Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia


IPWP, reefs, currents, ITF, Monsoon

Northwest Shelf

Stephen John Gallagher
The School of Earth Sciences
The University of Melbourne
+61 3 8344 6513
sjgall@unimelb.edu.au

Reefs, Oceans and Climate Northwest Australia

The Indonesian Throughflow (ITF) is a critical part of the global thermohaline conveyor. It plays a key role in transporting heat from the equatorial Pacific (the Indo-Pacific Warm Pool, IPWP) to the Indian Ocean and exerts a major control on global climate. The complex tectonic history of the Indonesian Archipelago due to the continued northward motion and impingement of the Australasian Plate into the SE Asian part of the Eurasian plate makes long-term (million year) reconstructions of ITF history difficult. The best areas in the Indian Ocean to determine ITF history are either in the deep ocean away from strong tectonic deformation or along passive margin regions that are directly under the influence of the ITF. While previous deep-water ODP and DSDP cores in the Indian Ocean have been used to chart IPWP influence (and by proxy ITF variability), these sections lack direct biogeographic and sedimentological evidence of the ITF. We propose to drill a transect of shelf to shelf margin cores over 10° latitude in the Northwest Shelf of Australia (NWS) to obtain a five million year record of ITF, IPWP and climate evolution that has the potential to match orbital scale deep sea records in its resolution. Drilling the NWS will reveal a detailed shallow water history of ITF variability and its relationship to climate. It will allow us to understand the history of the Australian monsoon and its variability, a system whose genesis is thought to be related to the initiation of the East Asian monsoon and which is hypothesized to have been in place perhaps since the Pliocene or earlier. It also will lead to a better understanding of the nature and timing of the development of aridity on the Australian continent. Detailed palaeobathymetric and stratigraphic data from the transect will also help us to constrain the spatial and temporal pattern of vertical motions caused by the interaction between plate motion and convection within the Earth’s mantle, known as dynamic topography. The NWS is in an ideal location to study this phenomenon since it is positioned on the fastest moving continent since the Eocene, on the edge of the degree two geoid anomaly. Accurate subsidence analysis over 10° of latitude will resolve whether northern Australia is moving with/over a time transient or long term stationary downwelling within the mantle, thereby vastly improving our understanding of the dynamics of deep Earth processes.
Scientific Objectives

We propose to drill a latitudinal transect from 18°S to 28°S to achieve three objectives:
1) To determine the timing and variability of the ITF, IPWP and onset of the Leeuwin Current in order to understand the controls on Quaternary extra-tropical carbonate and reef deposition.
2) To obtain a 5 Myr orbital scale tropical to subtropical climate and ocean archive comparable to deep ocean oxygen isotope and ice core archives. This will be used to chart the variability of the Australian Monsoon and the onset of aridity in northwestern Australia.
3) To provide empirical input into the spatio-temporal patterns of subsidence along the NWS that can be used to place fundamental constraints on the interaction between Australian plate motion and mantle convection, and to ground truth geodynamic models.

Hypotheses to be tested:
1) That tectonic restriction of the ITF was variable on a secular timescale. Throughflow reached a maximum during the Middle Pleistocene and the Leeuwin Current initiated, leading to widespread tropical carbonate and reef development. NWS reef expansion was intermittent and asynchronous as tropical carbonates migrated southward in response to Leeuwin Current intensification.
2) That the Australian Monsoon has undergone repeated cycles of initiation and shutdown, paced by eccentricity, obliquity bands of insolation forcing in the absence of topographic effects. Monsoonal intensity decreased through the Plio-Pleistocene leading to increasing continental aridity.
3) Australia’s rapid northward motion towards the Southeast Asian subduction slab graveyard induced dynamic drawdown of the Earth’s surface that progressively swept southwards across the continent.

Non-standard measurements technology needed to achieve the proposed scientific objectives.

Proposed Sites

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Position (Lon, Lat)</th>
<th>Water Depth (m)</th>
<th>Penetration (m)</th>
<th>Brief Site-specific Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWS-5A</td>
<td>112.925, -27.375</td>
<td>214</td>
<td>336 0 336</td>
<td>Southern record of latitudinal tropical to subtropical carbonate deposition and Leeuwin Current (Drilling Objective 1). A Plio-Pleistocene record of southwest Australian climate (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (drilling objective 3).</td>
</tr>
<tr>
<td>NWS-4A</td>
<td>115.083, -20.216</td>
<td>138</td>
<td>1122 0 1122</td>
<td>Record of tropical to subtropical carbonate deposition, ITF and Leeuwin Current. Constraining the age and setting of the buried reef upward dip and landward of section (Drilling Objective 1). Obtaining an long term orbital scale record of the Australian monsoon (Drilling Objective 2).</td>
</tr>
<tr>
<td>NWS-3A</td>
<td>115.709, -19.824</td>
<td>88</td>
<td>842 0 842</td>
<td>Record of tropical to subtropical carbonate deposition, ITF and</td>
</tr>
<tr>
<td>Site</td>
<td>Coordinates</td>
<td>Age</td>
<td>Bathymetry</td>
<td>Comments</td>
</tr>
<tr>
<td>--------</td>
<td>---------------</td>
<td>-----</td>
<td>------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>NWS-2A</td>
<td>117.622, -18.967</td>
<td>141</td>
<td>579</td>
<td>Part of a latitudinal shelf transect, to sample Plio-Pleistocene sub-tropical to tropical transition. Oolitic facies is expected in this section. Charting the Leeuwin current and ITF (Drilling Objective 1). Obtaining an interglacial record of the Australian monsoon (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (Drilling Objective 3).</td>
</tr>
<tr>
<td>NWS-1A</td>
<td>118.732, -18.325</td>
<td>146</td>
<td>475</td>
<td>The most northerly of the shelfal latitudinal transect, to sample Plio-Pleistocene sub-tropical to tropical transition and date seismic reflectors and by proxy date buried reef &quot;shoal&quot; along strike (Drilling Objective 1). Obtaining an interglacial record of the Australian monsoon (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (Drilling Objective 3).</td>
</tr>
</tbody>
</table>
Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

Stephen Gallagher, School of Earth Sciences, The University of Melbourne, Australia (micropalaeontologist and stratigrapher) email: sjgall@unimelb.edu.au
Craig Fulthorpe, University of Texas Institute for Geophysics, John A. and Katherine G. Jackson School of Geosciences, Austin, TX 78758-4445, USA (seismic stratigrapher)
Andrew Heap, Geoscience Australia, Canberra, Australia (seismic stratigrapher)
Christian Heine, School of Geosciences, University of Sydney, Australia (mantle dynamicist)
Karol Czarnota, Department of Earth Sciences, University of Cambridge, UK (mantle dynamicist)
Neville Exon, School of Earth Sciences, Australian National University, Australia (stratigrapher)
David Greenwood, Dept. of Biology, Brandon University, Canada (palaeobotanist)
Nicholas Herold, Department of Earth, Atmospheric and Planetary Sciences, Purdue University, USA (climate modeler)
Yasifumi Iryu, Department of Earth and Environmental Sciences, Graduate School of Environmental Studies, Nagoya University, Japan (tropical carbonate sedimentologist)
Willem Renema, Naturalis Biodiversity Center, Nationaal Natuurhistorisch Museum, Leiden, the Netherlands (micropalaeontologist)
Yair Rosenthal, Institute of Marine and Coastal Science, Rutgers University, USA (geochemist)
Tokiyuki Sato, Faculty of Engineering and Resource Science, Akita University, Japan (nannofossils)
Kale Sniderman, School of Earth Sciences, The University of Melbourne, Australia (palynologist)
Asrar Talukder, CSIRO Petroleum, Kensington, WA, Australia (marine geology and geophysics)
Barbara Wagstaff, School of Earth Sciences, The University of Melbourne, Australia (palynologist)
Malcolm Wallace, School of Earth Sciences, The University of Melbourne, Australia (carbonate sedimentologist)
Abstract and summary (see Proposal Cover Sheet Summary and Abstract)

1. Introduction (Scientific background)

During the past 5 million years (Myrs), Earth’s climate experienced a major transition from the mid-Pliocene warmth to the late Pleistocene ice ages. While we now have increasing amounts of high-resolution records of climate variability during this time from high-latitudes and equatorial regions, there is only sparse high-resolution information for the Northwestern region of Australia. The wedge of sediment that has accumulated over the last 5 million years in the Northwest Shelf epitomizes the geological history of Australia’s northern margin (Fig. 1). The sequence is made up of a variety of sediment types including sub-tropical to tropical shelf calcarenite, calcilutite, marl and deep-water mudstone and siltstone eroded by submarine canyons. In combination, these sediments make up a prograding shelf-type facies typical of much of the Australian continental margin. The enormous amount of seismic, wire line log and subsurface (cuttings and rare side wall cores) data accumulated during hydrocarbon exploration in the region makes this one of the best places in the world in which to study this facies association. Our drilling objectives fall under three main headings:

ITF, Leeuwin Current and Reef Development. During the late Neogene, the NWS has acted as a relatively stable subsiding platform upon which is recorded most of the major events and environmental changes. Located at the fringes of the IPWP, this margin is therefore an ideal region in which to study tropical oceanography (Rosleff-Soerensen et al., 2012) and the history of the ITF. The ITF also helps drive the Leeuwin Current, which is the only southward flowing eastern boundary current in the Southern Hemisphere. This current extended tropical reef development to 29°S during the Late Pleistocene (Collins et al., 2006). We propose to determine orbital scale variability of this current using tropical sedimentary (coral reefs and ooids) and fossil biogeographic indices, and by proxy determine the underlying controls that triggered Plio-Pleistocene reef development. Drilling a latitudinal transect from 18°S to 27°S will enable us to determine whether the switch to tropical sedimentation was synchronous or diachronous in this region. This drilling proposal will provide a long-term perspective on how coral reefs in the East Indian Ocean developed through variable climatic conditions.

