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# HELIUM-3 INSIDE ATOLL BARRIER REEF INTERSTITIAL WATER : A CLUE FOR GEOTHERMAL ENDO-UPWELLING

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Abstract. Interstitial waters from boreholes in the reef conglomerate of Tikehau atoll (S.W. Pacific) contain positive anomalous concentrations of dissolved inorganic nutrients compared to adjacent oceanic and lagoonal waters. These anomalies have been interpreted by geothermal circulation of deep oceanic waters penetrating the porous reef carbonates and ascending through the atoll flanks by thermo-convective advection as already proposed for other atolls. We present here a new strong evidence of this geothermal circulation inside atoll reefs from the record of helium-3 anomalies in borehole waters of Tikehau atoll. These results bear directly on three controversial aspects of reef history : the efficiency of thermal energy for circulation of reef pore waters, the sources of nutrients to support the net productivity of reef ecosystems, the early diagenesis of reef foundation carbonates.

## Introduction

The endo-upwelling concept is born from the question raised by the atoll high productivity in the central desert region of the tropical ocean. The first support for the geothermal

samples were drawn at different depths from permanently inserted tygon polytubes and analyzed (oxygen, nitrate, phosphate, silicate, ammonia, alkalinity, pH) within a few hours of collection in the laboratory at Tikehau. The results of seven sets of analyses of borehole interstitial waters and of adjacent lagoonal and oceanic waters are presented in Table 1.

These data clearly indicate that the interstitial waters in the reef are nutrient-rich : concentrations of inorganic dissolved phosphate, nitrate and silicate are 7 to 20 times higher than the surrounding ocean and lagoon and are similar to concentrations at 500 m in the upper Antarctic Intermediate Water (AIW). These findings support the geothermal endo-upwelling model.

## The atoll as a biological singularity within the oceanic tropical desert

Reef ecosystems found in clear oligotrophic tropical waters are net exporters of organic matter and would not survive unless the long-term value of the photosynthesis/respiratory ratio exceeds 1. They require a permanent input of nutrients

TABLE 1.
Chemical properties of interstitial (averaged from n borehole data during 1989), lagoonal, shallow and intermediate (500 m) oceanic waters, (Tikehau atoll). Oceanic data from 1986-1989 R.V. Marara cruises [J. Rancher, pers. com.].

| data | depth | salinity | $O_2$ | $PO_4$-P | $NH_4$-N | $NO_3$-N | $SiO_3$-Si | pH | total alk | redox pot. |
|---|---|---|---|---|---|---|---|---|---|---|
| n | m | ‰ | l/m$^3$ | nutrients (mmole/m$^3$) | | | | | eq/m$^3$ | mV |
| | | | | | interstitial water | | | | | |
| 21 | 10 | 35.5 | 1.3 | 1.1 | 0.6 | 4.8 | 7.1 | 7.55 | 2.25 | 100 |
| 21 | 20 | 35.6 | 1.4 | 1.1 | 0.4 | 5.4 | 6.5 | 7.62 | 2.22 | 100 |
| 21 | 30 | 35.6 | 1.2 | 1.0 | 0.5 | 6.6 | 8.8 | 7.66 | 2.15 | 100 |
| | | | | | lagoon | | | | | |
| 21 | 0-20 | 36.0 | 5.4 | 0.2 | 0.5 | 0.2 | 0.8 | 8.35 | 2.33 | 180 |
| | | | | | ocean | | | | | |
| 6 | 0-100 (TSW) | 36.2 | 5.0 | 0.1 | 0.2 | 0.1 | 0.7 | 8.30 | 2.30 | 200 |
| 6 | 500 (AIW) | 34.5 | 2.8 | 1.8 | 0.1 | 25 | 12 | 7.90 | 2.40 | 100 |

1987]. Hence, $^3$He can be used as a tracer to detect the presence of intermediate depth Pacific water in reef interstitial water.

Sampling for helium was done from Tikehau interstitial water in October 1989. Copper tubes were flushed and then filled directly with interstitial water from the polytubes of three of our boreholes and sealed with clamps. In the laboratory, the 40 cm$^3$ seawater samples were extracted and their dissolved gaseous component analyzed for helium-3 and helium-4 by mass spectrometry following the routine analytical procedure used in Saclay [Jean-Baptiste et al, 1988]. In addition, an oceanic helium profile was made a few miles off Tikehau atoll from the R.V. Marara. Helium-3 data are given (Table 2) in delta % values, i.e by the deviation of the isotopic ratio $^3$He/$^4$He of the sample to the atmospheric isotopic ratio ($R_A$=1,384.10$^{-6}$) :

$$\delta = (( ^3He/^4He)_{sample}/(^3He/^4He)_{atm} - 1) \times 100$$

The mean accuracy is ± 0.3 % for delta values.

The $\delta^3$He values of the borehole samples show a progressive increase with depth. Moreover, at each depth, the $\delta^3$He value is significantly in excess relative to the oceanic mixed layer value between the surface and 150 meter depth (typically ranging between -2.2 % and - 1 %).

