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Images of diagenetic textures in Porites corals from Papua New Guinea and Indonesia

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Abstract
Diagenesis is now recognized as a potentially major source of error in paleoclimate reconstructions from fossil and modern coral geochemical records. Key to avoiding spurious results caused by diagenesis is thorough screening of coral material prior to geochemical analysis. In this data brief we present color images from thin sections of fossil and modern Porites corals and demonstrate the effectiveness of thin sections in detecting low levels of diagenesis. The images presented here cover a range of coral preservation levels from pristine aragonite to 100% calcite. We particularly focus on samples containing around 1% diagenetic material, a level known to create artifacts in key climate parameters such as sea surface temperature, and close to the detection limits of other screening methods such as X-ray diffraction (XRD). A qualitative scheme is also presented to rate the degree of diagenesis in a coral, where XRD results are not available or where secondary aragonite is present. Overall, this collection of images is designed as a starting point, in combination with other techniques, to assist in identifying and screening corals for diagenesis.

Keywords
Images, diagenetic, textures, Porites, corals, from, Papua, Guinea, Indonesia, GeoQUEST

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Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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Images of diagenetic textures in *Porites* corals from Papua New Guinea and Indonesia

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[1] Diagenesis is now recognized as a potentially major source of error in paleoclimatic reconstructions from fossil and modern coral geochemical records. Key to avoiding spurious results caused by diagenesis is thorough screening of coral material prior to geochemical analysis. In this data brief we present color images from thin sections of fossil and modern *Porites* corals and demonstrate the effectiveness of thin sections in detecting low levels of diagenesis. The images presented here cover a range of coral preservation levels from pristine aragonite to 100% calcite. We particularly focus on samples containing around 1% diagenetic material, a level known to create artifacts in key climate parameters such as sea surface temperature, and close to the detection limits of other screening methods such as X-ray diffraction (XRD). A qualitative scheme is also presented to rate the degree of diagenesis in a coral, where XRD results are not available or where secondary aragonite is present. Overall, this collection of images is designed as a starting point, in combination with other techniques, to assist in identifying and screening corals for diagenesis.

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1. Introduction

Long-lived, massive corals have proved invaluable archives of tropical environmental and climate changes. Geochemical tracers including δ¹⁸O, trace element/Ca, radiocarbon, and U/Th are incorporated in skeletal aragonite as a coral grows. These tracers have been used to reconstruct climate parameters such as sea surface temperature (SST), sea surface salinity, pH, ocean circulation, upwelling, river discharge, and past sea levels through the Holocene and beyond [see Gagan et al., 2000, 2004; Corrège, 2006; Grottoli and Eakin, 2007].

Diagenesis, however, is recognized as a major source of error in reconstructing these environmental variables. For example, secondary aragonite, typical for early marine diagenesis of modern corals, causes considerable alteration of coral geochemistry and creates “cool” SST artifacts [Bar-Matthews et al., 1993; Enmar et al., 2000; Müller et al., 2001; Lazar et al., 2004; Müller et al., 2004; Allison et al., 2007]. Secondary calcite, both in very young corals and fossil coral samples, can lead to “warm” SST artifacts [Houck et al., 1975; MacIntyre and Towe, 1976; McGregor and Gagan, 2003; Allison et al., 2007; Nothdurft et al., 2007]. Dissolution was shown to create “cool” anomalies in a range of trace element SST proxies [Hendy et al., 2007]. Numerous studies have called for screening for diagenesis in modern and fossil corals to become standard procedure [Gagan et al., 2004; Quinn and Taylor, 2006; Allison et al., 2007; Hendy et al., 2007].