Australian Monsoon and Continental Aridity: The shelf and slope of this region host a vast, but barely explored, archive of late Neogene climate variability (van der Kaars and De Deckker, 2002) because they lie directly offshore from the semi-arid Australian continent that was climatically dominated by the Australian monsoon (Suppiah, 1992). Drilling the
Northwest Shelf will therefore allow us to understand the long term geographic controls Australian monsoonal variability and its relationship to the onset of aridity in Australia.

Subsidence and geodynamics of Australian Plate: Obtaining high resolution stratigraphic data from the NWS will lead to much improved burial and subsidence estimates for this region. These data will also enable us to decipher the contribution of large scale geodynamic processes such as dynamic topography on the vertical motions of the Earth’s surface, and associated effects on the sedimentary system of the NWS.

Fig. 1: A map of the NWS showing major basins and location of modern and “fossil” reefs. The stars denote proposed drilling sites. Seismic data near NWS-4A is on Fig. 7. The location of DSDP/ODP Sites and other core locations (green
2. Tectonic setting

The NWS is a rifted passive margin that has existed since late Palaeozoic time, when Australia was part of eastern Gondwana (Longley et al., 2003; Etheridge & O’Brien 1994; Exon and Colwell, 1994). Ribbon-like microcontinents separated from this part of the margin in multiple rifting events, with the latest phase of rifting occurring in the Late Jurassic (Heine & Müller, 2005; Exon & Colwell, 1994; Metcalfe, 1988). Two of our proposed drilling sites (NWS-5A and NWS-6A) are in the northern part of the Perth Basin (Fig. 1). The remainder lie in the Northern Carnarvon Basin (NCB) and Roebuck Basin with a minimum stratigraphic thicknesses of 8 km (Longley et al., 2003; Goncharov, 2004). Here, earliest rifting occurred during the late Permian (initial breakup of eastern Gondwana) (Sengor, 1987). Subsequent rifting episodes occurred during the Late Triassic-Early Jurassic and Late Jurassic (Driscoll & Karner, 1998; von Rad et al., 1992). Final rifting in the latest Jurassic also culminated in earliest Cretaceous separation of greater India from Australia (Boote & Kirk, 1989; von Rad et al., 1992; Heine & Müller, 2005). The post-rift thermal subsidence history of the margin has been affected by mild shortening, generally attributed to plate boundary forces resulting from plate reorganization (Romine et al., 1997; Driscoll & Karner, 1998; Sayer et al., 2001; Cathro et al., 2003; Dyksterhuis et al., 2005). The most recent major nearby tectonic event was late Miocene collision between northern Australia and the Banda Arc (Audley-Charles et al., 1988; Lee & Lawver, 1995; Richardson & Blundell, 1996). Though several hundred km to the north, intraplate stresses associated with this ongoing collision have resulted in localized reactivation and inversion of extensional faults in the NCB (Malcolm et al., 1991; Struckmeyer et al., 1998; Cathro et al., 2003).

3. Oceanographic setting

The IPWP is a region of warm surface waters with an average surface temperature of 28°C, which covers most of the tropical western Pacific and eastern Indian Oceans (Fig. 2). The IPWP plays a major role in heat transport from low to high latitudes, and it is subject to variability on decadal scales due to the El Niño/Southern Oscillation (ENSO) (de Garidel-Thoron et al., 2005). The intensity of the IPWP functions as a switch in the climatic system and it is consequently a key influence on long- and short-term global climate change (Xu et al., 2006). Therefore, the history of the IPWP is crucial to our understanding of the global climatic and oceanic systems, as well as their regional effects on the NWS. Climatic cooling since 15 Ma and an evolving tectonic configuration created appropriate boundary conditions.
to create “near-modern” oceanic conditions in the Indo-Pacific. The IPWP (Fig. 2) is trapped by the Indonesian archipelago and released into the Indian Ocean via the ITF (Gordon, 2005). The ITF transports 10 to 15 Sverdrups (1 Sv=10^6 m^3 s^-1) of low salinity warm water via the Indonesian archipelago (Kuhnt et al., 2004) to the Indian Ocean, forming an important switching point in the global thermohaline conveyor. The shelfal extra-tropical regions of the Indo-Pacific are strongly influenced by shallow (50-300 m) currents that originate in the IPWP region. The oceanography of the NWS from 5 to 15°S is dominated by the South Equatorial Current (Collins et al., 2002; Fig. 2). South of 15°S the shallow and narrow Leeuwin Current (Fig. 2) (<100 km wide; <300 m deep) transports warm, low-salinity nutrient-deficient water southward along the west coast of Australia (Pattiaratchi, 2006).

Fig. 2: The oceanography and climate of the western Pacific adapted from Gallagher et al. (2009). The currents (warm = red, cold = blue) are indicated. The direction (green arrows) and geographical extent of the summer monsoon (dashed green lines) are adapted from Kershaw et al. (2003). The average January position of the Inter Tropical Convergence Zone (ITCZ) is indicated (cf. Huang et al., 2011). The target transect is indicated with yellow stars.

It is driven by long-shore winds and an upper-ocean pressure gradient (upper 250-300 m; Tomczak & Godfrey, 1994) that overcomes equatorward wind stress and upwelling to flow southward (Pattiaratchi, 2006). Another driver for this current is the steric height difference between the low density and low salinity Timor Sea and the cooler, denser, saline waters off the coast of Perth. It is the only south-flowing eastern boundary current in the southern hemisphere and has an enormous effect on the climate of the region. The current extends modern coral reef development to 29°S (the Houtman-Abrolhos reefs, Fig. 1; Collins et al., 1993) and the tropical/subtropical transition as far south as Rottnest Island (33°S; Greenstein and Pandolfi, 2008). James et al. (1999) suggested that the Leeuwin Current ceased during glacial periods and restarted during interglacials. Kendrick et al. (1991) used fossil molluscs to suggest the onset of the Leeuwin Current occurred <500 kyrs ago whereas Sinha et al.
(2006) and Karas et al. (2011) suggested onset at 2.5 Ma and McGowran et al. (1997) proposed a Late Eocene (40 Ma) onset age. However, Gallagher et al. (2009) used subsurface well cutting data from the NWS to suggest that the “modern” Leeuwin Current is younger than 1 Ma.

4. Climate and Palaeoclimate setting

The arid to semi-arid conditions of the Australian interior extend to the west coast of Australia. In the north rainfall is erratic but predominantly monsoonal (Fig. 2), with the dominance of summer rainfall declining sharply towards the south (Sturman and Tapper, 2005). Warm, moist, equatorial air is the major source of monsoonal and cyclonic rain in the north but is replaced in the south by tropical air from the Indian Ocean also known as the ‘pseudo-monsoon’ (Gentilli, 1972). The area is too dry for organic microfossil preservation onshore; data is restricted to marine sequences. The marine pollen record from 6-1.8 Ma at ODP Site 765 at 15°S (Fig. 1) shows progressive drying with replacement of sclerophyll forest dominated by Casuarinaceae and grassland by increased saltbush from 5-3 Ma, especially since 1.8 Ma (McMinn & Martin, 1992; Martin & McMinn, 1994). By contrast, <1 Ma strata yield sufficient Eucalyptus indicating woodland cover, but it is not clear whether this is related to increased rainfall or an evolutionary change associated with higher burning levels. A marine core (GC17, water depth 1093 m: Fig. 1) from offshore Cape Range shows marked changes in total and seasonal rainfall in the last 100,000 years with changing monsoon intensity (van der Kaars & De Deckker, 2002). Climate variation has been quantified for this record, using transfer functions from core top pollen samples in the region (van der Kaars et al., 2006).

5. Sedimentation History

Northward drift of Australia led to a transition from siliciclastic to predominantly carbonate deposition on the NWS. Carbonate sedimentation was already dominant by the Eocene, although a siliciclastic component persisted (Hull & Griffiths, 2002). Northward drift has brought the NWS into tropical latitudes (Veever et al., 1991; Muller et al., 2008); the region had reached 36-40° S by the early Oligocene and is now at 18-22° S. Prograding carbonate clinoforms developed in the early Oligocene and continue to the Miocene (Hull & Griffiths, 2002; Cathro et al., 2003). Late early Oligocene-early late Miocene carbonate sediments are heterozoan, i.e., derived from light-independent organisms, comprising benthic foraminifera, with subordinate bryozoan and rare coral fragments (Cathro et al., 2003). Such sediments
develop unrimmed platforms lacking reefs. Resulting clinoformal sequences comprise fine-grained calcilutites on the slope, a mixture of calcisiltites and calcarenites near clinoform rollovers (equivalent to paleoshelf edges), and calcarenites on paleoshelves (Hull & Griffiths, 2002; Moss et al., 2004). Evidence for reef development is limited; seismically identified reefs or reef mounds occur in the Oligocene-Miocene section (Romine et al., 1997; Cathro et al., 2003; Ryan et al., 2009; Liu et al., 2011). Rare reefs also occur in the Pliocene-Quaternary section (Ryan et al., 2009) and conditions were favorable for late Quaternary reef development even farther south to 28°S (Collins, 2002). However, sedimentation rates, even in temperate water carbonates, can be high (>40 cm/kyr), comparable to the lower end of the spectrum of tropical carbonate platform growth rates (James and Bone, 1991). This bodes well for paleobathymetric resolution if and when the NWS is drilled by IODP.

