuelan coast, and St. Maarten, St. Eustatius and Saba located in the Windward Group of the Lesser Antilles, i.e. the island-chain from the Virgin Islands to Grenada. Most of the work was carried out on Bonaire, some work was done on Curaçao while Aruba and St. Maarten were only briefly visited. The author was enabled to visit these islands in 1970 and 1972 thanks to grants from the Netherlands Foundation for the Advancement of Tropical Research (WOTRO). The 1972-visit was made together with Mr. J. W. Focke who started an investigation on the bluegreen algae on Bonaire and assisted the author very well.

## 1. *General Setting.*

The core of Aruba, Bonaire and Curaçao is formed by folded Cretaceous strata unconformably overlain by carbonate rocks of Plio-Pleistocene age. Due to successive uplifts, terraces have been formed surrounding the islands. The lowest terrace, the « 6-meter terrace » often forms a prominent cliff which on many places drops off steeply into the sea. This is especially the case on the eastern, windward, side of the islands where the cliffs are being battered by the surf. Bonaire and Curaçao are also surrounded by a submarine terrace sloping gently down to about 10 m. depth. On most parts it is covered with sand and coral debris. The width of the terrace is visible from the air and from land since the water above it has a lighter blue color than the sea beyond it. The border between these two zones is being called « the blue edge ». Beyond this edge the seabottom drops off steeply to about 45 m. Reef formation takes place at the foot of cliffs formed by the 6-meter terrace and on the edge of the submarine terrace.

Generally *Acropora palmata* is found nearest to the shore where wave-action is strongest. Further outward on the submarine terrace, at a depth of 3-5 m., *Acropora cervicornis* is present. The edge of the terrace is crowded with corals, *Montastrea annularis* and *Dendrogyra cylindrus* being abundantly present. (Roos, 1964 and 1971).

## 2. *The hypersaline basins of Bonaire.*

On the windward side of Bonaire a 3 km wide lagoon, *the Lac* (fig. 1), is gradually becoming isolated from the Caribbean Sea by a submerged extension of one of the many coral rubble ridges that frequently rim the islands. The lagoon has a maximum depth of 3 m. and is rimmed by mangrove forests. Its bottom is covered by *Thalassium, Halimeda, Goniolithon* and other algae while *Calianassa*-mounds are frequently found. The debris of the algal vegetation forms the main component of the sand in

