Coral reconstructions of 20th century changes in coral calcification and reef growth caused by increase in atmospheric CO_2

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Recent research suggests that future decreases in the aragonite saturation state of surface seawater associated with the projected build-up of atmospheric CO_2 could cause a global decline in coral reef-building capacity. Whether significant reductions in coral calcification are underway is a matter of considerable debate. Experimental and modeling studies suggest that rates of coral calcification should have already declined in response to the 20th century build-up of atmospheric CO_2 (Gattuso et al., 1999, Kleypas et al., 1999, Langdon et al., 2000, Leclercq et al., 2000, Marubini et al., 2001). It is estimated that aragonite saturation in the tropical surface ocean will decrease by ~14 – 40 % due to the rising partial pressure of CO_2 and temperature of seawater under a doubling of the pre-industrial atmospheric CO_2 (Kleypas et al., 1999; Langdon et al., 2000). Gattuso et al., (1998) provided experimental evidence for non-linear changes in calcification rate as a function of aragonite saturation state. Given that a significant acclimation of coral to a reduced saturation state is not expected, it is likely that a decreased saturation state will result in reduced coral calcification rates, a shift toward calcite secretors, or a competitive advantage for non-calcifying reef organisms (Smith and Buddemeier, 1992, Buddemeier, 1994).

Multi-century records of skeletal calcification extracted from massive corals have the potential to reconstruct the progressive effect of anthropogenic changes in aragonite saturation on coral reefs. Studies of calcification parameters in massive coral skeletons have provided evidence for changes in coral reef growth over the past few centuries. A composite record from 35 *Porites sp.* coral cores from the Australian Great Barrier Reef showed a significant decline in skeletal density and calcification over the period 1934 – 1982 (Lough and Barnes, 1997). Analyses of several multi-century coral cores from the Great Barrier Reef, however, shows a significant increase in calcification in the late 20th century relative to the previous two centuries (Lough and Barnes, 2000). Analysis of a long coral core from French Polynesia also shows increased calcification through time (Bessat and Buiges, 2001). Both these studies attributed the rise in calcification rate to increased sea water temperatures. Lough and Barnes (1997) did, however, note a tendency for skeletal density in Great Barrier Reef *Porites* to decline through time. The average skeletal density in 60 % of the long coral cores was significantly higher in the oldest 30 years compared with the youngest 30 years.

In this paper, we show that there may be a tendency for early addition of secondary marine aragonite to the basal portions of massive *Porites* to create an apparent reduction in skeletal

tal calcification rate toward the younger portions of coral records. Early marine aragonite cements are commonly precipitated from porewaters in the basal portions of massive coral skeletons and, if undetected, could result in apparent reductions in coral calcification towards the present. This tendency could lead to errors in the interpretation of past trends in coral calcification and reef growth. To address this issue, we compared records of coral skeletal density, extension rate, calcification rate and $\delta^{13}C$ values for well preserved and diagenetically altered coral cores (cf Müller et al., 2001) spanning ~1840 – 1994 AD at Ningaloo Reef Marine Park, Western Australia. The pristine coral record shows no significant trend in skeletal density or calcification indicative of anthropogenic changes in aragonite saturation state or an oceanic Suess effect. In contrast, progressive addition of early marine inorganic aragonite toward the base of the altered coral produces a ~25 % decrease in skeletal density towards the present, which misleadingly matches the 20th century decrease in calcification predicted by recent modeling and experimental studies (Fig. 1). The slope of the trend agrees most closely with the experimental study of Langdon et al. (2000), who suggest a decline in coral reef calcification of ~40 % between 1880 and 2065 A.D. However, the results of this study demonstrate that a long-term decline in skeletal calcification rate over the life of a coral colony may be purely an artefact of early marine diagenesis in the older part of the coral skeleton.