6. Stratigraphic and site selection data

The NWS has been extensively drilled for oil/gas over the last 40 years, and a huge amount of well (cuttings) and seismic data exists from which to choose potential drilling targets. However, cores that sample the upper kilometer (Miocene to Recent carbonate section) are extremely rare. The only continuous cores that exist are from engineering boreholes that typically sample Late Pleistocene carbonates in the upper 100 m (Fig. 4) and intermittent sidewall cores (Fig. 6). Since hydrocarbons are being actively produced on the NWS, we are sensitive to drilling safety concerns. Hence, our proposed sites redrill 5 pre-existing industry wells, where hydrocarbons are known to be absent from the targeted section (Table 1).

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Redrill Well</th>
<th>Well Class</th>
<th>Position Lat/long</th>
<th>Water depth (m)</th>
<th>Penetration (m)</th>
<th>Sediment Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWS-1A</td>
<td>Minilya-1</td>
<td>P&amp;A</td>
<td>18 19.48'S 118 43.95'E</td>
<td>146</td>
<td>475</td>
<td>Shelf marl/Ist</td>
</tr>
<tr>
<td>NWS-2A</td>
<td>Picard-1</td>
<td>P&amp;A</td>
<td>18 58'S 117 37.34'E</td>
<td>141</td>
<td>579</td>
<td>Shelf marl/Ist</td>
</tr>
<tr>
<td>NWS-3A</td>
<td>Fisher-1</td>
<td>P&amp;A</td>
<td>19 49.42'S 115 42.54'E</td>
<td>88</td>
<td>842</td>
<td>Shelf marl/Ist</td>
</tr>
<tr>
<td>NWS-4A</td>
<td>WTR-1</td>
<td>Proj.</td>
<td>20 12.94'S 115 5'E</td>
<td>138</td>
<td>1122</td>
<td>Shelf marl</td>
</tr>
<tr>
<td>NWS-5A</td>
<td>Morangie-1</td>
<td>P&amp;A</td>
<td>27 22.49'S 112 55.5'E</td>
<td>214</td>
<td>336</td>
<td>Slope marl</td>
</tr>
<tr>
<td>NWS-6A</td>
<td>Houtman-1</td>
<td>P&amp;A</td>
<td>28 39.92'S 113 34.58'E</td>
<td>152</td>
<td>328</td>
<td>Shelf/slope marl</td>
</tr>
</tbody>
</table>

Table 1. A list of the proposed drill sites and their equivalent petroleum wells (Fig. 1). P&A = plugged and abandoned well. Proj. = Projected 2km to site, NWS-4A is 2 km northeast of West Tryal Rocks-1 (WTR-1) a well that has hydrocarbons deeply buried beneath 3km of tight mudstone/carbonates. ISt = calcarenites.

The proposed sites lie along a latitudinal transect designed to sample the lateral variability in subsidence and tropical conditions in the NWS over the last 5 million years (Fig. 1). These targets have gamma wire line logs (mostly to the sea bed, Fig. 3) and cutting samples. We have analysed two continuously cored engineering bores (BHC4 and BHC1) near Angel-1 at 19.5°S in water depths of 80-90 m (Figs. 1, 4). Facies data (%CaCO₃) is directly comparable to the LR2004 oxygen isotope record. For example the lower carbonate marly facies (with
relatively high gamma response) were deposited during interglacial highstands and the high carbonate calcarenites (with ooids) were deposited as sea level fell to glacial conditions. We interpret the presence of increased siliciclastics (gamma peaks) on the NWS to be related to increased precipitation and terrestrial runoff across the shelf during the interglacial periods (probably due to an enhanced Australian Monsoon). The decrease in terrestrial input during glacial was due to increasingly arid conditions starving the shelf of siliciclastics. We believe that this sedimentation model is applicable throughout the Plio-Pleistocene shelfal carbonate section (Figs. 3 and 5) because it is likely that regional subsidence has facilitated the preservation of the majority of the eccentricity/obliquity controlled eustatic cycles (Fig. 5).

![Graph](image)

**Fig. 3:** A correlation of the gamma logs of 8 shelfal wells (Fig. 1) in the NWS (including drilling targets NWS-1A, NWS-2A, NWS-3A and NWS-6A). The vertical scale is metres and the seabed is indicated. The pick of the top Miocene/base Pliocene (orange) is based on age data (green numbers) from Gallagher et al. (2009) for Good-7 and Good-6 (Good = Goodwyn) and unpublished biostratigraphic data from side wall cores in Fisher-1 (NWS-3A). The base is poorly defined in Hout-1 (NWS-6A, Houtman-1), however well completion data suggests that it is above 500 m. More stratigraphic data for Angel-1 can be found in Fig. 4. The black arrow denotes a possible correlation point in the Middle Pleistocene. The 0.6 (Ma) correlation datum is interpreted from stratigraphic data in Fig. 5. The log data are corrected for borehole width effects.

In addition, the gamma log pattern clearly changes through time: Pliocene strata are more gamma rich and there is a shift to lower values during the Pleistocene (Fig. 3 and 5). This might reflect progressive progradation of the shelf seaward with time; however, the affect of this factor can be “filtered” out using palaeobathymetric estimates in each section.
addition, the prevalence of this upward decreasing gamma pattern across 10° of latitude suggests that it also reflects an upward increase of aridity through time and decreasing influence of the Australian Monsoon. The shelfal sections also yield well-preserved *Globigerinoides ruber* and *Cibicidoides* spp. (plus many other benthic foraminiferal species) in the interglacial marly facies. The *G. ruber* and *Cibicidoides* spp. yield isotope values close to deep-sea Pleistocene values in the region (Wells & Wells, 1994). Therefore, there is an opportunity to use proxy data for salinity and temperature variations (such as paired Mg/Ca and δ¹⁸O analyses) for each interglacial to investigate the shallow (<200 m) influence of the IPWP and ITF on the region and their relationship to the Leeuwin Current.

Fig. 4. a: The benthic foram δ¹⁸O curve is from Lisiecki & Raymo (2004) correlated with wells and cores in the Angel-1 region (Fig. 1) b: The %carbonate in core BHC4; e and f: oxygen data from 3 horizons in BHC4 (Dutton pers. comm.); numerous individual foraminifera were analysed at several horizons and the average values for each calculated, the values lie within the Quaternary ranges obtained from regional deep sea studies (Wells & Wells, 1994); d: The % carbonate in core BHC1; e: the gamma log for Angel-1 (Fig. 3). The vertical scale for b, c, d and e is in metres and cores BHC4, BHC1 and the Angel-1 well are ca. 50 m apart. Preliminary carbon dating of molluscs indicates that log level 100 metres in BHC1 and BHC4 is at least 40,000 years old.

7. **Scientific objectives**

The interpretation of past climate records to inform our future is one of the major themes (Theme 2) of the IODP Science Plan for 2013-2023. This proposal focuses on the 5 Myr marine history of a passive margin down stream of a major arm of the global thermohaline
conveyor (transported via the ITF) to understand what triggered the onset and variability of key oceanic and climate features. We are particularly interested in the relationship between ocean gateways and marine conditions in the transition from the warmer Early Pliocene to the cooler Pleistocene (Theme 2, Challenge 1, 2013-2023) and what controls the onset and variability of the Australian Monsoon (Theme 2, Challenge 3, SP 2013-2023). The drilling will also reveal insights into the tectonic gateway history, palaeobathymetry and subsidence that are directly related to Theme 4, Earth Connections Challenge 8: what is the composition, structure and dynamics of Earth’s upper mantle. This proposal is an international collaborative outcome of an IODP Indian Ocean Workshop in Goa in 2011 (Exon et al., 2012; Gallagher et al., 2012).

**Fig. 5.** a and b: gamma log data for Maitland North-1 (MN1: Fig.1) and Austin-1 (A1: Fig. 1); age datums are from Gallagher et al., 2009 and the inferred age of the first ooids and reefs in this region are shown (see Fig. 7), the black arrows represent an Early Pleistocene tie point (see also Fig. 3); c and d: the two sections shown in a and b plotted in age using the age/depth model of Gallagher et al. (2009) and correlating gamma peaks to interglacial events (grey vertical lines) (cf. deMenocal et al., 1992; Carter & Gammon, 2004), red arrow indicate bio-chronostratigraphic tie points and regularly occurring gamma peaks can be correlated (vertical grey lines) to the benthic foraminiferal δ18O curve of Lisiecki & Raymo (2004) (e).

We propose to drill a latitudinal transect from 18°S to 28°S (Fig. 1) to achieve three key objectives:
1) To determine the timing and variability of the ITF, IPWP and onset of the Leeuwin Current in order to understand the controls on Quaternary extra-tropical carbonate and reef deposition.

2) To obtain a 5 Myr orbital scale tropical to subtropical climate and ocean archive that is directly comparable to deep ocean oxygen isotope and ice core archives. This will be used to chart the variability of the Australian Monsoon and the onset of aridity in northwestern Australia.

