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Is the core top modern? Observations from the eastern equatorial Pacific

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ABSTRACT

A compilation of ages from 67 core tops in the eastern equatorial Pacific (EEP) does not display an easily discernible regional pattern. The ages range from 790 to over 15,000 years. The youngest core tops with the highest sediment focusing factors are located in the Panama Basin. There are weak but statistically significant inverse relationships between core top age and age-model based mass accumulation rates, bioturbation depth, linear sedimentation rate and sediment focusing factors. However, we found no statistically significant relationship between core top age and calcite dissolution in sediments or ^{230}Th-normalized mass accumulation rates. We found evidence suggesting that greater amount of sediment focusing helps to preserve the carbonate fraction of the sediment where focusing is taking place. When focusing factors are plotted against percent calcite dissolved, we observe a strong inverse relationship, and core tops younger than 4500 years tend to occur where focusing factors are high and percent calcite dissolved values are low. Using labile organic carbon fluxes to estimate bioturbation depth in the sediments results in the observation that where bioturbation depth is shallow (<4 cm), the core top age has a strong, inverse relationship with sediment accumulation rate. We used the *Globorotalia menardii* Fragmentation Index (MFI) as an indicator of percent calcite dissolved in deep sea sediments. There is a distinct pattern to core top calcite dissolution in the EEP which delineates bands of high surface ocean productivity as well as the clear increase in dissolution downward on the flanks of the East Pacific Rise.

1. Introduction

Reconstructing past oceanographic and climatic conditions largely rests on the ability of paleoceanographers to accurately calibrate proxies. Proxies are substitute measurements for oceanographic parameters which are difficult or impossible to measure directly. Proxy calibration is based on finding associations between some feature of core top sediments and a corresponding parameter of the modern ocean, such as seawater temperature, pore water $[CO_3^{2-}]$, or the like. For proxies to produce reliable results in down core applications, it is imperative for the core tops used in their calibration to be "modern" and therefore comparable to the characteristics of the modern ocean.

This poses many difficulties. First, what is meant by "modern"? Ideally once sediments are laid down they would not be disturbed, and the core top would be the same age as the average reservoir age of its sedimentary components. This is almost never the case. In many studies core top ages ranging between 500 and 3000 years is considered "modern" enough for reliable proxy calibration (e.g. Broecker and Clark, 2011; Dekens et al., 2002; Mekik et al., 2002, 2010; Foster, 2008; Regenberg et al., 2009). However, core tops can be much older. Mekik (2014) showed radiocarbon evidence of core top ages greater than 7000 years from the Rio Grande Rise. Anderson et al. (2008) list radiocarbon ages from the central equatorial Pacific ranging between 4000 and 12,700 years in the top 2 cm of the cores. Broecker et al. (1999) list ages from the top 2 cm of cores on the Ontong Java Plateau which range between 3000 and 10,400 years. Thus, even multicores that are thought to have recovered the sediment-water interface (e.g. Anderson et al., 2008) may have apparent core top ages of several thousand years.

A second complicating factor is whether the core top has been preserved intact or disrupted during drilling. Coring mishaps and resulting damage to core tops are often not recorded. Cores raised with multi-corers and box cores offer the best preserved and least disrupted core tops.

Abbreviations: MFI, *G. menardii* Fragmentation Index; EEP, eastern equatorial Pacific; OJP, Ontong Java Plateau; MAR, mass accumulation rates; SEC, South Equatorial Current; CEP, central equatorial Pacific.

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Methods used to determine the age of core tops also vary widely across studies. Oxygen isotope ($\delta^{18}O$) stratigraphy is used to date and correlate findings among deep sea cores. Often $\delta^{18}O$ stratigraphies are supported by radiocarbon dates at various intervals. While not a common practice, some core tops have been dated with radiocarbon. Radiocarbon dating offers absolute ages but has many shortcomings as well. One important issue creating uncertainty in interpreting radiocarbon ages is whether the bulk sediment or individual components of the sediment have been dated. A 7000 year radiocarbon age difference between co-occurring alkenones and shells of planktonic foraminifera has been observed from the Bermuda Rise (Ohkouchi et al., 2002). Similarly, a 2500 year radiocarbon age difference was observed between co-occurring planktonic foraminifer tests and alkenones from the Benguela Basin (Mollenhauer et al., 2003). In contrast, Kusch et al. (2010) found that the radiocarbon ages of alkenones, co-occurring planktonic foraminifers, and total organic carbon agreed well with one another in cores from the Panama Basin in the eastern equatorial Pacific.