To this end, we present color images from our photo micrograph collection depicting typical diagenetic textures observed in fossil Porites sp. corals from Papua New Guinea (PNG) and Indonesia. Diagenesis that produces an addition of

<table>
<thead>
<tr>
<th>Coral Sample字母</th>
<th>Calendar Age and Error (years BP)</th>
<th>% Calcite</th>
<th>Qualitative Diagenesis Rating</th>
<th>Figure</th>
<th>Present-Day Diagenetic Zone</th>
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<tr>
<td>MS01 modern</td>
<td>0.3 (BDL)</td>
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<td>1a, 2c–2d</td>
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<td>-</td>
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<tr>
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<td>3d</td>
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<tr>
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<td>good</td>
<td>7d</td>
<td>freshwater vadose</td>
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<tr>
<td>TM01-A-4 6650–7130</td>
<td>-</td>
<td>excellent</td>
<td>3e</td>
<td>freshwater vadose</td>
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a Samples with prefix XRDFM08 are from coral FM08 and samples with the prefix XRDFM19 are from coral FM19. Samples marked with asterisks have XRD samples and thin section collocated.

b Papua New Guinea (PNG) coral ages based on U-Th dating, data from McGregor et al. [2008]. Mentawai coral ages based on radiocarbon dating, with calibration using the marine database of Calib5 and an additional local reservoir correction of 85 ± 65 years [Abram et al., 2003; Hughen et al., 2004]. Calibrated radiocarbon ages are reported as a 2 sigma range.

c Calculated using the Rietveld method, which does not take into account measurement errors. “BDL” signifies calcite at below the X-ray diffraction (XRD) detection limits.

d For the fossil corals listed it should be noted that the diagenetic zone indicates the present-day setting of each coral; each fossil sample will have been in other diagenetic environments (including marine phreatic growth environment) in the past. Also, in general just because a coral is in a given diagenetic environment does not mean that diagenesis will occur.
10% or more secondary material to the skeletal bulk density can be detected in coral density profiles, X-radiographs, and UV luminescence photos [Hendy et al., 2007]. For lower levels of diagenesis, X-ray diffraction (XRD) has been the most commonly used diagenesis screening method in coral paleoclimate studies. Thin section analysis has the advantage in that it can distinguish secondary aragonite from primary aragonite, whereas XRD cannot (both give the same XRD diffraction pattern). In addition, the XRD detection limit is at best around 1% calcite [Klug and Alexander, 1954; McGregor and Gagan, 2003; Allison et al., 2007]; however, even such low levels of calcite have been shown to cause significant alteration of coral proxy climate signals [McGregor and Gagan, 2003; Allison et al., 2007; Nothdurft et al., 2007].

While the identification of low levels of coral diagenesis is possible using petrographic sections, no specific guides exist to assist coral paleoclimatologists in screening for diagenesis using this method. The color images presented here are designed as a resource to aid in the identification of secondary aragonite, calcite, and dissolution in coral thin sections. We show a range of diagenesis levels and focus on diagenetic textures at around the 1% calcite level. While by no means a collection of all possible diagenetic textures in corals, these images provide a comprehensive starting point for further investigation.

2. Methods

Fossil and modern Porites sp. corals photographed and analyzed in this study are from PNG and Indonesia. Fossil coral cores from PNG were drilled from the intertidal zone of Muschu and Koil Islands, offshore of the Sepik River mouth in northeastern PNG [McGregor and Gagan, 2003]. The Indonesian fossil corals were collected from raised paleofringing reefs in the intertidal/vadose zone surrounding the Mentawai Islands, western Sumatra [Abram et al., 2003]. All fossil corals described here are of Holocene age [Abram et al., 2003; McGregor et al., 2008]. Modern coral samples were also collected from the present-day reefs at both localities.

Diagenesis of coral skeletal aragonite typically occurs in phreatic or vadose zones, and the present-day diagenetic zones for the corals in this study are given in Table 1. The terms phreatic and vadose refer to the saturation state of pore spaces within and around the coral. In phreatic zones pores are completely saturated with either seawater or freshwater. Freshwater phreatic zones are generally below the water table. In vadose zones pore spaces are filled with a mixture of air with seawater (marine vadose) or freshwater (rainwater or meteoric; freshwater vadose).