3) To provide empirical input into the spatio-temporal patterns of subsidence along the NWS that can be used to directly place fundamental constraints on the interaction between Australian plate motion and mantle convection, and to ground truth geodynamic models.

Hypotheses to be tested:

1) That tectonic restriction of the ITF was highly variable on a secular timescale. Throughflow reached a maximum during the Middle Pleistocene transition and the “modern” Leeuwin Current initiated, leading to widespread tropical carbonate and reef development. NWS reef expansion was intermittent and asynchronous as tropical carbonates migrated southward in response to intensification of the Leeuwin current.

2) That the Australian Monsoon has undergone repeated cycles of initiation and shutdown, paced by eccentricity, obliquity (and precessional) bands of insolation forcing (cf. Wyrwoll et al., 2007, 2012) in the absence of topographic effects. Monsoonal intensity decreased through the Pliocene and Pleistocene leading to increasing continental aridity.

3) Australia’s rapid northward motion towards the Southeast Asian subduction slab graveyard induced dynamic drawdown of the Earth’s surface that progressively swept southwards across the continent.

8. Details of scientific objectives and strategies

In order to achieve our scientific objectives we require a robust chronostratigraphic framework for each site. We will use several methods: Biostratigraphy- Planktic foraminifera and nanofossils are common in NWS shelfal sections especially the highstand and outer shelf to upper slope facies (they are absent in the oolitic facies and poorly preserved in the coarse calcarenites), they are abundant in all the facies of West Tryal Rocks-1 well (near proposed Site NWS-4A; see data and zonation in Gallagher et al., 2009). There are a few useful dinoflagellate datums (McMinn, 1992; McMinn, 2002) in the Plio-Pleistocene section to assist age calibration. Magnetostratigraphy- typically this technique is used to provide a chronostratigraphy for deep water siliciclastics or carbonates, however Sakai and Jige (2006)
successfully demonstrated that it can also be useful in calibrating Pleistocene shallow water tropical carbonates in the Ryukyus (Japan), therefore we anticipate that it will work well in the finer grained more marly facies of the NWS. Correlation to oxygen isotope curves- in the previous section we demonstrated that with a few biostratigraphic calibration points, it is possible to correlate log gamma maxima to interglacial events. This is similar to the method adopted by Carter & Gammon (2004) who correlated the gamma profile from ODP Site 1119 to oxygen isotope data to achieve a millennial scale record of New Zealand upper slope sedimentation for the last 3.9 million years. This type of wire line analyses has also revealed Plio-Pleistocene 40 kyr scale climate variability in the Japan Sea (deMenocal et al., 1992). Carbon isotope dating- there are sufficiently well preserved molluscs in the upper sections to be drilled to allow for this technique to be used, it has already been applied successfully near the top of core BHC4 (Fig. 4). Strontium isotope dating: with thorough petrographic screening for diagenetic effects such as subaerial exposure, it is possible to use strontium isotopes from bioclasts to construct age depth profiles. Ehrenberg et al. (2006) have successfully dated calcitic bioclasts (such as bivalves, red algae and large benthic foraminifera) from Miocene platform carbonates. We anticipate encountering such macrofossils in most of the shelfal sequences to be drilled.

8.1 Objective 1: To determine the timing and variability of the ITF, IPWP and onset of the Leeuwin Current to understand the controls on extra-tropical carbonate and reef deposition.

The ITF cannot be considered in terms of an ‘open’ and ‘closed’ gateway, but rather the interaction between (1) the source of the water (south versus north Pacific), (2) the location of the main outlet and (3) variable sills, depths and locations through time (Kuhnt et al., 2004). The current eastern (main) outlet through the Timor Sea probably originated around 2-2.5 Ma; until then the Bali-Lombok strait was more important (Kuhnt et al., 2004; Hall, 2009). We intend to document ITF influence on the NWS using fossil biogeography/geochemistry and sedimentary/seismic facies:

(i) Fossil biogeography and geochemistry: The early history of the IPWP in the Indo-Pacific region has been interpreted from planktic microfossils. Kennett et al. (1985) suggested that the IPWP formed due to Indonesian seaway closure at ~8 Ma. In contrast, Srinivasan & Sinha (1998) used planktic foraminiferal biogeography to suggest IPWP formation at ~5.2 Ma. Jian et al. (2006) suggested a late Miocene (~10 Ma) IPWP with the “modern” warm pool developing at ~4 Ma. Karas et al. (2011) used comparisons between the Mg/Ca and
stable isotope data from ODP Sites 709C and 763A on the western and eastern sides of the Indian Ocean, respectively (Fig. 1) to suggest ITF restriction from 3.5 to 3 Ma causing 3°C cooling in the region (Fig. 6). Preliminary biogeographic analyses of NWS well cuttings by Gallagher et al. (2009) showed that particular species of shelfal benthic foraminifera (Asterorotalia spp., Pseudorotalia spp. and Heterolepa margaritiferus) migrate to the NWS from the southwest Pacific with the waxing and waning of the ITF. Elsewhere these taxa have proven useful tracers of the warmer Tsushima Current offshoot of the Kuroshio Current in the Japan Sea (Hoiles et al., 2012). Further foraminiferal analyses of 60 sidewall cores from the NWS Fisher-1 Well (NWS-3A) reveal at least three periods of ITF restriction during the Pliocene (Fig. 6). Gallagher et al. (2009) also used these species to interpret the onset of more intense Leeuwin Current and ITF (than today) around 1 million years ago during the Middle Pleistocene transition.

Palynomorphs are also useful as tracers of Leeuwin Current flow. For example pteridophyta spores with Indonesian affinities have been found in surface (modern) and subsurface Late Pleistocene marine sediment on the NWS (van der Kaars & De Deckker, 2002; 2003). Spooner et al. (2011) documented 500,000 years of Leeuwin Current variability from a deep sea core (MD002361, Fig. 1; 1805 m water depth) using stable isotopes and planktic foraminiferal proxies. Spooner et al. (2011) interpreted a weaker Leeuwin Current during glacial periods when the West Australian Current was dominant and a stronger Leeuwin Current during interglacials, especially Marine Isotope stage 11. The southerly migration of

---

**Fig. 6:** The Plio-Pleistocene stratigraphy of the Northwest Shelf and its relationship to various tectonic and climatic events. The horizontal grey bars denote likely periods of Indonesian seaway restriction. The benthic foram δ18O curve is from Lisiecki & Raymo (2004). The NWS foraminiferal data (cuttings) is from Gallagher et al. (2009) and preliminary results from Fisher-1 well (NWS-3A). The temperature data are from ODP Site 763A (Fig. 1) by Karas et al. (2011).
Indo-Pacific molluscs and corals to southwest Australia have been used to document the Late Pleistocene history of the Leeuwin Current (Kendrick et al., 1991; Greenstein & Pandolfi, 2008). We anticipate using the combination of benthic foraminiferal, palynological and macrofossil analyses described above to chart ITF onset and variability, and to trace Leeuwin Current activity through time. Further insights into this variability can be achieved using paired C/O isotope and Mg/Ca analyses of foraminifera from NWS interglacials to interpret middle to outer shelf temperature variations that might reflect the waxing and waning ITF through time. These data will strongly complement the nearby Plio-Pleistocene deep sea records (Karas et al. 2009; Karas et al. 2011; Spooner et al. 2011).

(ii) Transition to Warm-Water Carbonate Development: Warm water carbonates are dominated by photozoan organisms (i.e. organisms relying on photosymbionts such as corals). Two key features that distinguish tropical from non-tropical carbonates are the presence of coral reefs and ooids (Clarke, 2009; Bosence, 2009). Coral reefs are confined to seawater >18°C (Kleypas et al., 1999). Ooids form at temperature >20°C with salinities >37‰ (Lees & Buller, 1972). We hypothesize that these two key diagnostic tropical features appear late in the history of the NWS, first developing during the Pleistocene south of 18°S and that they are time transgressive becoming progressively younger southwards. Drilling will address this hypothesis as follows:

Determining the timing and history of late Neogene reef development: The distribution and timing of coral reef development in West Australia is intimately related to the Leeuwin Current (Kendrick et al., 1991). Collins (2002) summarized late Neogene reef distribution in Northwest Australia describing a series of late Tertiary reefs that have discontinuously developed over time. The late Quaternary stratigraphic evolution of Scott (14°S), Rowley Shoals (17.3°S), Ningaloo (22.7°S) and Houtman-Abrolhos (28°S) reefs (Fig. 1) have been described in detail (Collins & Testa, 2010) and their evolution related to a combination of increased amplitude of subsidence towards the north, variability in the Leeuwin Current and sea level change. Ryan et al. (2009) described a series of structurally controlled Miocene reefs in seismic data (Fig. 1) from 15 to 18°S (Fig. 1) that drowned at the end of the late Miocene (Messinian) as they failed to keep up with sea level change. Further south Cathro et al. (2003) interpreted possible Miocene “barrier” reefs or mounds in seismic data to 22°S. Liu et al. (2011) also interpreted possible Miocene reefs based on seismically imaged mounds. Ryan et al. (2009) acknowledge the dearth of post Miocene and pre-late Quaternary reefs in the region. However, Jones (1973) and Ryan et al. (2009) described an un-named
post-Miocene drowned “fossil” reef imaged using shallow- and deep-penetration seismic data close to the Rowley Shoals (Fig. 1). Another series of drowned “fossil” reefs are shown in seismic data from 20° to 22°S (Figs 1, 7 & Site Summary forms for NWS-4A and NWS-3A). We do not propose to drill these inferred reef features because the JOIDES Resolution is not suited to recovery of the mixed lithologies, with differing degrees of cementation, that are characteristic of reefal carbonates. However, we will be able to date late Neogene reef re-initiation by sampling and dating the platform/slope facies down dip or along strike from “fossil” reefs imaged by seismic data.

