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Interpretation of the origin of massive replacive dolomite within atolls and submerged carbonate platforms: strontium isotopic signature ODP Hole 866A, Resolution Guyot, Mid-Pacific Mountains

P.G. Flood [a], J.A. Fagerstrom [b], F. Rougerie [c]

[a] *University of New England, Department of Geology and Geophysics, Armidale, NSW 2351, Australia*
[b] *University of Colorado, Department of Geological Sciences, Boulder, Colo. 80309-0250, USA*
[c] *Centre ORSTOM, Oceanography Department, B.P. 529, Papeete, Tahiti, French Polynesia*

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Abstract

Endo-upwelling is a geothermally driven convective process operating within the upper part of the volcanic foundation and overlying carbonate pile, in atolls and guyots. By this process deep oceanic water, rich in CO_2 and dissolved nitrates, phosphates and silicates is drawn into the pile, circulates slowly upward through the porous-permeable carbonate interior and emerges at either the reef crest or lagoon on atolls to support the primary productivity of the surficial communities, or towards the interior of the platform surface on guyots.

Continuous operation of the endo-upwelling process requires: (a) heat from the volcanic foundation; (b) an external impermeable apron on the submerged flanks to confine the convective flow within the pile; and (c) a porous cap from which water exiting the plumbing system returns to the ocean.

At ODP Hole 866A on Resolution Guyot, Mid-Pacific Mountains, the Sr isotopic signature of massive white-coloured, coarsely crystalline dolomite indicates a considerable time delay of approximately 100 Ma between carbonate deposition and dolomitization. This time delay is determined by comparing the Sr isotopic value of the dolomite and the time that ocean seawater displayed a similar Sr isotopic value. This interpretation of the Sr isotopic values assumes that all of the Sr is viewed as coming from seawater and none from any precursor limestone.

The massive white replacement dolomite from Resolution Guyot possibly provides confirmation of the origin of dolomite by way of thermally driven convective flow within submerged carbonate platforms. Endo-upwelling seawater probably enters the carbonate pile at some depth, thermally circulates upwards, and produces carbonate dissolution and could conceivably produce massive dolomite replacement.

1. Introduction

Atoll dolomite was first recorded in the subsurface at Funafuti by Cullis (1904) who inferred that seawater played a critical role in the transformation of a carbonate precursor by secondary replacement dolomite. Lately, the idea of convective fluid flow being responsible for dolomitization has gained additional support and some confirmation with the publications of Schlanger

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(1963), Saller (1984), Aharon et al. (1987), Hardie (1987), Aissaoui et al. (1986), Vahrenkamp and Swart (1990), Wilson et al. (1990), Vahrenkamp et al. (1991), Hein et al. (1992), and Flood and Chivas (1995).

A general model of dolomitization associated with thermal convection within atolls and carbonate platforms has been described by Tucker and Wright (1991). It requires a zone of higher heat flow to be present beneath the carbonate platform and lateral flow operating along the platform margin. This situation is commonly referred to as 'Kohout convection'. The essence of this model is embodied in the geothermal endo-upwelling mechanism described by Rougerie and Wauthy (1988, 1993), Rougerie et al. (1992) and Rougerie and Fagerstrom (1994). This model of thermal convection operates within atolls and carbonate platforms whereby deep oceanic waters, rich in CO_2 and dissolved nitrates, phosphates, and silicates is drawn into the carbonate pile, circulates slowly upwards through the porous-permeable interior and emerges at the reef crest or carbonate platform surface to support primary productivity of the surficial carbonate-producing communities (Fig. 1).

2. Dolomite

Drillings on Pacific Ocean atolls (Kita-daito-jima, Enewetak, Midway, Niue, Aitutaki, Mururoa, and Fangataufa) and guyots (Resolution) have recorded the presence of dolomitization from near-surface to considerable depths. However, there is range of opinions regarding the origin of such dolomite and the mechanism of dolomitization. Results obtained from massive replacive dolomite which occurs within the Early Cretaceous age carbonate rocks recovered from ODP Leg 143 Hole 866A on Resolution Guyot, Mid-Pacific Mountains provide an insight into the potential of the geothermal endo-upwelling convection process for dolomite formation.