Diagenesis results in different minerals (secondary aragonite or calcite) depending on the zone [Longman, 1980]. The growth of secondary aragonite on the coral skeletal structure typically occurs within marine phreatic and marine vadose zones [Longman, 1980]. Secondary calcite, growing on the skeletal structure or replacing the original organic aragonite, occurs during subaerial exposure in the marine or freshwater vadose zones or can occur in freshwater phreatic environments [Longman, 1980]. Dissolution of coral aragonite can occur in any diagenetic environment and can...
Figure 2. Thin section images of pristine modern coral aragonite. (a) Coral TN99-A-4 and (b) coral PG01-A-2, both from the Mentawai Islands, and in cross-polarized light. (c) Coral MS01, PNG, and (d) increased magnification of coral MS01 for the area indicated by the box in Figure 2c. In Figures 2c and 2d, images on the left-hand side are in cross-polarized light and images on the right are in plane-polarized light. Black, double-headed arrows in Figure 2a indicate the width of trabeculae and are aligned perpendicular to growth direction (toward top left of the image). The brown lines along the center of trabeculae are the COC. The circles in Figure 2a indicate areas where trabeculae are linked by synapticulae. U-shaped dashed lines in Figure 2d outline the edge of sclerodermites. The colors within the sclerodermites are the interference colors of the radiating fans of fasciculi forming sclerodermites. Dashed lines in Figure 2d indicate daily growth bands, and arrow indicates the dark, linear COC. Cross-polarized image in Figure 2c after McGregor and Gagan [2003].
occur within decades of skeletal formation [Hendy et al., 2007]. The diagenetic textures in this study are predominantly from diagenesis in the vadose zones, though the high rainfall in PNG and western Indonesia may have led to diagenetic textures more like those of the freshwater phreatic zone [McGregor and Gagan, 2003].

[5] XRD analysis was used to estimate the percent of secondary calcite present in coral samples. Samples were ultrasonically cleaned, and then approximately 100 to 200 mg of material was ground under ethanol to approximately 25 μm and smeared onto a glass slide. The slides were analyzed on a Siemens Diffractometer with the Cobalt X-ray tube on 90% loading (30 mA, 50 mV) and scanned from 2θ of 20° to 60°. The percent aragonite and calcite in each sample was estimated using SIROQUANT v. 2.5 software. Errors on estimates of percent calcite are ~1–2%.

[10] Thin sections were used to evaluate the presence of secondary aragonite, calcite, and dissolution in the coral samples. Thin section blocks were set in epoxy resin, and then standard 0.03 mm thick, 60 × 20 mm petrographic thin sections were prepared for each coral. Images of coral thin sections were made using a Nikon Optiphot-pal petrographic microscope fitted with a Polaroid DMC digital camera. Photographs were taken in plane- and/or cross-polarized light, and, where necessary, images were adjusted for brightness, contrast, and color using Adobe Photoshop.

[11] Fossil corals FM08 and FM19 have been used previously to investigate geochemical changes due to diagenesis [McGregor and Gagan, 2003], and additional thin section images from these corals are presented in this study. The images were matched as closely as possible to samples used for XRD analysis [see McGregor and Gagan, 2003]. For the other PNG corals used in this study XRD samples were taken from a similar region to the thin section blocks.

[12] The thin section images of PNG corals were grouped based on the percent of calcite from XRD analysis (Table 1) and on observed thin section diagenetic textures (Figures 1 to 10). Images from the Mentawai corals were qualitatively compared to PNG corals to rate the degree of diagenesis, for instances where XRD results are not available or secondary aragonite is present: “excellent” preservation is equated to calcite below detection levels and no diagenetic textures are observed in thin section; “good” preservation is equivalent to <1% calcite or rare diagenetic textures in thin section; “fair” preservation is equivalent to 3–5% calcite; “poor” preservation equates to ≥10% calcite.

[13] Calcite and aragonite have similar optical properties when viewed in thin section under plane-polarized and cross-polarized light. In plane-polarized light both inorganic calcite and aragonite appear colorless, and both have high relief [Kerr, 1977]. Calcite may also “twinkle” in plane-polarized light. That is, the relief changes markedly as the stage is rotated [Shelley, 1985]. In cross-polarized light aragonite and calcite have similar high birefringence of 0.156 and 0.172, respectively [Kerr, 1977]. The maximum interference colors for these minerals are pearl gray (Figure 1a) or perhaps even high-order white for calcite. Birefringence depends on the thickness of the thin section, natural properties of the mineral and the direction that the mineral is cut [Kerr, 1977]. In sections slightly thinner than 0.03 mm, or at the thinner edges of slides, the aragonite and calcite minerals may show the pastel pinks and greens of the fourth- or fifth-order birefringence colors. If bright yellows, blues, and pinks are visible then the thin section is probably too thin (<0.01 mm) and the colors are the lower second-order colors (Figure 1b).