For example, proposed Site NWS-1A (Minlya-1) is 50 km up dip from the buried “fossil” reef described by Ryan et al. (2009) and parallel, laterally persistent reflectors connect these locations on seismic profile JN87-07 (see site summary form). Therefore improved ages for these reflectors will allow us to date this reef. In addition, proposed Site NWS-4A is down
dip from a drowned reef (Fig. 7), so new age data will similarly constrain its onset. Furthermore, downslope transported reefal detritus from this section will enable analysis of reef development in response to variable sea level. Proposed site NWS-3A is along strike from several drowned reefs and data from this site may be used to constrain the age of their formation (see site summary form). Farther south, proposed Site NWS-6A (Houtman-1) is directly seaward of, and down dip from, the Houtman-Abrolhos main reef complex (see site summary data). Dating, coupled with seismic correlation into this complex, will provide insight into its pre-late Quaternary history.

The significance, timing and onset of ooid formation: Ooids typically form in shallow (<5 m) agitated, tide-dominated tropical environments with elevated evaporation and salinity (James et al., 2004). Globally they have been interpreted to be direct evidence of physiochemical precipitation from sea water during periods of elevated seawater alkalinity and supersaturation (Rankey & Reeder, 2009). As such their occurrence in the subsurface of the NWS may be used as a sea surface temperature, palaeobathymetry and aridity index. James et al. (2004) described in situ and “relict” ooids in modern sediment of the NWS from 17° to 21°S. They suggested that “relict” grains formed from 15.4 to 12 ka and were stranded at 30 to 300 m water depths by the Holocene transgression. James et al. (2004) attribute their formation to the re-initiation of the Leeuwin Current (ca. 12 ka) as sea levels rose after the last glacial maximum (LGM) when the current was thought to have been inactive. The most southerly occurrence of ooids on the NWS is in the shallow supersaturated environment of Shark Bay (Fig. 1, 25.5°S; Davies, 1970). Ooids are rare in the Indian Ocean (Braithwaite, 1994) for reasons that are enigmatic. The majority of ooids are described from late Quaternary sediments because no older records exist from the NWS. Hearty et al. (2006) described 3.3 kyr old ooids from northwest Australia (18.5°S) and suggests that they formed during periods of slow sea level rise (Hearty et al., 2010). Braithwaite (1994) interpreted ooid formation in the Maldives to have occurred in the early cooling and late warming phase of the last glacial cycle. Our preliminary work shows that ooids are present in a core dated at 200 ka (Fig. 4) and in cuttings younger than 600 ka from Maitland North-1 (Fig. 5). These represent the oldest recovered ooids in the Indian Ocean, but numerous questions remain. For example: When do they first occur? Does the advent of ooid formation signify the onset of stronger aridity in the last 600 ka? Is there a palaeoceanographic trigger (the ITF?) for ooid formation that resulted in increased alkalinity in the Indian Ocean? Is there a relationship between these physiochemical conditions and the onset of reef deposition? What is the relationship between
the glacio-eustatic cycles, aridity and ooid formation? These questions can only be answered by coring. We will seek ooids by drilling shelfal sections and expect shallow water facies suitable for ooid preservation in the Quaternary intervals sampled by proposed Sites NWS-1A, NWS-2A and NWS-3A and possibly further south at Sites NWS-5A and NWS-6A.

8.2 Objective 2: To obtain a 5 million year orbital scale tropical to subtropical climate and ocean archive that is directly comparable to deep ocean oxygen isotope and ice core archives. This will be used to chart the variability of the Australian Monsoon and the onset of aridity in Australia.

The aridity of Australia is alleviated by the Australian summer monsoon, which delivers substantial moisture to the northern part of the continent (north of 25°S) from December to March (Herold et al., 2011; Suppiah, 1992). The winds blow predominantly from the northwest in the rainy season while in the dry season the winds blow from the southeast. These changes are associated with the seasonal migration of the mean, latitude of the subtropical high-pressure belt, from 40° to 30°S, respectively. In the southern winter the Intertropical Convergence Zone (ITCZ) is positioned north of Indonesia, moving south in summer to a position immediately north of Australia (Fig 2). The ITCZ moves even farther south over tropical Australia in February, associated with the peak of the northern Australian wet season (Williams et al., 2009). The Australian monsoon is thought to be caused by land-ocean temperature contrasts and inter-hemispheric flow from the Asian monsoon. Australian monsoon strength and timing is influenced by changes in insolation due to obliquity and precessional forcing (Wyrwoll et al., 2007; Wyrwoll et al., 2012). The Australian summer monsoon lacks the topographic influence that controls the Indian–East Asian summer monsoon, and therefore it is weaker and more sensitive to variations in insolation (Wyrwoll et al., 2007). The region affected by the Asian and Australian monsoon systems, from 70° to 150° E, is one of the most significant heat sources that drive global climate.

*The palaeomonsoon:* An (2000) speculated that the histories of the East Asian and Australian monsoons are linked and they originated before 7 Ma. Bowman et al. (2010) suggested (in the absence of any definitive northern Australia pre-Quaternary records) that “the (Australian) monsoon is of great antiquity” due to the pronounced diversity and strong adaptations of biota adapted to the wet-dry tropical climate and their strong adaptability. Herold et al. (2011) noted the near complete lack of knowledge of the nature and intensity of the pre-Quaternary Australian monsoon and investigated its potential Miocene impact on rainfall levels using a general circulation model constrained with a vegetation model. Herold et al. (2011) and
Greenwood et al. (2012) compiled available palaeontological proxy data for the Miocene and reconstructed a seasonally wet northern and interior Australia, supporting a biota (i.e., seasonally dry deciduous vine forests and sclerophyllous woodlands) consistent with a monsoonal precipitation regime wetter than today’s. The only pollen record from the semi-arid northwest Australian continent is marine core GC17 from west of the Cape Range Peninsula (Fig. 1, water depth 1093 m) and spanning the last 100,000 yrs (van der Kaars & De Deckker, 2002; van der Kaars et al., 2006). This location is at the southern extremity of the Australian summer monsoon and receives 200 to 300 mm of rainfall per year, making it an ideal core to record changes in the latitudinal position of the monsoon (Fig. 2). van der Kaars et al. (2006) used transfer functions to interpret rainfall from the pollen record and hypothesized a marked reduction in summer rainfall occurred in the absence of monsoonal activity during the LGM. Other deep-water Quaternary records of the Australian monsoon have been obtained from farther north in the Timor Sea at 13°S (Holbourn et al., 2005), and Banda Sea at 5°S (Beaufort et al., 2010) and 8.5°S (Spooner et al., 2005). Holbourn et al. (2005) used foraminiferal and geochemical proxies to chart Timor Sea palaeoproductivity over the last 350,000 years and noted that the Timor Sea productivity record matches the 25°S summer insolation curve and interpret a strong precessional and eccentricity control. This indicates that tropical and/or southern hemisphere insolation forcing is an important modulating factor for Australian monsoon intensity. Spooner et al. (2005) combined stable isotope analyses with planktic foraminiferal assemblage analyses to interpret the 80,000 year variability of the monsoon and concluded that it was less intense during the first 60 ka and then intensified at ~15 ka. Beaufort et al. (2010) used nannofossil proxies to suggest a precessional control on primary productivity and Australian monsoon intensity over the last 150,000 years.