Furthermore, whether it is the bulk sediment or some component of the sediment that is dated is important in making inferences about the geological record. Ideally one would date the sedimentary archive (foraminifer shells vs. organic matter) that best serves the application of the proxy down core in interpreting the geological record rather than dating the bulk sediment because different sedimentary components may follow different pathways to the sea bed, each with different time scales. It is important to be aware of these complicating issues when assigning ages to core tops and down core horizons. Unfortunately it is not always possible to date the archive of interest directly because the archive may be too scarce for radiocarbon dating (such as specific organic compounds) or may not contain datable material (such as dust-derived minerals). Consequently, it is common practice to apply dating methods to the most abundant suitable components of the sediments.

1.1. Oceanographic processes modifying core top age

Coring and dating difficulties notwithstanding, many natural processes also significantly alter core top ages and can potentially explain the observations of differing ages among core tops and among various sedimentary components within core tops. These processes, schematically depicted in Fig. 1, can be broadly grouped into four: carbonate dissolution, bioturbation within sediments, regional differences in mass accumulation rates, and lateral sediment redistribution – both syn-depositional and post-depositional involving the erosion and redeposition of old sediment (reworking).

After correcting for reservoir ages, many studies assume that radiocarbon dating of planktonic foraminifer tests provides the closest age to the age of deposition of the sedimentary layer (or core top), and provides more accurate age estimates than radiocarbon dating of the bulk sediment. Dating planktonic foraminifers is preferred over other microfossils, such as coccolithophores because planktonic foraminifers are heavy enough to settle quickly through the water column after death (Schiebel, 2002). The most commonly used foraminifer species for radiocarbon dating in samples from the EEP is *Neogloboquadrina dutertrei* (Appendix).

Several studies have shown the effect of increasing core top age with increasing **dissolution** of the calcareous component of the sediment (e. g. Broecker et al., 1991; Broecker et al., 1999; Anderson et al., 2008; Barker et al., 2007; Broecker and Clark, 2011; Mekik, 2014). The impact of $CaCO_3$ dissolution on core top ages may also be species dependent. Barker et al. (2007) and Mekik (2014) both observed great age offsets among co-occurring planktonic foraminifer species. Both studies attributed this to differential dissolution of tests of different species with varying test structure, porosity and robustness. In the extreme case of **chemical erosion**, the remaining bulk sediment tends to be much older than "modern" (Keir, 1984; Broecker et al., 1991; Barker et al., 2007; Mekik, 2014).

Lateral sediment transport can lead to large age offsets among core tops (Fig. 1). For example, age offsets between alkenones and planktonic foraminifers have been attributed to post-depositional lateral sediment transport (Ohkouchi et al., 2002; Mollenhauer et al., 2003). However, both Mollenhauer et al. (2003) and Kusch et al. (2010) observed that even in sediments that have experienced great lateral sediment redistribution, sometimes various sedimentary components are similar in age. Kusch et al. (2010), from their cores in the Panama Basin, interpreted this observation to be a result of syn-depositional redistribution of sediment. So, if the lateral movement of sediments is syn-depositional, we would not expect to see great age offsets among various components of the sediment. However, if lateral sediment redistribution is post depositional and involves the erosion of sediments and redeposition of older sediments, this would cause core top ages of bulk sediment to become significantly older in regions where older sediment is redepositied (Fig. 1). This reworking of sediment could also lead to great age offsets between the organic compounds in the

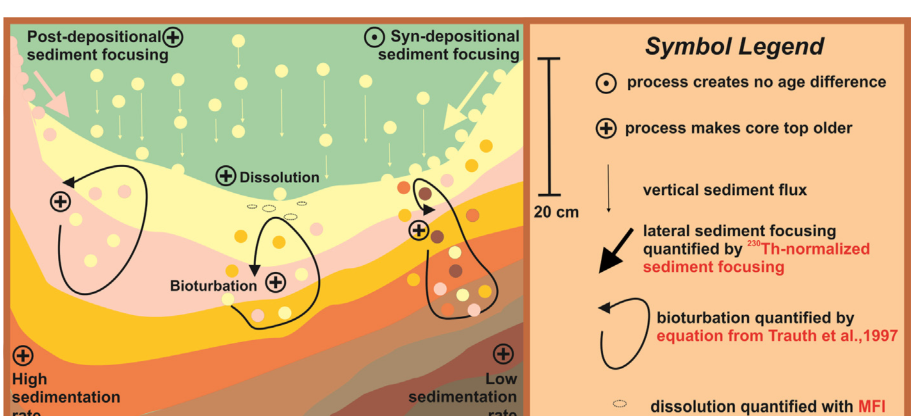

Fig. 1. Cartoon depicting sedimentary processes potentially modifying core top age. Loops with arrows represent bioturbation. Processes leading to older core top ages are designated with a plus sign. Colors depict relative age of sediment. MFI = *Globorotalia menardii* Fragmentation Index which is a measure of percent calcite dissolved (after Mekik et al., 2002, 2010). See text for detailed description of processes and their effect on core top age. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)