[14] Because of the similar optical properties of calcite and aragonite, staining techniques and/or characteristic textures must be used to differentiate these minerals. Inorganic calcite is likely to have an anhedral crystal form, whereas inorganic aragonite shows a fibrous or needle-like structure. The organic aragonite of coral material also has distinctive growth textures that facilitate...
Figure 3
Figure 4. Aragonite pieces produced as algae bore into a coral skeleton. PNG corals (a) FM22, (b) FK05, and (c) increased magnification of the area indicated by the box in Figure 4b. Examples of aragonite pieces are indicated by the arrows in the images. Cross-polarized light images are on the left and plane-polarized light images are right. These postdepositional changes would not be detected by XRD.

Figure 5. Thin section images from PNG coral FM15. (a) Cross-polarized light image of well-preserved coral from 40 cm from the top of coral FM15, and (b) increased magnification, cross-polarized (upper) and plane-polarized (lower) for the area indicated by the box in Figure 5a. (c) Cross-polarized light image of rims of isopachous, fibrous secondary aragonite needles (arrows) around primary coralline material toward the base of core FM15. Some dissolution of COC is also present, and (d) increased magnification cross-polarized (left) and plane-polarized (right) light images of isopachous secondary aragonite from the boxed area in Figure 5c. (e) Small amounts of secondary calcite spar (arrows) growing into voids at the base of core FM15. Identification of diagenesis in thin sections of coral FM15 is in contrast to XRD analysis that indicates no secondary calcite (Table 1) and highlights the value of thin section analysis.
Figure 6
evaluations of the preservation of original coral carbonate.

3. Results and Discussion

3.1. Pristine Modern and Fossil Corals

Coral skeletal elements and crystal structure can be seen in unaltered modern coral thin section images (Figure 2). The images show trabeculae linked by support rungs (synapticulae) [Cohen and McConnaughey, 2003]. Dark centers of calcification (COC) are visible along the middle of the trabeculae. COC consist of ≤1 micron sized, randomly oriented, equant crystals that appear dark to opaque in thin section (total COC width ~5 micron) [Wainwright, 1963]. The COC may be surrounded by a brown zone (as seen in thin section), which is a mixture of micron-sized crystals and elongated aragonite needles [Wainwright, 1963; James, 1974]. Aragonite fibers, arranged in spherulitic bundles, form fasciculi growing and fanning out from the COC, which together form sclerodermites, the “cone in cone” building blocks of the trabeculae [James, 1974; Cohen and McConnaughey, 2003]. The fasciculi show typical aragonite birefringence colors. Finally, at the edge of the trabeculae, fasciculi are planed off and a fine layer of submicron-sized microcrystalline aragonite is precipitated [Constantz, 1986a], again brown in thin section and visible particularly in plane-polarized light. Dissepiments, thin (10–40 μm), horizontal layers spaced approximately every 1–2 mm [Barnes and Lough, 1993], may be present in thin section, though are not represented in Figure 2.

In thin section, well-preserved modern and fossil corals should show all original coral skeletal features, as well as an absence of void filling by calcite or secondary aragonite [Constantz, 1986b]. It should be noted that although modern corals are less likely to be affected by diagenesis they are not exempt. There are now several documented examples of modern corals affected by secondary aragonite, often within years of the deposition of the skeleton [Enmar et al., 2000; Müller et al., 2001; Lazar et al., 2004; Müller et al., 2004; Quinn and Taylor, 2006; Hendy et al., 2007]. Secondary aragonite is the most likely diageneis in modern corals and the textures are similar to secondary aragonite precipitated in fossil corals.

Examples of good preservation of fossil corals are presented in cross- and plane-polarized light in Figure 3. Images show excellent preservation of COC. The radiating sclerodermites are visible, as are the dissepiments and in some places daily growth bands. No borings, sediment infillings, or cements are present and there is minimal leaching. These images show that it is possible to find well-preserved fossil corals that are at least many thousands of years old.

