Carbonate Compensation Depth and Carbonate Carbon Flux in the Pacific Ocean Since the Early Cenozoic

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INTRODUCTION

Carbonate Carbon

Originates from pelagic carbonate dominated by remains of coccolithophorids and planktic foraminifera.

Carbonate Compensation Depth (CCD)

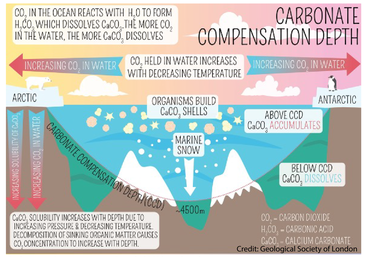
Water depth at which carbonate supply from the surface is balanced by its dissolution at depth.

Study Aim

To estimate the carbonate carbon flux to the Pacific seafloor over the Cenozoic by modelling the evolution of the CCD on regional scales.

Study Importance

The Pacific Ocean, as the largest and deepest ocean, plays a prominent role in the global carbon cycle. However, there remains a significant gap in understanding its deep carbon cycle because the deep-sea carbonate carbon storage, as a major component of deep carbon and hence long-term global carbon cycle, across this ocean is unknown. Additionally, the CCD is essential for computing carbonate carbon storage and flux through time. The history of the CCD is currently very poorly constrained throughout the Pacific Ocean, except for the eastern equatorial region.



Carbonate Compensation Depth (CCD) and carbonate accumulation and dissolution.

METHOD & DATA

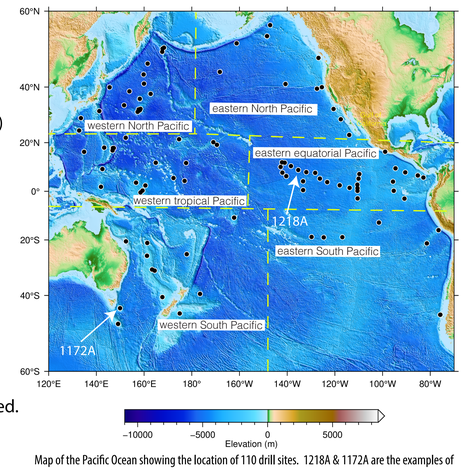
1- CCD Modelling:

- Data compilation
  - Lithology core logs
  - Carbonate content
  - Dry bulk density
  - Age-depth Models (NSB database and Lyle (2002))

  DSDP, ODP and IODP
- Backtracking to compute paleo-water depth by:
  - Using pyBacktrack software: https://github.com/EarthByte/pyBacktrack ; Müller et al. (2018a)
  - incorporating:
    - dynamic topography
    - eustatic sea-level
- Carbonate Accumulation Rate (CAR) computation by:
  - $CaCO_3$(wt%) × dry bulk density × linear sedimentation rates binned into 1 My wide moving window.
- CCD determination through:
  - Linear reduced major axis regression of CAR values versus paleo-water depth (Campbell et al., 2018) at each 0.5 My time interval, assuming that CAR values extrapolate to zero with increasing the depth (Lyle, 2003) as the CCD is approached.

2- Carbonate Carbon Computation:

- Workflow of Dutkiewicz and Müller (2022).
- Utilizing CCD models, sedimentation rates and paleobathymetry (using pyGPlates (https://www.gplates.org/docs/pygplates/pygplates_introduction.html (Mather et al., 2023)).

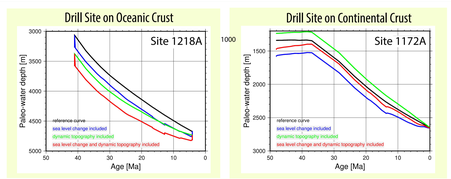


Map of the Pacific Ocean showing the location of 110 drill sites. 1218A & 1172A are the examples of drill sites backtracking.

