Geochemically tracing the intermediate and surface waters in the Tasman Sea, southwest Pacific

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Except where otherwise indicated in the text, the research described in this thesis is my own original work.

Helen C. Bostock
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Chemical oceanography is at a crossroads connecting almost all branches of marine sciences. Therefore, chemical oceanographers must learn more or less all the disciplines of oceanography. Furthermore, taking into account the fact that chemical substances are four dimensionally cycling on the Earth, chemical oceanographers must investigate not only the present ocean, but also the atmosphere, biosphere and geosphere, including the past and future of the Earth.

Tsunogai (2002)

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Abstract

The relatively understudied intermediate waters of the world have been implicated as an important part of the global ocean circulation. This thesis discusses the intermediate waters of the Pacific over space and time. Initially, by using geochemical tracers to look at the present distribution, sources and mixing of the water masses. Secondly, by using oxygen and carbon isotopes from sediment cores to study changes in Antarctic Intermediate Waters (AAIW) over the late Quaternary in the north Tasman Sea.

The geochemical tracers highlight the presence of three separate intermediate water masses in the Pacific: North Pacific Intermediate Water (NPIW), AAIW and Equatorial Intermediate Water (EqIW). The EqIW has previously been considered an extension of intermediate water masses to the north or south. The unique geochemical characteristics of EqIW indicate, however, that it cannot be formed by direct mixing of the NPIW and AAIW. Geochemical tracers suggest instead that EqIW must also include mixing with nutrient rich, oxygen deficient, old Pacific Deep Water (PDW).

The AAIW distribution and circulation shows a primary formation region in the southeast Pacific. The high oxygen, low salinity signature of this southeast Pacific source is altered during its circulation of the subtropical gyre. This is the result of aging during circulation and mixing with other intermediate waters entering the region. A second source region is in the eastern equatorial Pacific (EEP), where mixing occurs with the old, nutrient rich EqIW. Mixing between the EqIW and AAIW is evident as far south as 30°S. The data also suggests a tongue of EqIW, overlying and mixing with the upper layers of the AAIW flows south adjacent to the South American coast. A third source of AAIW enters the south Tasman Sea directly from the Southern Ocean. This third source, has little influence on the main subtropical gyre. However, it contributes to the geochemistry of the intermediate waters in the Tasman Sea and Coral Sea. The uniformity of the AAIW in the Tasman Sea and Coral Sea advocates for a separate recirculating gyre in the southwest Pacific. The main exit of AAIW from the south Pacific is either through mixing to form the EqIW along the equator, or south to the east of the Tonga-Kermadoc Ridge following the subtropical gyre circulation. This present day distribution and chemistry of the intermediate water masses allows interpretation of past conditions.

A series of marine sediment cores were collected from a depth transect in the Capricorn Channel (~23°S), off the southern Great Barrier Reef (GBR) province. Data extracted from the cores provide a preliminary model of hemipelagic deposition within this region over the late Quaternary. The sedimentary evidence highlights the importance of bathymetry, especially the morphology of reef platforms and the continental shelf, to understand hemipelagic systems over time. Compared to the northern GBR province, the southern GBR province continues to be influenced by terrestrial sediments during the glacial lowstand. These terrestrial sediments are primarily distributed by the Fitzroy River system, which meanders across the continental shelf and flows into the Capricorn Channel.

The sediments in the Capricorn Channel appear to be focussed at intermediate water depths, possibly related to an increase in the slope gradient. This provides a high sedimentation rate core (FR1/97 GC-12) to look at relatively high resolution palaeoceanographic variations during the last deglaciation. Stable oxygen and carbon isotope compositions were analysed on a suite of planktonic foraminifera (*Globigerinoides ruber, Globigerinoides sacculifer, Globoratalia menardii* and *Globoratalia truncatulinoides*) and benthic foraminifera (*Cibicidoides spp.*), to examine changes in the water column throughout this period. Comparison of the $\delta^{13}C$ data of the different species were used to determine changes in the ocean circulation and display three distinct phases 1) Glacial, 2) Deglaciation 18-12 ka BP and 3) 12-0 ka BP.