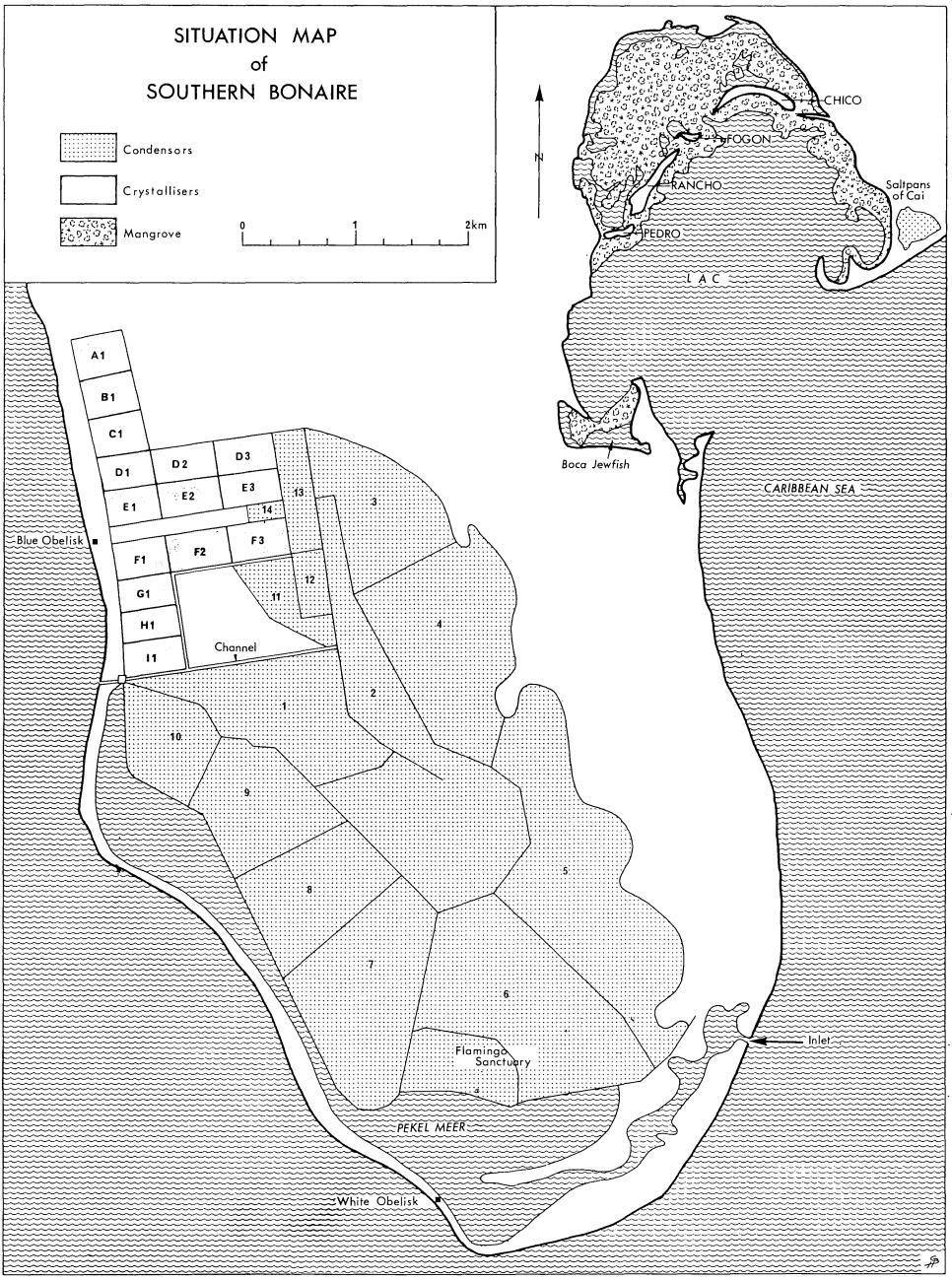


Figure 1. — Situation map of Southern Bonaire showing the extensive complex of saltpans now in use, the Lac and its immediate surroundings.

this lagoon. It has been swept up by bottomcurrents against the submerged rubble ridge, forming a substantial sandspit, and on other places minor spits are isolating subsidiary embayments from the lagoon. Four sand islands form a barrier across the Lac. The area behind it is a dense mangrove forest in which the trees are dying off due to the higher salinity of the water behind these islands. Algal biscuits occur in Boca Jewfish, a subsidiary bay in the southern part of the Lac. The salinity of the water in this bay is equal to that in the Caribbean Sea. Algal mats are abundantly present in the supratidal zone on the sandspits and islands. On the northeastern end of the Lac a spit must have isolated a bay in the past which has resulted into the formation of a small evaporite basin, the saliñas di Cai. Natives have exploited this area for some time and constructed five saltpans in it. These are now abandoned and their bottom is covered by a layer of calcareous sand and gypsum which in some places form hard crusts of aragonite and gypsum cemented sand. The bottom of the pans is crowded with *Cerithium* and brine shrimps. Most bluegreen algae in these pans are coccoid forms.

Another much more extensive area with hypersaline conditions lies in the southern part of Bonaire, *the Pekelmeer-area*. Here a coral rubble ridge has isolated, since Pleistocene times, a large lagoon from the sea. This lagoon gradually changed into an evaporite basin through a series of sedimentary stages nowadays observable in the Lac. Coring by Deffeyes et al. (1965), Lucia (1968) and this author and Focke (1970 & 1972) shows that the basal sediment, overlying hard Pleistocene limestones, is a slightly dolomitic bioclastic, and lithoclastic, sand in some places followed by a mangrove-peat, a well sorted calcarenite, a pelletal sand with abundant *Cerithium*-shells (often forming hard crusts) and almost pure gypsum at the top. Hence we have to do with a sequence of normal marine, lagoonal, sediments changing upward into the hypersaline gypsum deposits.

Since the late sixties the Antilles International Salt Company has drastically altered the scenery in southern Bonaire. The whole Pekelmeer-area is now covered by an extensive complex of saltpans (fig. 1). Seawater is being driven into this system by the tradewind through an eastern inlet. It then circulates through fourteen condensors in each of which the brine is being condensed to a specific gravity (and thus salinity). The bottom of the condensors is being held impermeable by a thick layer of bluegreen algae and we found here the same abundance of brine shrimps and *Cerithium*-shells. The shrimps are food for a flamingo colony and other birds all held in high esteem by the Salt Company since their droppings contribute nutrients for the algae. After the brine has passed through the first six condensors gypsum starts to precipitate. In condensors 7 and 8 it has formed in a few years time a 2-3 cm thick layer of gypsum crusts on the bottom of the condensors. These crusts are broken into a polygonal pattern and can have become shoved one over the other into a « teepeestructure » -- like manner.