RESULTS & DISCUSSION

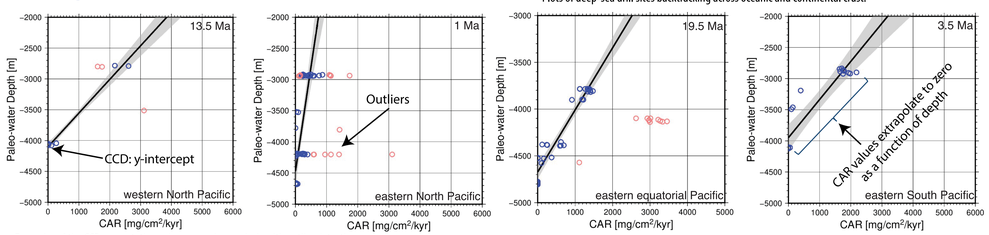
1- Backtracking

Paleo-water depth is estimated considering the effect of dynamic topography and sea-level components based on Model M6 from Müller et al. (2018b)



Plots of deep-sea drill sites backtracking across oceanic and continental crust.

2- CCD Computation

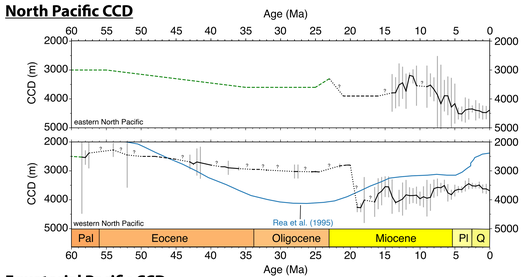


Examples of the CCD computation using regression analysis with outlier detection.

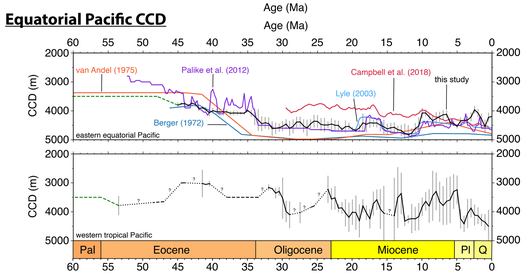
3- CCD Modelling

- Distinct CCD patterns within six regions of the Pacific reflecting regional and latitudinal oceanographic controls on carbonate burial and dissolution.
- Deepest CCD from the eastern equatorial Pacific ranged between ~ 3.7 km and ~ 4.7 km before the middle Miocene.
- Shallow CCD of the western North Pacific was between ~ 2.3 km and ~ 4 km during the Cenozoic, rarely exceeding 4 km.
- Westward shallowing trend of the CCD around 1 km across the equator (prior to the Pliocene).