The $\delta^3$He values of the borehole samples linearly correlate with the measured salinity (Figure 2). Also indicated is the salinity/$\delta^3$He plot from the surface to 800 m for the open ocean outside the atoll. This $\delta^3$He/salinity relationship suggests the mixing of two end-components : a) tropical surface waters (TSW) with $\delta^3$He values between -2.2 % and -1 % and salinity between 36 ‰ and 36.5 ‰ and b) deeper waters of lower salinity and higher helium-3 content. The

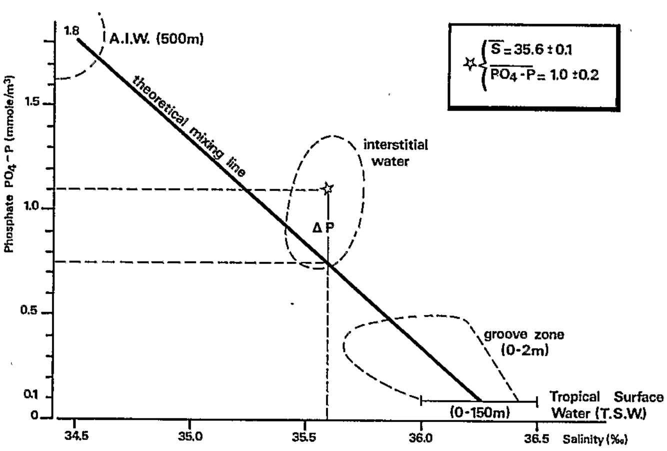


Fig. 1.1. Inter-relation between salinity and dissolved phosphate concentration in AIW and tropical surface water (TSW). Interstitial water salinity averages 35.6 ‰ between 10 and 30 meters depth. At this salinity, the measured mean $PO_4$ concentration of 1.1 mmol/m$^3$ is in excess compared to the theoritical value obtained through the mixing line AIW/TSW (0.75 mmol/m$^3$). Interstitial water salinity is stable (unchanged by precipitation, evaporation or biological processes) within the matrix.

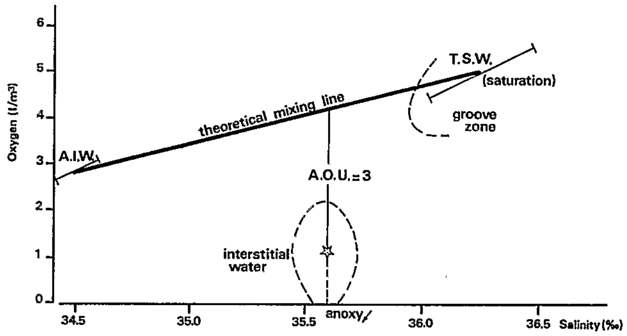


Fig. 1.2. Inter-relation between salinity and dissolved oxygen concentration in AIW and TSW. Interstitial borehole water characteristics average 35.6 ‰ for salinity and 1.2 l/m$^3$ for dissolved oxygen content. At this salinity the theoritical mixing line indicates that the oxygen concentration should be 4.2 l/m$^3$. The apparent oxygen utilization (AOU) of 3.0 l/m$^3$ can reflect the "in situ" biodegradation of organic matter, a process able to release the 0.35 mmol/m$^3$ of excess inorganic phosphate (Figure 1.1).

[redacted]

significantly affected although the estimated "recharge" depth of 700-800 m may be slightly overestimated. Future measurements will include deeper sampling levels (where the tritium effect will be totally negligible) and will bring a clear answer to that question.

## Implications of results

Our helium-3 data give evidence for the endo-upwelling mechanism and bear directly with some controversial aspects of reef history.

Reef communities and ecosystems are very complex and highly integrated with a restricted set of controlling environmental factors [Fagestrom, 1987]. The flux of near-surface interstitial water with high nutrient concentration appears to play a major role in driving the ecosystem. Therefore, it is apparent that our chemical borehole data will provide a better understanding of the detailed functions of the superficial communities as well as certain aspects of reef diagenesis [Schroeder and Purser, 1986].

The early diagenesis of deep limestones from various islands and atolls is well documented [Machel and Mountjoy, 1986 ; Aharon et al., 1984]. Dolomitization is presumed to result from the penetration of deep ocean water that is undersaturated with respect to calcite below 900 m but still supersaturated with respect to dolomite [Saller, 1984].

Geologists and biologists have engaged in a long-running debate over the origin of fluoroapatite found atop some uplifted oceanic atolls [Aharon and Veeh, 1984]. The endo-upwelling model supports recent investigations suggesting that these phosphate accumulations may have formed from diagenesis of lagoonal muds [Burnett et al., 1989] or by direct precipitation from phosphate saturated sub-lagoonal interstitial water [Rougerie et Wauthy, 1989].

Others have shown the presence of large-scale geothermally driven circulation through limestones in the Florida East Plateau [Kohout, 1965] and the West Florida continental shelf [Fanning et al., 1981]. Thermal profiles and geochemical signatures indicate that oceanic water penetrates these porous platform limestones at depths of 500-1000 m

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