3.2. Textures With <1% Diagenesis

Although XRD is a useful tool in detecting secondary calcite in coral material it cannot be relied upon alone to detect diagenesis. Figures 4–7 show examples of diagenesis in samples where XRD analysis shows calcite levels at or below the ~1% XRD detection limit.

XRD of corals FM22 and FK05 from PNG suggested that calcite was absent from these corals. However, thin sections show that diagenesis resulting from algal boring is present (Figure 4). As algae bore into the coral structure they produce castings of the coralline aragonite, which show similar birefringence to the surrounding coral. If the castings are not removed by ultrasonic cleaning, the geochemical signal obtained by high-resolution analysis (e.g., laser ablation) of the coral may be smoothed. Otherwise, the presence of minor amounts of algal borings alone is not likely to influence climate reconstruction.

More problematic are occurrences of secondary aragonite, which in XRD are not distinguished from primary coral aragonite, and which cause an increase in coral Sr/Ca [Enmar et al., 2000; Müller

Figure 6. Images of coral diagenetic textures in PNG coral samples FM08 and FM19 with <1% calcite as indicated by XRD. (a) Rims of secondary calcite and calcite spar (arrows) growing from the edge of coral skeletal material into pore spaces in coral FM08. Dissolution of COC (arrow with Dis) is also evident. (b) Increased magnification of secondary calcite in FM08 for the boxed area in Figure 6a. Features in the image are labeled as for Figure 6a. (c) Cross-polarized light image of secondary calcite overgrowths (arrows) in coral sample XRD FM19-AR. This image was taken from the location where XRD indicated <1% calcite (Table 1). (d) Increased magnification of boxed area in Figure 6c. (e) Images from coral FM08 of rims of secondary calcite growing along the edge of primary coral material (arrows), and dissolution of COC (arrows with “Dis”). In Figures 6a, 6b, and 6e, images on the left are in cross-polarized light and on the right are in plane-polarized light.
Figure 7. Images of PNG coral diagenetic textures at \( \leq 1\% \), compared with diagenetic textures in Mentawai corals rated as “good” preservation. (a) Secondary calcite (arrows) and dissolution (arrows with “Dis”) in coral sample XRDFM08–3, from PNG. The XRD sample gave 1% calcite and was located as close as possible to the thin section location from which this image was taken (Table 1). (b) Increased magnification of secondary calcite (arrow) and dissolution (arrow with Dis) for the boxed area in Figure 7a. In Figures 7a and 7b, images on the left-hand side are in cross-polarized light and images on the right are in plane-polarized light. Mentawai corals (c) LB99-A-7 and (d) TN99-A-1b from the Mentawai Islands. Both these images are in cross-polarized light and show rare aragonite rims (arrows) lining the original coral aragonite structure. Texturally, these corals are likely equivalent to samples with <1% calcite.
Figure 8. Images of diagenetic textures associated with 3–5% calcite in PNG corals and with Mentawai corals rated as “fair.” (a) Images of PNG coral FM08 taken from a similar location to sample XRDFM08–6 (3% calcite; Table 1). (b) Images of PNG coral FM19 taken from a similar location to sample XRDFM19–2 (5% calcite; Table 1). (c) Image of Mentawai coral AT99-A-3b rated as having “fair” preservation. Cross-polarized light images are on the left and plane-polarized light images are right. In the PNG coral images secondary calcite overgrowths (arrow) have thickened compared to samples with ≤1% calcite. Calcite spar (arrow with “C”) replaces original aragonite in places, and dissolution of coralline skeletal material continues (arrow with “Dis”). Fasciculi are less distinctive. The thicker calcite rims and the increased dissolution along the COC in Figure 8c suggest that the “fair” rating roughly equates to 3–5% calcite. Cross-polarized light image in Figure 8a after McGregor and Gagan [2003].
Figure 9
et al., 2001; Quinn and Taylor, 2006; Hendy et al., 2007]. This is exemplified by PNG coral FM15 (Figure 5). Multiple XRD analyses of this coral suggested near 100% aragonite (Table 1). Five thin sections were made for coral FM15, spaced down the 0.9 m length of the core. Thin sections from the upper section of the core showed pristine coral aragonite. However, the basal thin sections showed secondary aragonite, characterized by ~40 μm wide clusters of thin acicular needles (isopachous fibers) filling the skeletal voids. In addition, the basal section of core FM15 also contains minor, equant-grained calcite crystal overgrowths. The brown areas in Figure 5 are due to dissolution of the coral skeleton (dissolution is discussed below). The diagenesis in FM15 would not have been detected using XRD alone, highlighting the usefulness of assessing the alteration of coral material using thin sections.