1. During the glacial there is a large $\Delta\delta^{13}C$planktonic-benthic difference of 1.1‰, implicating a well stratified surface to intermediate depth ocean. Abundant *Gr. menardii* and *Gr. truncatulinoides* suggest that the thermocline was shallow and the intermediate waters were thick. The AAIW in the Tasman Sea appears to be dominated by the southern source, directly from the Southern Ocean, and may be mixing with the underlying nutrient rich deep waters.

2. At ~18 ka BP there is a collapse in the $\Delta\delta^{13}C$planktonic-benthic offset to ~0.4‰. This is the result of a rapid ventilation event in the AAIW and a switch from the southern source to the northeast source waters in the Coral Sea. During this phase the *Gr. menardii* and *Gr. truncatulinoides* decrease in abundance and *G. ruber* and *G. sacculifer* return to prominence. The $\delta^{13}C$ planktonic minimum is evident over a wide geographical extent and the AAIW has been implicated as the driver for the release of deep-water CO_2 and the main conduit for transporting this preformed $\delta^{13}C$ signal within the southern hemisphere ocean basins. This $\delta^{13}C$ planktonic minimum correlates with the rise in atmospheric CO_2 measured in ice cores.

3. At ~12 ka BP the $\Delta\delta^{13}C$planktonic-benthic offset begins to recover and reaches modern values of 0.7‰. This is possibly related to the onset of the NADW formation and the return to present day thermohaline global ocean circulation.

The $\delta^{18}O$ data from *G. ruber* from the same core (FR1/97 GC-12) was also compared with another high sedimentation rate core RV105 GC-25 from ~26°S in the Tasman Sea.

The differences in the $\delta^{18}O$ values suggest variations in the surface current, the East Australian Current (EAC), during the last deglaciation.

The EAC is the western boundary current (WBC) of the south Pacific subtropical gyre and important for modulating the climate of eastern Australia and New Zealand. Like all WBCs it separates from the coast at a particular location and flows out to sea in an eastward jet, the Tasman Front. Recent modelling suggests the reason for the EAC separation and the formation of the Tasman Front is related to a rapid gradient in the zonally integrated wind stress curl at this latitude.

The $\delta^{18}O$ *G. ruber* data from GC-12 exhibits a 1.5‰ decrease between the last glacial maximum (LGM) and present. Taking into account ice volume and assuming no salinity changes, this represents a temperature difference of 2-3°C, comparable to the estimates from foraminiferal abundances. RV105 GC-25, a core from ∼3° south of GC-12, displays a ∼2.2‰ decrease since the LGM, suggesting an ∼6°C difference compared with present sea surface temperatures (SST). This large temperature gradient of 3-4° in ∼3° latitude is similar to the temperature gradient evident across the Tasman Front today. This suggests that during the LGM the EAC separation occurred north of RV105 GC-25 at ∼26°S. Palaeo-evidence suggests that there is a considerable weakening of the trade winds as a result of a reduction in the equatorial east-west SST gradient. There is also increasing evidence to suggest a ∼3-5° equatorial shift of the subtropical westerlies, combined with a strengthening of the westerlies, especially in the south. These changes in the winds would have had a considerable affect on the wind stress field, and consequently the wind stress curl of the south Pacific, potentially causing the EAC separation to shift as far north as 26°S.

A rapid convergence of the $\delta^{18}O$ *G. ruber* data from FR1/97 GC-12 and RV105 GC-25 is evident between 12-11 ka BP suggesting the EAC was forced south of 26°S at this time. This shift is synchronous with a rapid warming in tropical SSTs at the end of the Younger Dryas and the onset of a La Niña-like state in the Pacific. This change in the east-west SST gradient would have enhanced the easterly trade winds, altering the wind stress field. The EAC separation would have readjusted accordingly. This marks the onset of modern circulation in the southwest Pacific. Present EAC flow, however, was probably only achieved when complete modern conditions, including present day El Niño Southern Oscillation (ENSO) periodicities, are achieved after 5 ka BP.

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