3. ODP Leg 143, Hole 866A

The subsidence history of Resolution Guyot is reasonably well constrained. Shallow-water carbonate sediments accumulated from about 124 Ma (Barremian) to about 100 Ma (late Albian). Then for some unknown reason(s) (see Rougerie and Fagerstrom, 1994) sedimentation ceased and

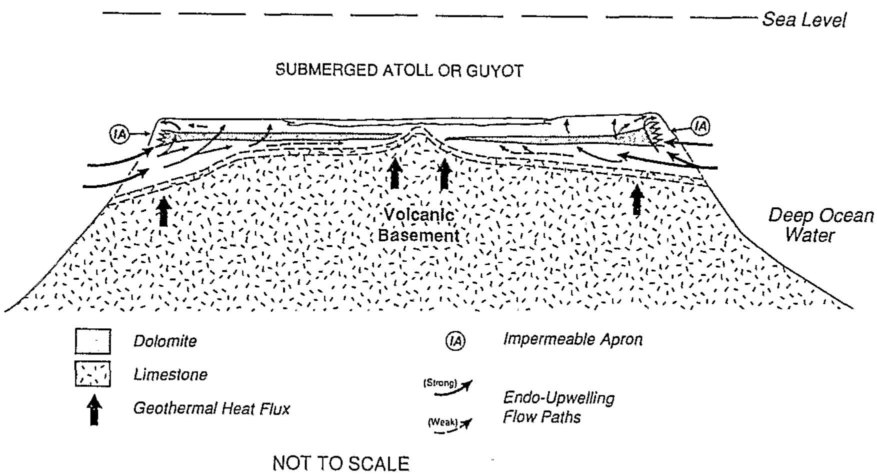

Fig. 1. Schematic cross-section of an atoll or carbonate platform, the thermal convection process associated with geothermal endo-upwelling circulation, and the occurrence of massive dolomitization. Modified from Aissaoui et al. (1986, fig. 1B).

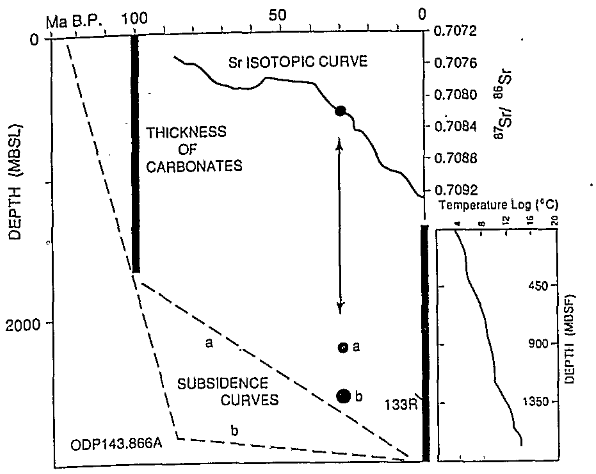

Fig. 2. Subsidence history of Hole 866A, Resolution Guyot. The heavy solid lines of the figure represent the drill hole section through the shallow-water carbonate sequence during the initial subsidence–accretion phase (upper left) and at present time (lower right). It is not known whether the subsidence proceeded according to that indicated by curve *a* or curve *b*. The samples of massive white dolomitization analysed for the strontium isotopic signature were from Core 133R. Comparison of published strontium isotopic seawater curve and the measured strontium isotopic value indicates that the massive white dolomitization occurred ca. 24 Ma (100 m.y. after deposition) when the guyot was covered by 2000 m of water. Points *a* and *b* provide age and depth of massive dolomitization corresponding to subsidence curve *a* or *b*, respectively. Irrespective of which subsidence curve is correct, the dolomitization event occurred within the carbonate platform at a depth below 2000 m. The shipboard temperature log measured within Hole 866A is indicated to the lower right.

for the following 100 m.y. the guyot slowly subsided to its present depth where the upper surface is now covered by more than 1300 m of water. A 1961-m-thick carbonate platform is surrounded by deep ocean waters and it has not been buried in basinal sediments.

Massive replacive brown-coloured dolomite is ubiquitous below 1200 mbsf in a core from Hole 866A (Flood and Chivas, 1995) which was drilled through the drowned carbonate platform. Of particular interest is a 50-m-thick interval of white dolomite recovered from Core 133R (Fig. 2) at approximately 1300 m below the sea floor. This white dolomite interval occurs within the more extensive interval of brown dolomite.