[21] XRD results from corals FM08 and FM19 from PNG suggest that parts of these corals contain calcite at near the ~1% detection level (Table 1; other areas have much higher percentage of calcite as discussed later in the text). One percent secondary calcite is enough to cause 1°C warming artifacts in absolute Sr/Ca SST reconstructions [McGregor and Gagan, 2003], although seasonal variability in Sr/Ca SST may still be preserved [McGregor and Gagan, 2003]. Thin sections were taken from as close as possible to the XRD sampling sites in corals FM08 and FM09. The diagenetic textures reveal that the calcite is distributed as irregular rims around skeletal voids and occasionally replaces the coralline aragonite (Figure 6).

[22] Dissolution of coral aragonite is also visible (Figure 6). Dissolution may alter the original coral trace element signal [Hendy et al., 2007] and is also not detected by XRD. Dissolution usually begins at the COC and is identified in thin section by darkening of the COC and/or by a brown hue surrounding calcification centers. The coloring of dissolution seen in thin section is due to internal reflection of light in minute voids between the dissolved primary aragonite needles [James, 1974]. If progressed far enough, dissolution can result in complete removal of the original coral material.

[23] Mentawai corals with a qualitative preservation rating of “good” are shown in Figure 7. These corals show early signs of aragonite dissolution and fine-scale rims of secondary material. Comparison with the PNG corals FM08 and FM19 shows dissolution and rims are far less developed and likely represent <1% diagenetic carbonate.

### 3.3. Textures With >3% Calcite

[24] As the degree of diagenesis increases the diagenetic textures in thin section become more distinctive and, where the diagenesis is caused by calcite, XRD becomes more definitive. With 3–5% calcite in the PNG corals (Figure 8) dissolution outward from the COC becomes more extensive. The rims of void-filling, spary calcite become wider, up to 50 μm in Figure 8a. Sclerodermites are difficult to distinguish and calcite may begin to replace the original skeletal aragonite. This calcite replacement texture is particularly clear in plane-polarized light, where it has a clear appearance that differs from the fibrous structure of original coral aragonite. Dissolution and thickening calcite rims also characterize Mentawai corals classified as having “fair” preservation.

[25] At 10–30% calcite (Figure 9), dissolution and leaching is more extensive in the PNG corals. In thin section the coral structure appears brown, and as dissolution and leaching extend further it begins to be evident in hand specimens of coral as a softer zone with the hardness of chalk [James, 1974; Pingitore, 1976]. At 10–30% diagenesis, calcite rims and calcite replacement of primary aragonite may also be present, and some voids begin to be filled with single crystal calcite spar. This single crystal calcite spar goes into extinction simulta-

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**Figure 9.** Images of diagenetic textures associated with 10–30% calcite in PNG corals, and with Mentawai corals rated as “poor”. (a) Images of PNG coral FM19 taken from a similar location to sample XRDFM19–9 (13% calcite; Table 1). (b) Another image from PNG coral FM19. For Figures 9a and 9b, cross-polarized light images are on the left and plane-polarized light images are right. (c) Cross-polarized and (d) plane-polarized light image of Mentawai coral SPB01-A-1b. (e) Cross-polarized light image of Mentawai coral SPB01-A-2. The presence of 10–30% secondary calcite in the PNG corals is characterized by continued thickening of secondary aragonite rims (arrows) and dissolution (arrow with “Dis”), more prominent replacement of original aragonite by calcite spar (arrow with “C”), the first instances of void-filling by single calcite spar (V), and thickened dark brown, micritic rims (arrow with “M”). The “poor” preservation rating for the Mentawai corals is likely equivalent to at least this secondary calcite content.
Figure 10

A. V C
100 μm

B. M
100 μm

C. N NF
500 μm

D. N NF
500 μm

E. V C
200 μm

V C
neously across the whole crystal when rotated under cross-polarized light. Mentawai corals that were given a qualitative preservation rating of "poor" are equated with at least this level of diagenesis. The Mentawai corals show thick micritic rims, aragonite dissolution with calcite replacement, and rims of equant calcite crystals filling voids.