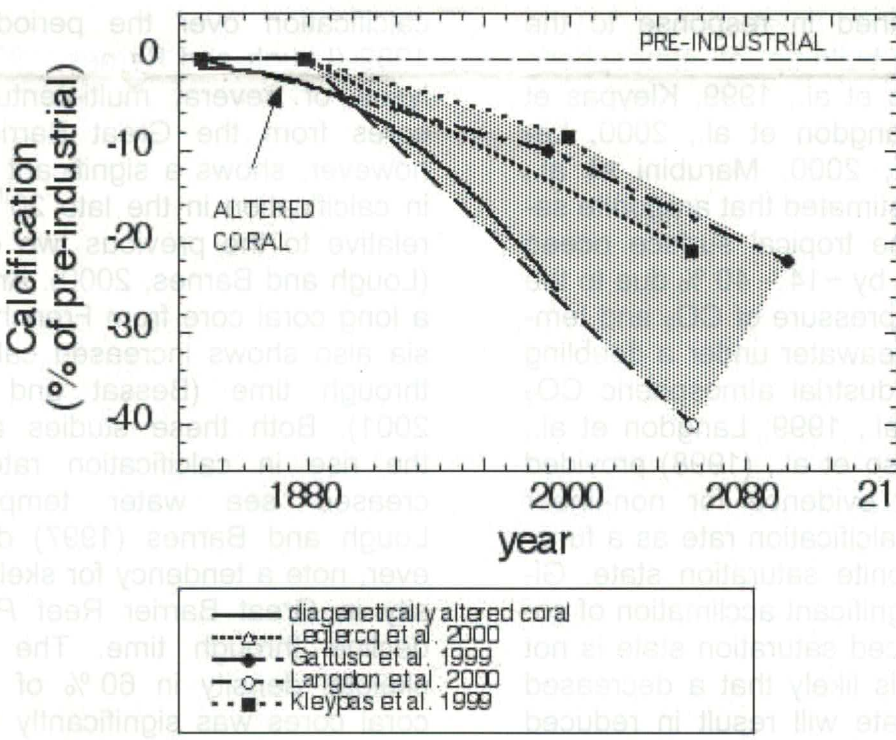

Fig. 1: Second order polynomial curve fit for calcification rates expressed as % decrease after 1880 of pre-industrial values for the diagenetically altered coral from South Muiron Island. The mean value for calcification rates for the diagenetically coral before 1880 (1.50 g.cm^{-2}yr^{-1} for 1830 – 1879) is used as an estimate of 'pre-industrial' calcification rates (i. e. 100 %) Also shown are experimental and modelling estimates of decline in coral calcification due to projected changes in ocean aragonite saturation state from Gattuso (1999), Kleypas et al. (1999), Leclercq et al. (2000) and Langdon et al. (2000).

In addition, the inorganic aragonite is enriched in ^{13}C, relative to coral aragonite, resulting in a decrease in $\delta^{13}C$ toward the present, which mimics the decrease in $\delta^{13}C$ expected from the oceanic Suess effect. The secondary inorganic aragonite is enriched in ^{13}C, relative to coral aragonite, resulting in a 1.6 ‰ decrease in $\delta^{13}C$ toward the present. While this shift is twice as large as that expected in the subtropical surface ocean (~0.8 ‰; Gruber et al., 1999), the trend is similar to that observed for the $\delta^{13}C$ of atmospheric CO_2. Taken together, these diagenetic changes in skeletal calcification and $\delta^{13}C$ could be misinterpreted to reflect changes in surface-ocean aragonite saturation state driven by the 20th century build-up of atmospheric CO_2.

Consequently, early marine diagenesis in coral skeletons can cause significant changes in coral growth and isotopic and geochemical (Müller et al., 2001) tracers that are unrelated to large-scale environmental signals. If undetected, such diagenesis can lead to erroneous conclusions concerning the oceanic Suess effect as the increased cementation in the older part of a coral can result in an apparent decrease in ^{13}C towards the present. If undetected, such diagenesis can also lead to erroneous conclusions concerning changing aragonite saturation state due to increasing atmospheric CO_2 as the increased cementation in the older part of a coral can result in an apparent decrease in coral calcification rate towards the present. Early marine diagenesis can be detected through thin section analysis, comparisons of the magnitude of density and geochemical changes and/or comparisons of calcification rates and $\delta^{13}C$ values. We suggest that evidence for reduced coral calcification in recent decades must be supported by evidence that early marine aragonite cements are not present in the coral cores. With this proviso the records contained in massive coral skeletons can make a significant contribution to understanding and detecting environmental change due to human activities.

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