**Charting the 5 Myr record of the Australian monsoon:** We propose to drill a continental margin to slope section (NWS-4A, Fig. 7) in order to obtain a >4.2 million year orbital scale record of climate variability and monsoon history that will be comparable in its resolution to other global climate proxy records. Most such records are from the deep ocean basins. However, one benefit of coring in a continental-margin setting is that the pollen is likely to be more abundant, delivered by fluvial outflow during the rainy season (van der Kaars & De Deckker, 2003). In comparison, pollen in deep-ocean cores relies on eolian delivery and is less abundant. This location is also close to the southern edge of Australian monsoonal influence and can therefore be used chart its latitudinal variability. Furthermore, analyses of cutting from West Tryal Rocks-1 (near NWS-4A) reveals a 4.2 Myr old, 1.1 km-thick section.
in which slope planktonic ooze dominates in the lower 300 m overlain by mudstones/marls with 35 to 55% planktic foraminifera (see Table 1 in Gallagher et al., 2009). While there are likely to be some gaps in the section created by slope erosion, thick intervals have accumulated in low energy conditions (at palaeodepths >400 m) owing to significant subsidence. This palaeodepth is important, because studies on pollen content in modern marine sediment of the NWS have concluded that the bioclimatic zones of the adjacent Australian continent are extremely well represented especially at depths ≥400 m (van der Kaars & De Deckker, 2003). We also anticipate good pollen preservation in the Plio-Pleistocene interglacial gamma rich units at the shelfal sites and also where gamma peaks/mudstones/marls are most common in the Pliocene sections. Incorporation of these shelfal analyses will provide a long-term (5 Myr) interglacial perspective on the Australian monsoon over 10° of latitude. If the gamma maxima reflect fluvial input (and, by proxy rainfall) to the shelf, the gamma profiles of the NWS (Fig. 3) show a (wetter?) Pliocene to Early Pleistocene period (increased gamma) followed by increased dryness during the middle to late Pleistocene (lower gamma values). Little is known about the timing of the development of the characteristic synoptic-scale division of Australia into a winter-wet south, and summer-wet north. To first approximation, the intensity and timing of the dry seasons of monsoonal northern Australia and of frontal-dominated southern Australia are both controlled by the intensity and seasonal migration of the subtropical anticyclone. Hence the history of the southern subtropical anticyclone may be critical to our understanding of the evolution synoptic systems at both ends of the continent. However, it is unknown whether the late Neogene evolution of the Australian monsoon was synchronized with contemporaneous climatic evolution in the south of the continent. Nevertheless, the timing of patterns seen in the gamma maxima of the NWS (Fig 3) shows similarities with data from southeastern Australia. For example, fossil insect and pollen analyses from a small upland paleolake in southeastern Australia indicate that high annual and summer rainfall, inconsistent with the modern climates and vegetation patterns, persisted there until at least 1.5 Ma, well into the Early Pleistocene (Sniderman et al., 2009), while drying of a megalake in what is now the semi-arid interior of southeastern Australia did not occur until the Early Pleistocene (1.5 to 1.4 Ma) (McLaren & Wallace, 2010), just when the NWS gamma profile becomes subdued (the arrow on Fig. 3). In central Australia, there is evidence that the final phase of aridification, marked by the presence of active dunefields, was not initiated until ~1 Ma (Fujioka & Chappell, 2010). Hence it is possible that the onset of ‘modern’ patterns of rainfall seasonality across the continent, as well as the initiation of full aridity in inland
Australia, were synchronized. This proposal will provide new data to constrain our understanding of southern hemisphere Pleistocene climate evolution across a tropical to temperate gradient, by including both the monsoonal sites and Site NWS 5A. Further insight into the relative input from precipitation can be obtained by analyzing the clay mineralogy (x-ray diffraction) of the marly facies (Gingele et al., 2001a; 2001b). The %kaolinite/illite/chlorite content in each horizon will vary depending on the relative intensity of precipitation and runoff from the source coastal hinterland. For example reduced chlorite associated with a decrease in kaolinite is interpreted to indicate arid conditions on the NWS during the Holocene (Gingele et al., 2001a). Geochemical and foraminiferal proxy analyses at all proposed sites will determine whether palaeoproductivity maxima exist and whether they were related to Australian monsoon and position of the ITCZ. At upper-slope Site NWS-4A, microfossil palaeoproductivity analyses might also reveal the dominance of the Western Australian Current over the Leeuwin Current in glacial periods (cf. Spooner et al., 2011) when the Australian monsoon is thought to have been weak. Site NWS-5A, at ~28°C, is located at the northern edge of the modern, winter-dominated rainfall regime of southwestern Australia. It is therefore ideally located to chart the timing of onset of the mid-latitude, westerly wind regime that drives this winter-dominated precipitation regime through analysis of characteristic pollen assemblages.

Turney et al. (2006) suggested that late Quaternary climatic variability across northern Australia probably reflected changes in the latitude of the ITCZ, the westerlies and ocean masses. However, these authors stated that ‘few local records are available that enable the frequency, timing and latitudinal span to be reconstructed with great confidence’. They note that biological or geomorphic proxy evidence might often show a time-transgressive response to climatic variability. They concluded with a plea to perform quantitative reconstructions of past climates in this region, with a refined chronology.

8.3 Objective 3: Provide empirical input into the bathymetric and subsidence history of the NWS that can directly feed ground-truth geodynamic models of the Australasian/Eurasian Plate, providing for the first time a detailed account of spatiotemporal vertical surface motion over recent geological history.

Mantle convection patterns and lateral displacement of continents relative to them have significant impact on the flooding history of continental platforms and margins (Sleep, 1976; Gurnis, 1990, 1993; Russell & Gurnis, 1994). Eustatic curves constructed from data from a single margin are known to misrepresent actual global sea level because of the influence of dynamic topography (Müller et al., 2008, Spasojevic et al., 2008, Moucha et al., 2008). Since
the breakup and dispersal of eastern Gondwana in the Cretaceous, the Australian plate has moved several thousand kilometers northward (Fig. 8) and recorded anomalous flooding patterns that cannot be reconciled with known eustatic variations (Fig. 9; Russel & Gurnis 1994; Gurnis et al., 1998; Veevers, 2001; DiCaprio et al., 2009; Heine et al., 2010). Apart from these continental-scale observations there is a global paucity of critically important accurate measurements of the amplitude, wavelength and rate of dynamic topography that are needed to constrain mantle convection models.

Neogene and Quaternary subsidence anomalies along the NWS are ideal targets for investigation of dynamic topography due to their spatial position on the edge of the degree two geoid anomaly and on the fastest moving continent since the Eocene. These anomalies have long been known (Müller et al., 2000; Kennard et al., 2004) and can confidently be ascribed to dynamic topography because the effects of thermal subsidence and flexure are negligible. Post-rift thermal subsidence is driven by cooling of the lithospheric mantle until it returns to its pre-rift thickness. Given that the last phase of rifting on the NWS occurred more than 130 Myr ago, the lithospheric mantle should have completed rethickening by the Neogene and therefore thermal subsidence should have been insignificant during the Neogene and Quaternary. Flexural effects are likely to be negligible for two reasons. First, the proposed drill sites are positioned beyond the ~200 km flexural response wavelength of plate boundaries. Secondly, the present elastic thickness of the NWS is ~5 km and therefore loads approach Airy isostasy (Fowler & McKenzie, 1989).

In the last five years advancements in computer modeling have attributed subsidence anomalies along the NWS to dynamic drawdown of the Earth’s surface driven by Australia’s rapid northward motion over a generally stationary accumulation of subducted slabs within the mantle beneath southeast Asia (Lithgow-Bertelloni & Gurnis, 1997; Heine et al., 2010). These models predict that the NWS should be affected by a southward propagating wave of subsidence related to Australia’s northward motion over this stationary cold and dense mantle anomaly. Because Australia’s northward motion is ~70 km/Myr and the proposed drill sites span 10° of latitude, this model predicts a resolvable subsidence diachronity of >10 Myr between the northern and southern proposed drill sites.

In contrast to the diachronous results of geodynamic modeling, recent backstripping of NWS clinoform rollover positions indicates that margin-wide anomalous subsidence was synchronous and commenced at 9 ± 3 Ma, with a down-to-the-north gradient equal in amplitude to adjacent oceanic floor residual depth anomalies (Czarnota et al, 2012; in review). This study suggests the mantle anomaly responsible for the subsidence is transient and must
be coupled to the motion of the plate. However, a weakness of this work is the lack of temporal resolution in the interval between 0-5 Ma since there are no well-defined clinoform rollovers of this age. Accurate, high-temporal resolution subsidence analysis can directly resolve the discrepancy between the two end member scenarios presented here thereby providing fundamental insight into the interplay between plate motion and mantle convection.

Fig: 8: Plate tectonic history of the Australian Plate for the last 70 Ma. Coloring refers to the position of Australia in an absolute reference frame (Müller et al., 2008b) in 10 Myr time steps from 70 Ma to present (filled solid gray). Figure from Heine et al. (2010).

Tectonic Subsidence: We aim to construct a detailed Neogene and Quaternary subsidence history for the NWS with unprecedented accuracy along the proposed drilled transect. In order to compare subsidence histories between drilling locations we will calculate 1D water loaded basement subsidence histories assuming Airy isostasy. Flexural backstripping can also be performed because of the abundance of industry seismic profiles near the drill sites, but the low flexural rigidity of the region renders this degree of complexity unnecessary. Accurate knowledge of paleobathymetry, sediment compaction parameters and lithology are essential throughout the 0-5 Ma time interval in question. All of these input parameters can be constrained from drill core. In addition, the compaction parameters, lithology and thickness of underlying sedimentary units are also needed because a large component of the accommodation space on passive margins results from the compaction of underlying sediments. Fortunately the petroleum industry, government and academia have extensively studied the underlying sedimentary pile and therefore the necessary data exist.
Fig. 9: Global eustatic sea level curves and inundation history of the Australian continent based on palaeoshorelines derived from Langford et al. (1995). Solid black curves based on Haq and Al-Qahtani’s (2005) global sea-level curve, with thin line representing the original estimate, thick line: filtered curve. Solid gray curves are based on Haq et al.’s (1987) global sea-level curve, with thin line representing original curve, thick line filtered curve. Filtered lines show long-wavelength component of the eustatic estimate using a cosine arch filter with a 10 Myr window. The amount of inundation is computed relative to the present-day 200 m isobath from the ETOPO2 global 2’ topography (N.O.A.A., National Geophysical Data Center, 2006). From Heine et al. (2010).