Halite does not precipitate before the brine has been led to the crystallizers, a separate system of saltpans, from which the halite is periodically harvested.

3. *Preliminary observations.*

Although our observations are only in a preliminary stage the following can be reported on the composition of the brines (figs. 2 & 3).

1) The pH of the brines, measured during day-time hours, varies between 7.4 and 8.9. The water from the Caribbean Sea having a pH of 8.3 and 8.9 being measured in condensor 6. The crystallisers had a pH of around 7.5.

2) The total amount of $CO_2$ shows a slight decrease in the first six condensors and increases thereafter.

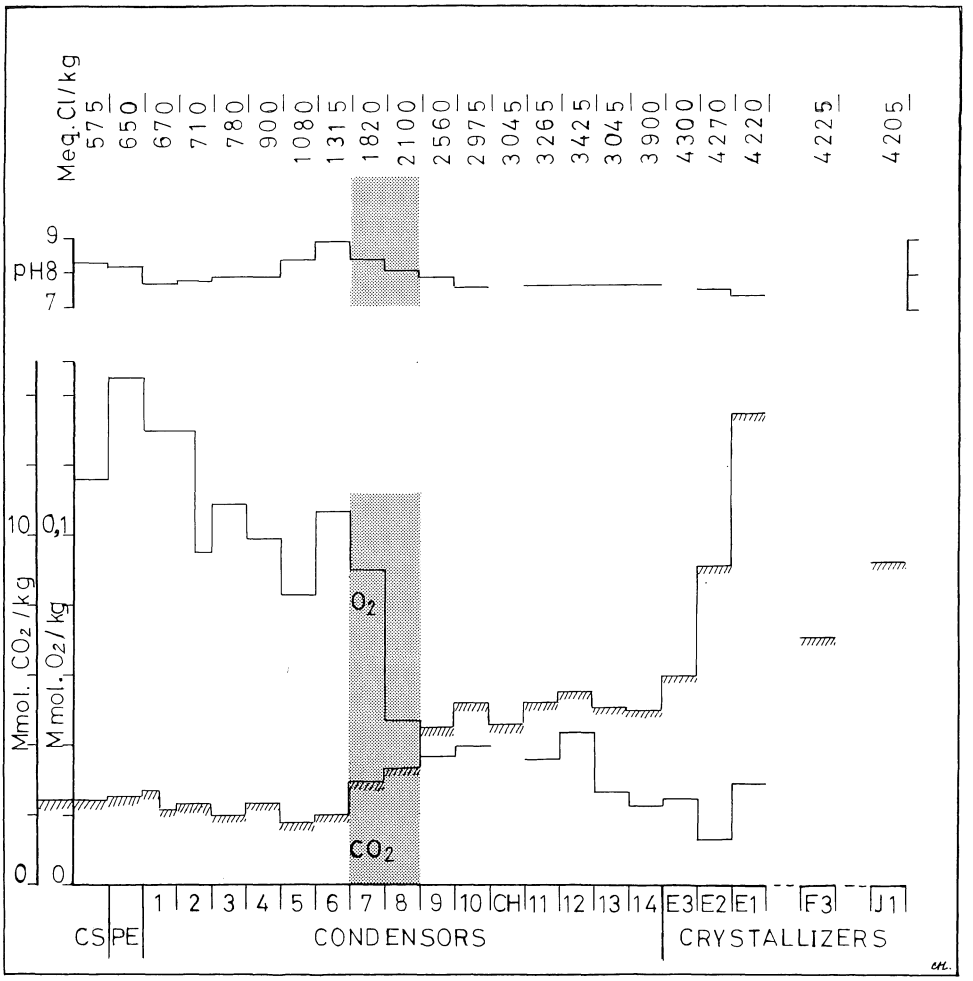


Figure 2. — Diagram showing the total amount of carbondioxyde, oxygen and chlorine as well as the pH present in the saltpans of the Antilles International Salt Company. CS = Caribbean Sea; PE = Pekelmeer; CH = Channel leading the brine from condensor 10 to condensor 11. Shaded area indicates the condensors in which gypsum precipitates.

3) The oxygen content of the brines decreases in the successive saltpans, a strong drop occurs in condensor 8.

4) The Mg/Ca-ratios of the brines decrease from $\pm$ 5.3 (normal seawater) to about 1.5 in condensor 5. After that they increase and almost reach infinity in the crystallizers.

5) The calcium content of the brines is the main reason for the behaviour of the Mg/Ca-curve in figure 3. The Ca-content of the brine, in milliequivalents $Ca^{++}$ per kilogram increases at first and decreases afterwards.