[26] For completeness we include examples of diagenetic textures at 40–100% calcite, although in reality the hand specimens, X-radiograph images, and geochemistry of corals with this level of diagenesis should make it obvious that such samples are dominated by the diagenetic overprint and are not suitable for paleoclimatic reconstructions. Textures at 40–100% calcite (Figure 10) show extensive mosaics of calcite spar replacing the skeletal aragonite. Micritic calcite rims are present where voids have not been filled with single crystal calcite spar. Millimeter-sized single crystals of calcite may be present, bounded by coral dissepiments. In addition, neomorphism may be observed, whereby aragonite is replaced with calcite without destroying the gross coral morphology [Bathurst, 1975]. This replacement is often associated with a neomorphic front, a zone where aragonite transforms to calcite across a thin film of water separating the two minerals. The minerals may also be separated by a "chalky" zone where dissolution of aragonite is occurring at a faster rate than the precipitation of calcite [Pingitore, 1976; McGregor and Gagan, 2003]. Finally, at essentially 100% calcite, the aragonite skeleton has been completely replaced by calcite that preserves the primary skeletal structure. Almost all voids are filled with single crystal calcite spar that is bounded by the original coral microstructure and forms fabric selective mosaics [Pingitore, 1976].

4. Conclusions

[27] Presented here are a selection of representative images of diagenetic textures in corals from PNG and Indonesia. The images show distinctive textures seen in coral samples over a range of levels of diagenesis. With diagenesis of around 1%, a level sufficient to alter the primary coral geochemical signal, thin sections are more effective than XRD at detecting diagenesis.

[28] While by no means an exhaustive list of diagenetic textures, the images here are designed as a starting point for other coral researchers to assist them in recognizing and avoiding diagenesis in their own coral samples. Ideally, thin section analysis should be used in combination with a suite of other methods such as XRD, scanning electron microscopy, and densitometry (to detect dissolution). However, in the absence of XRD and other methods, the qualitative scale presented here for the Mentawai corals appears to be a good substitute.

[29] Diagenesis, even at low levels, has the potential to distort the primary chemistry of coralline aragonite. Detecting and avoiding diagenesis is of utmost importance to coral paleoclimate research, and thin section analysis should play an important role in that endeavor.

Acknowledgments


Figure 10. Diagenetic textures associated with >40% calcite in PNG corals. (a and b) Images of coral FM19 taken from a similar location to sample XRDFM19–7 (53% calcite; Table 1) showing void filling calcite spar (V) and calcite spar, calcite spar replacement of primary skeletal material (arrow with "C"), micritisation (arrow with "M"), and calcite rims (arrow). (c) Image from coral FM08 of a 2 mm calcite spar crystal (V) bounded by coral dissepiments. Figure 10c also shows neomorphism (marked as "N"; a zone of complete replacement of original aragonite by calcite while preserving the outline of the coral skeleton) bounded by a neomorphic front (arrow with "NF"), with dissolving coral aragonite (dark brown) on the other side of the front. (d) Image from coral FM19 showing in more detail neomorphism (arrow with "N") and a well-developed neomorphic front (arrow with "NF") surrounding an area of void filling calcite (V). Black, double-headed arrow indicates the "chalky zone," where aragonite dissolution is occurring faster than calcite replacement. (e) Image of coral FM19 taken from a similar location to sample XRDFM19–11 (77% calcite; Table 1). In Figure 10e almost complete dissolution has occurred, followed by precipitation of a mosaic of spar calcite into the resulting mold. In Figures 10a, 10b, and 10e, cross-polarized light images are on the left and plane-polarized light images are on the right. Figures 10c and 10d are in cross-polarized light only. Cross-polarized image in Figure 10e after McGregor and Gagan [2003]. Figure 10c after Müller et al. [2006].
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