Paleobathymetric estimates: Paleobathmetry from foraminiferal and facies analyses is essential for backstripping analyses; continuously cored IODP boreholes, will provide the constraints necessary to estimate relative sea-level variations. We intend to use benthic assemblages, planktic percentage and sedimentary facies data to interpret palaeodepths. Modern shelfal foraminiferal assemblages on Australia’s continental margin are very similar to Plio-Pleistocene assemblages and can therefore be used as modern analogues for palaeodepth and palaeonutrient interpretation (Smith & Gallagher, 2003; Smith et al., 2001). We will use modern foraminiferal assemblage analog data from across the region, including: Sunda Shelf from 5° to 10°N (Biswas, 1976); Banda Sea and Timor Trough from 5° to 10°S (van Marle, 1988); Sahul Shelf and Timor Sea from 8° to 14°S (Loeblich & Tappan, 1994), Exmouth Gulf at 22°S (Haig, 1997; Orpin et al., 1999), Ningaloo Reef at 24°29’S (Parker, 2009) and the western Australian continental shelf from 20° to 34°S (Li et al., 1999; Betjeman, 1969; Quilty, 1977). The benthic foraminiferal assemblage analogue data will be enhanced with palaeodepth estimates from larger foraminifera distribution (Renema, 2006; James et. al, 1999; Hohenegger, 1995; Langer & Hottinger, 2000; Hohenegger, 2005). The percentage planktic foraminifera in total assemblage data can also be used to estimate palaeodepths (van der Zwann et al., 1990) and has been used to obtain palaeobathymetric estimates prior to backstripping and generation of subsidence curves (van Hinsbergen et al.,
2005). This holistic approach will be enhanced by interpretations of facies distributions (eg. *in situ* ooid distribution) to generate robust palaeobathymetric inputs into subsidence models.

**9. Need for drilling**

The hunt for hydrocarbons on the NWS has provided abundant site survey data for our proposal, including: well completion reports, seismic data, wireline logs, cuttings, (rare) sidewall core and limited core in the latest Quaternary sections. These data show the potential of drilling this region to reveal an *in situ* record of the history of key oceanographic and climate thresholds in an area downstream of a major arm of the global thermohaline conveyor (ITF). However, there are no continuous cores of Plio-Pleistocene age in the shelfal margin region of the NWS. We have targeted a 10° latitudinal transect to investigate tropical reef and carbonate diachronieity that is related to Leeuwin Current intensity and ITF/IPWP influence. All proposed sites lie at a sufficient spacing to reveal this lateral variability. In particular, proposed sites NWS-1A, NWS-3A, NWS-4A and NWS-6A will reveal insights into the timing and onset of reef development and are important targets since the pre-late Quaternary (post-Miocene) history of tropical reef development on the NWS is unknown. The proposed shelfal sites (NWS-1A, NWS-2A, NWS-3A, NWS-5A and NWS-6A) are necessary to obtain biogeographic evidence of ITF connectivity (Fig. 6), giving us a downstream record of this important ocean gateway that cannot be obtained by drilling deeper oceanic sites. These shelfal sites are also likely to yield ooids, and drilling will reveal the maximum age for the enigmatic tropical indices in the Indian Ocean. Knowing the temporal and spatial distribution of ooids in the NWS will also provide insight into regional aridity, Indian Ocean alkalinity and can also be used as palaeodepth indices. The presence of bathymetrically diagnostic facies, larger and smaller foraminifera at these 5 sites will permit well-constrained subsidence histories to be obtained across 10° latitude allowing the detailed temporal history of dynamic subsidence of northern Australian plate to be constructed for the first time. All proposed sites are likely to yield spores and pollen in the interglacials and therefore yield a 5 million year record of climate change and improve our understanding the timing and nature of aridification in northwestern Australia. Drilling closer to the shoreline will yield predominantly fluvial derived assemblages that will provide a more realistic assessment of regional climate compared to the eolian derived floral assemblages in deeper oceanic sites. Two shelfal to upper bathyal targets (NSW-4A, NSW-5A) are required to obtain a climate record of this margin. The 4.2 million year long climate record at proposed site NSW-4A is needed obtain a long term orbital-scale record of the Australian monsoon (directly comparable to deeper
ocean and ice core archives). This site will reveal insights into the onset and dynamics of the Australian monsoon and its relationship to obliquity forcing, representing potentially a quantum increase in our understanding of this important climate system as previous studies in the region focused only on the last 200,000 years. Proposed site NWS-5A is not likely to yield an orbital scale climate record due to slope erosional processes (see site summary form). However, it will complement proposed site NWS-4A, as it lies south of a climatic divide between the Australian monsoon dominated north and the westerly wind driven, winter rainfall dominated south (Fig. 2). Proposed site NWS-4A will provide a lower resolution (yet important) Plio-Pleistocene record of onset and variability of the southern Australian winter-dominated rainfall regime.

10. Proposed sites and drilling safety

We propose to redrill five wells that have been plugged and abandoned due to the lack of hydrocarbon shows (a clear plus for safety and for better defining our scientific objectives) and one close to a well that encountered hydrocarbon deeply buried beneath up to 3 km of tight mudstones. The NCB, Roebuck and Perth Basins are hydrocarbon provinces, but almost all hydrocarbon accumulations are trapped beneath the regional seal provided by Cretaceous shales. The single exception lies over 100 km inboard of the proposed NCB sites, where Paleocene sands are sealed by Eocene shale and marl. Petroleum accumulations are generally unlikely in the predominantly carbonate Neogene section, especially in the outer shelf and upper slope locations of the proposed sites. We propose recovery of 3682 m of continuous cores, well within the capabilities of JOIDES Resolution within a 2-month expedition, depending on the transits involved. Each site will involve triple APC in the upper 200 m (or to refusal) with the remaining section XCB to total depth (Table 2).

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Water depth (m)</th>
<th>Penetration (m)</th>
<th>Estimated Time on Site (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWS-1A</td>
<td>146</td>
<td>475</td>
<td>5.0</td>
</tr>
<tr>
<td>NWS-2A</td>
<td>141</td>
<td>579</td>
<td>5.5</td>
</tr>
<tr>
<td>NWS-3A</td>
<td>88</td>
<td>842</td>
<td>5.9</td>
</tr>
<tr>
<td>NWS-4A</td>
<td>138</td>
<td>1122</td>
<td>7.8</td>
</tr>
<tr>
<td>NWS-5A</td>
<td>214</td>
<td>336</td>
<td>4.9</td>
</tr>
<tr>
<td>NWS-6A</td>
<td>152</td>
<td>328</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Table 2 Summary of Proposed Drilling 33.8 days in total plus 10 days travel time.

11. Summary

We propose to drill a transect of six shelf to shelf margin cores over 10° latitude in the Northwest Shelf of Australia to obtain a five million year ITF, IPWP and climate record that
has the potential to match orbital scale deep sea records (and ice cores) in its resolution. Drilling will reveal a detailed shelfal record of ITF variability and timing and its relationship to climate. It will allow us to understand the controls on the origin and distribution of coral reefs and tropical carbonates in the eastern Indian Ocean and their relationship to surface oceanographic features such as the Leeuwin Current (the only southward flowing eastern boundary current in the southern hemisphere). Drilling will determine the cause(s) and variability of the Australian monsoon, a system thought to be related to the East Asian monsoon, leading to a better understanding of how the Australian continent became arid. Accurate subsidence analysis over 10° of latitude will resolve whether northern Australia is moving with/over a time transient or long term stationary downwelling within the mantle thereby improving our understanding of the dynamics of deep Earth processes.

12. References


Betjeman, K. J., 1969, Recent foraminifera from the western continental shelf of Western Australia: Contributions from the Cushman Foundation for Foraminiferal Research, v. 20, Part 4, p. 119-138.


Gentilli, J., 1972, Australian Climate Patterns, Melbourne, Thomas Nelson, 285 p.:


Hull, J. N. F., and Griffiths, C. M., 2002, Sequence stratigraphic evolution of the Albian to Recent section of the Dampier Sub-basin, North West Shelf, Australia, in Keep, M.,


Lithgow-Bertelloni, C., and Gurnis (1997), Cenozoic subsidence and uplift of continents from time-varying dynamic topography, Geology, v. 25, no. 8, p. 735-738.


Quilty, P. G., 1977, Foraminifera of Hardy Inlet, southwestern Australia: Journal of the Royal Society of Western Australia, v. 59, no. 3, p. 79-90.


Renema, W., 2006, Large benthic foraminifera from the deep photic zone of a mixed siliciclastic-carbonate shelf off East Kalimantan, Indonesia, Marine Micropaleontology, v. 58, p. 73-82.


Sniderman J.M.K., Porch N. & Kershaw A.P. 2009, Quantitative reconstruction of Early Pleistocene climate in southeastern Australia and implications for atmospheric circulation, Quaternary Science Reviews, 28, p. 3185-3196


Wells, P. E., and Wells, G. M., 1994, Large-scale reorganization of ocean currents offshore Western Australia during the Late Quaternary: Marine Micropaleontology, v. 24, p. 157-186.


Williams, M., Cook, E., Van der Kaars, S., Barrows, T., Shulmeister, J., and Kershaw, P., 2009, Glacial and deglacial climatic patterns in Australia and surrounding regions from 35 000 to 10 000 years ago reconstructed from terrestrial and near-shore proxy data: Quaternary Science Reviews, v. 28, no. 23, p. 2398-2419.