The strontium isotope values of the brown- and the white-coloured dolomite have been determined by the Precise Radiogenic Isotope Services of the Research School of Earth Sciences, Australian National University, Canberra Australia, using a Finnigan MAT 261 multicollector mass spectrometer. Also the $\delta^{18}O$ value of the dolomites was measured at the same Research School of Earth Sciences, using the Kiel preparation device manufactured by Finnigan MAT of Bermen, Germany and a Finnigan MAT 251 mass spectrometer.

A $^{87}Sr/^{86}Sr$ ratio of approximately 0.70735 and 0.70822 (Flood and Chivas, 1995) was obtained from the brown and white dolomites, respectively. In interpreting the Sr isotope values, all of the Sr is viewed as coming from seawater and none from any precursor limestone. Examination of seawater Sr isotope variations throughout time (Smalley et al., 1994) indicates that the brown dolomite formed during the early Aptian or early Albian (115–105 Ma) whereas the white dolomite formed about 24 Ma. That is 100 m.y. younger than the depositional age of the shallow-water carbonate sediments. The formation of the massive white dolomite occurred within the carbonate sediments in a water depth of approximately 2000 m.

Land (1985, p. 118) has published an equation for calculating the temperature of dolomite formation, based on the $\delta^{18}O_{PDB}$ values. The equation is:

$$T\ (^{\circ}C) = 16.4 - 4.3\left[(\delta^{18}O\ \text{dol.} - 3.8) - \delta\ \text{water}\right] + 0.14\left([\delta^{18}O\ \text{dol.} - 3.8] - \delta\ \text{water}\right)^2$$

For the brown dolomite the $\delta^{18}O$ values range from -1.6 to $+0.7$; the $\delta^{18}O$ for the white dolomite is $+3.7$. In interpreting the oxygen isotope values, all of the oxygen is viewed as coming from seawater and none from any precursor limestone. If differences in seawater isotopic compositions throughout time are allowed for the formation, temperature (using the $\delta^{18}O$ value for seawater; see Lohmann, 1988, p. 67, fig. 2.8) of the brown-coloured dolomite ranges from 15° to 30°C, whereas the white-coloured dolomite displays a formation temperature of approximately 17°C. This latter formation temperature approximates the shipboard-recorded temperature of 13.6°C measured at 1671.5 mbsf (Sager et al., 1993, fig. 59) and not the near-freezing (4°C) seawater surrounding the guyot. As interstitial waters in the interior of Resolution Guyot have a major-element composition similar to seawater (Sager et al., 1993), geothermal endo-upwelling convective processes could be responsible for fluid flow (sensu Wilson et al., 1990, fig. 14c; Tucker and Wright, 1991, fig. 8.28; or Kaufman, 1994, fig. 1c) circulating throughout the guyot. Paull et al. (1995) suggest that fluid flushing by more than 10,000 pore volumes of seawater has occurred since the carbonate platform was drowned. Massive dolomite could be a by-product of the guyot plumbing system with seawater supplying the required magnesium, and removing the calcium liberated in that ionic exchange. Whilst some degree of caution should be exercised in any interpretation, the contrasting $^{87}Sr/^{86}Sr$ ratio and the different $\delta^{18}O_{PDB}$ values of the two different-coloured dolomites does appear to support the proposition of different pulses of dolomitization.

4. Conclusion and implications

There is no obvious explanation for the preferential selection of the stratigraphic interval containing the white-coloured dolomite. The interval does not display evidence for the former presence of the early brown-coloured dolomite.

One possible interpretation concerning conditions favourable for dolomitization includes the following points.

(1) A permeable carbonate substrate.

(2) Contiguous deep ocean waters supplying an abundant source of Mg^{2+} ions (Land, 1985) and capable of dissolving aragonite (and calcite).

(3) A heat-generating basement that provides a geothermally driven convective process (endo-upwelling).

When these conditions combine there is the potential for massive dolomitization. Published results from Enewetak (Saller, 1984), Mururoa (Aissaoui et al., 1986), Niue (Aharon et al., 1987), and Resolution Guyot (Flood and Chivas, 1995) support the proposal. Endo-upwelling circulation may be also responsible for the reported occurrence of dolomite on other oceanic atolls and ancient carbonate platforms.

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