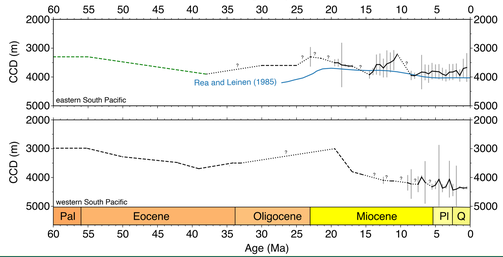
North Pacific CCD



Equatorial Pacific CCD



South Pacific CCD



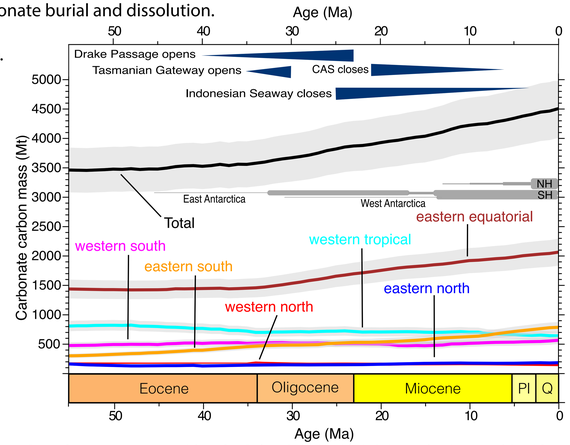
4- Carbonate Carbon Computation

Carbonate Carbon Mass

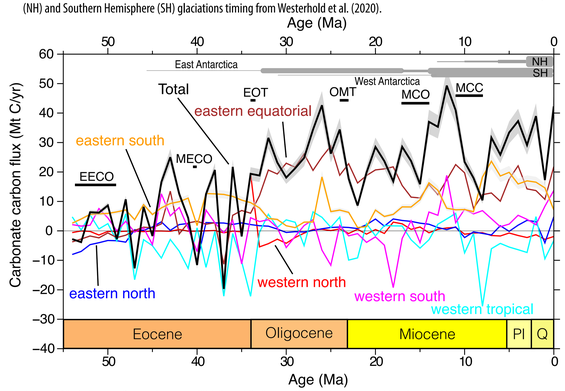
- Modest increase from ~ 3450 to ~ 3500 Mt between ~ 55 Ma and ~ 34 Ma.
- Gradual increase from ~ 3500 Mt at 34 Ma to ~ 4500 Mt at present day.
- Total carbonate carbon mass is dominated by the eastern equatorial Pacific ranging from ~ 1450 Mt to ~ 2100 Mt since ~ 55 Ma.
- Less carbonate carbon mass away from the equator towards the north (< 200 Mt) and south (~ 300 to 800 Mt).

Carbonate Carbon Flux

- Increase in total carbonate carbon flux from ~ -3 Mt C/yr at 55 Ma to ~ 43 Mt C/yr at present day.
- Higher flux from the eastern equatorial region, dominated since the early Oligocene.
- Lower flux from the western regions of the North and South Pacific.
- Significant increase from ~ -3 Mt C/yr to ~ 30 Mt C/yr from the late Eocene to the early Oligocene .
- Carbonate carbon flux corresponds to climate perturbations, the opening and closing of ocean gateways, Southern and Northern Hemisphere glaciations and deep-water circulation.



Timing of ocean gateway opening and closing from Eagles and Jokat (2014) for Drake Passage, from Straume et al. (2020) for Tasmanian Gateway and Central America Seaway (CAS), and from Bahr et al. (2023) for Indonesian Seaway. Northern Hemisphere (NH) and Southern Hemisphere (SH) glaciations timing from Westerhold et al. (2020).

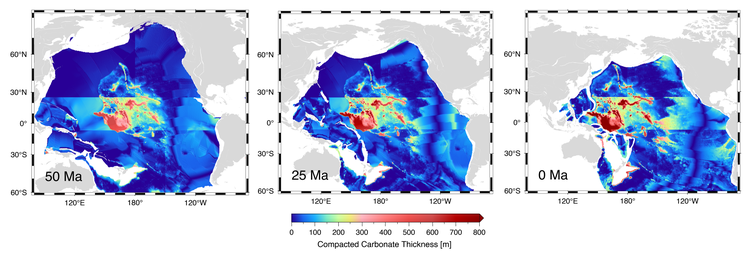


Timing of Early Eocene Climate Optimum (EEOC), Middle Eocene Climate Optimum (MECO), Eocene/Oligocene Transition (E/OT), Oligocene/Miocene Transition (O/MT), Miocene Climate Optimum (MCO), Northern Hemisphere (NH) and Southern Hemisphere (SH) glaciations from Westerhold et al. (2020), and Miocene Carbonate Crash (MCC) in the equatorial Pacific from Lyle et al. (1995).

COMPACTED CARBONATE THICKNESS MAP

The carbonate accumulation history of the Pacific seafloor since 55 Ma

- The Pacific Ocean has become smaller over the past 55 Ma due to subduction.
- Carbonate accumulation has been highest across the central equatorial Pacific since 55 Ma due to the presence of elevated seafloor topography.



The Pacific compacted carbonate thickness map at 50 Ma, 25 Ma, and 0 Ma time frames.

CONCLUSIONS

1) The Pacific CCD has fluctuated regionally by ~ 1–1.5 km, showing distinct patterns since 55 Ma.
2) The eastern equatorial Pacific, known as a high-productivity region of the Pacific, contains the highest carbonate carbon mass and carbonate carbon flux across the entire Pacific, correlating with its deeper CCD which ranges from ~ 3.7 to 4.7 km.
3) Moving away from the equator, both northward and southward, carbonate carbon mass and flux reduce, showing minimal amounts from the western and eastern North Pacific regions. This indicates significant latitude-longitude dependence in carbonate carbon flux and storage across the entire Pacific Ocean since 55 Ma.
4) The regional CCD reconstruction and carbonate carbon computation in the Pacific improves constraints on deep-sea carbonate carbon estimates in the context of the long-term global carbon cycle.

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