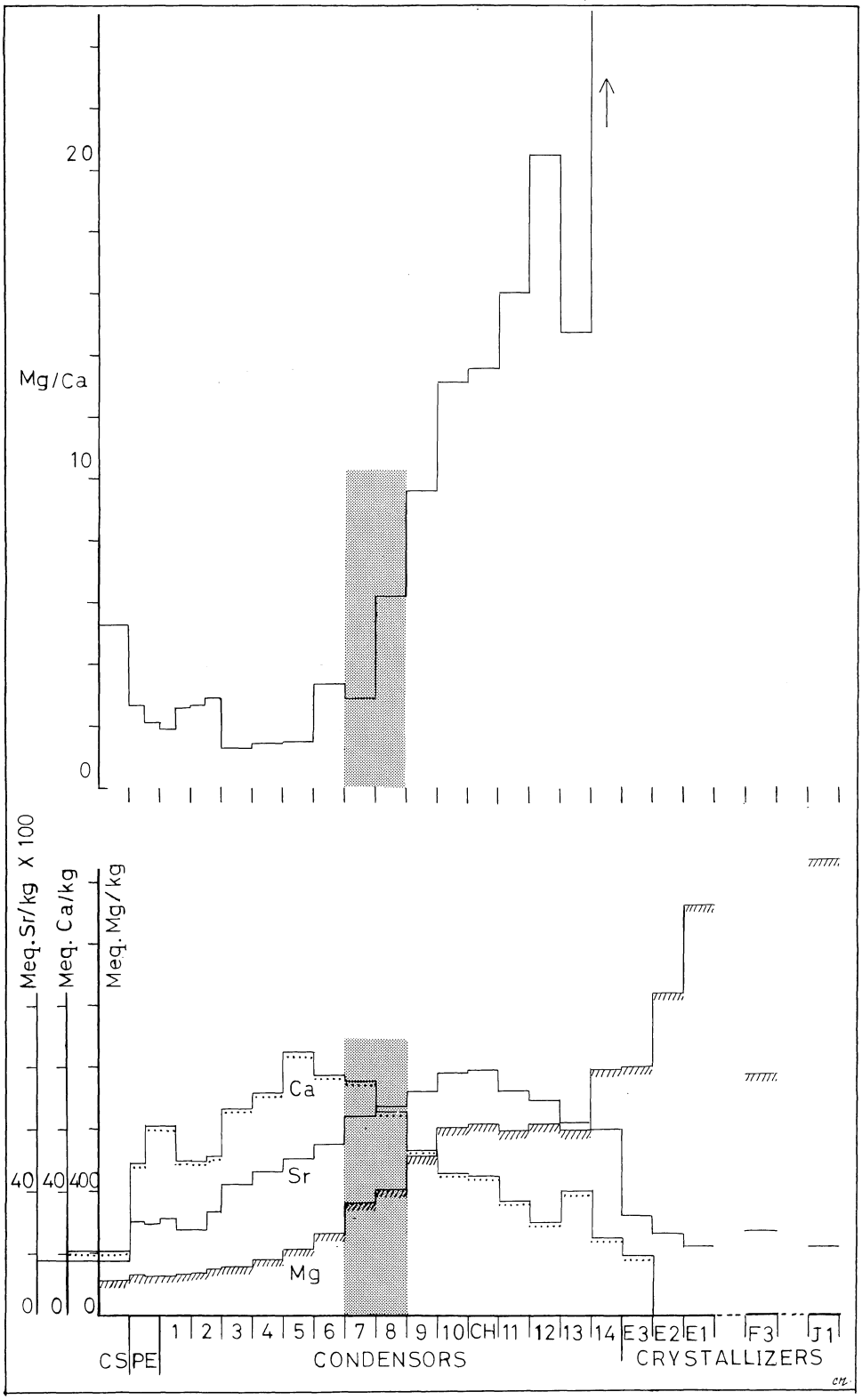


Figure 3. — Diagram of the calcium, magnesium and strontium contents of the saltpans and the Mg/Ca-ratios of the brines.

6) The magnesium content of the brines shows a steady increase in the amounts of magnesium present. There is a distinct similarity between the configuration of this diagram and the $CO_2$-diagram. It might be due to the formation of a $MgCO_3$-complex ion in brines with higher salinities.

7) The strontium in the brines increases in the first ten condensors and decreases afterwards.

Summing it all up the island of Bonair in particular presents geologists, on a relatively small area, a good opportunity for studying carbonate sedimentation in open marine, lagoonal and hypersaline environments. Both in natural basins as well as in man-made and man-controlled basins.

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