Potential Reviewers

Andre Droxler
Rice University, Department of Geology and Geophysics, MS-126, 6100 Main St, Houston, TX 77005-1892
Phone (713) 527-4885 Email: andre@rice.edu

Noel James
Department of Geological Sciences & Geological Engineering, Miller Hall, Queen's University, Kingston, Ontario, K7L 3N6
Phone: (613) 533-6170, Fax (613) 533-6592, Email: james@geol.queensu.ca

Myra Keep
School of Earth and Geographical Sciences/Faculty of Natural and Agricultural Sciences M004
The University of Western Australia
35 Stirling Highway
CRAWLEY WA 6009
Australia
Phone: 08 6488 7198
Fax: 08 6488 1037
Email: mkeep@tsrc.uwa.edu.au

Mike Gurnis
Email: gurnis@caltech.edu
Seismological Laboratory
MS 252-21
California Institute of Technology
Pasadena, California 91125

Lindsay B. Collins
Department of Applied Geology, Curtin University of Technology, Hayman Road, Bentley, Western Australia, 6102, Australia
Phone: 08 9266-7977
Email: lindsay@lithos.curtin.edu.au

Myra Keep
School of Earth and Geographical Sciences/Faculty of Natural and Agricultural Sciences M004
The University of Western Australia
35 Stirling Highway
CRAWLEY WA 6009
Australia
Phone: 08 6488 7198
Fax: 08 6488 1037
Email: mkeep@tsrc.uwa.edu.au

Peter Kershaw
School of Geography and Environment Sciences, Monash University Wellington Road Clayton, Victoria 3800 Australia
Phone 03 99052927
Email: peter.kershaw@monash.edu

Stephen McLoughlin
Swedish Museum of Natural History
P. O. Box 50007
SE-104 05 Stockholm, Sweden
Phone: +46 (0)8 519 541 42
Email: steve.mcloughlin@nrm.se

Louis Moresi
School of Mathematical Sciences, Monash University Wellington Road Clayton, Victoria 3800 Australia
Phone 03 99054450
Email: Louis.Moresi@monash.edu

Martin Langer
Institut für Paläontologie, Rheinische Friedrich-Wilhelms Universität Bonn,
Nussallee 8, 53115 Bonn, Germany
Phone: 49 - (0) 228 - 734026 Fax: 49 - (0) 228 - 733509
Email: martin.langer@uni-bonn.de
# IODP Site Summary Forms:

## Form 1 – General Site Information

### Section A: Proposal Information

<table>
<thead>
<tr>
<th>Title of Proposal:</th>
<th>Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Form Submitted:</td>
<td>2012-10-04 04:43:58</td>
</tr>
<tr>
<td>Site Specific Objectives with Priority (Must include general objectives in proposal)</td>
<td>Southern record of latitudinal tropical to subtropical carbonate deposition and Leeuwin Current. Constraining the age and setting of the Houtman Abrolhos Reef complex: drilling objective 1. Obtaining bathymetric estimates for subsidence history: drilling objective 3.</td>
</tr>
<tr>
<td>List Previous Drilling in Area:</td>
<td>This is a redrill of a plugged and abandoned petroleum well: Houtman-1</td>
</tr>
</tbody>
</table>

### Section B: General Site Information

<table>
<thead>
<tr>
<th>Site Name:</th>
<th>NWS-6A</th>
</tr>
</thead>
<tbody>
<tr>
<td>If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#:</td>
<td></td>
</tr>
<tr>
<td>Latitude:</td>
<td>Deg: -28.665</td>
</tr>
<tr>
<td>Longitude:</td>
<td>Deg: 113.576</td>
</tr>
<tr>
<td>Coordinate System:</td>
<td>WGS 84</td>
</tr>
<tr>
<td>Priority of Site:</td>
<td>Primary: yes Alt:</td>
</tr>
<tr>
<td>Area or Location:</td>
<td>Northwest Shelf Australia, Perth Basin</td>
</tr>
<tr>
<td>Jurisdiction:</td>
<td>Australia</td>
</tr>
<tr>
<td>Distance to Land:</td>
<td>100 (km)</td>
</tr>
<tr>
<td>Water Depth (m):</td>
<td>152</td>
</tr>
</tbody>
</table>
## Section C: Operational Information

**Proposed Penetration (m):**

<table>
<thead>
<tr>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>328</td>
<td>0</td>
</tr>
</tbody>
</table>

**Total Sediment Thickness (m):**

| 328       |

**Total Penetration (m):**

| 328       |

**General Lithologies:**

- Calcarenites and calcilutites

**Coring Plan:**

- Triple APC to refusal (200 m)/XCB to total depth

<table>
<thead>
<tr>
<th>APC</th>
<th>XCB</th>
<th>MDCB</th>
<th>PCS</th>
<th>RCB</th>
<th>Re-entry</th>
</tr>
</thead>
</table>

**Wireline Logging Plan:**

- WL
- LWD
- Porosity
- Density
- Gamma Ray
- Resistivity
- Sonic (Δt)
- Formation Image
- Check-shot

**Standard Measurements:**

- Magnetic Susceptibility
- Magnetic Field
- Borehole Temperature
- Nuclear Magnetic Resonance
- Geochemical
- Resistivity
- Nuclear Magnetic Resonance
- Density
- Gamma Ray
- Porosity
- Sonic

**Special Tools:**

- Magnetic Field
- Borehole Temperature
- Nuclear Magnetic Resonance
- Geochemical
- Resistivity
- Nuclear Magnetic Resonance
- Density
- Gamma Ray
- Porosity
- Sonic

**Max. Borehole Temp.:**

| 0°C       |

**Mud Logging:**

- Cuttings Sampling Intervals:
  - from m to m m intervals
  - from m to m m intervals

**Estimated Days:**

- Drilling/Coring: 3.4
- Logging: 1.3
- Total On-site: 4.7

**Observatory Plan:**

- Longterm Borehole Observation Plan/Re-entry Plan

**Potential Hazards/Weather:**

- Shallow Gas
- Hydrocarbon
- Shallow Water Flow
- Abnormal Pressure
- Man-made Objects (e.g., sea-floor cables, dump-sites)
- H₂S
- CO₂
- Other:

- Complicated Seabed Condition
- Soft Seabed
- Landslide and Turbidity Current
- Gas Hydrate
- Fracture Zone
- Diapir and Mud Volcano
- Fault
- High Temperature
- High Dip Angle
- Ice Conditions

- Sensitive marine habitat (e.g., reefs, vents)

**Preferred weather window:**

<table>
<thead>
<tr>
<th>Preferred weather window</th>
<th>Other:</th>
</tr>
</thead>
</table>
### IODP Site Summary Forms: Form 2 - Site Survey Detail

**Proposal #:** 807  
**Site #:** NWS-6A  
**Date Form Submitted:** 2012-10-04 04:43:58

*Key to SSP Requirements*

- **X** = required; **X** = may be required for specific sites; **Y** = recommended; **Y** = may be recommended for specific sites;
- **R** = required for re-entry sites; **T** = required for high temperature environments; † = Accurate velocity information is required for holes deeper than 400 m.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>In SSDB</th>
<th>SSP Req.</th>
<th>Details of available data and data that are still to be collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a High resolution seismic reflection (primary)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>1b High resolution seismic reflection (crossing)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
</tbody>
</table>
| 2a Deep penetration seismic reflection (primary) | no      | X        | Line A-A’ (shown on site summary form 6) seismic line - a89-010ar (dip section east-west) this will be submitted by Dec 1 deadline  
|                                           |         |          | Location: a89-010ar                                                        |
| 2b Deep penetration seismic reflection (crossing) | no      | X        | Line B-B’ (shown on site summary form 6) seismic line - a76-29r (oblique strike section north south) this will be submitted by Dec 1 deadline  
|                                           |         |          | Location: a76-29r                                                          |
| 3 Seismic Velocity          |         |          | In submitted Houtman-1 well completion report                              |
| 4 Seismic Grid              |         |          |                                                                             |
| 5a Refraction (surface)     |         |          |                                                                             |
| 5b Refraction (bottom)      |         |          |                                                                             |
| 6 3.5 kHz                   |         |          |                                                                             |
| 7 Swath bathymetry         |         |          |                                                                             |
| 8a Side looking sonar (surface) |       |          |                                                                             |
| 8b Side looking sonar (bottom) |       |          |                                                                             |
| 9 Photography or video      |         |          |                                                                             |
| 10 Heat Flow                |         |          |                                                                             |
| 11a Magnetics               |         |          |                                                                             |
| 11b Gravity                 |         |          |                                                                             |
| 12 Sediment cores           |         |          | None                                                                        |
| 13 Rock sampling            |         |          | Cuttings every ca. 10 m in Houtman-1 described in submitted well completion report |
| 14a Water current data      |         |          | Information in published literature                                         |
| 14b Ice Conditions          |         |          |                                                                             |
| 15 OBS microseismicity      |         |          |                                                                             |
| 16 Navigation               |         |          |                                                                             |
| 17 Other                    |         |          | Wireline logs (gamma) to sea bed in Houtman-1 and well completion report    |
### IODP Site Summary Forms:

**Form 3 – Detailed Logging and Downhole Measurement Plan**

<table>
<thead>
<tr>
<th>Proposal #:</th>
<th>807</th>
<th>Site #:</th>
<th>NWS-6A</th>
<th>Date Form Submitted:</th>
<th>2012-10-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Depth (m):</td>
<td>152</td>
<td>Sed. Penetration (m):</td>
<td>328</td>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site:

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
<th>Relevance (1=high, 3=low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Geochemical</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>VSP</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Other (SET, SETP, …)</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
### Summary of Operations at site.

Triple-APC to 200 mbsf (or to refusal), XCB to 328 mbsf

### All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.

The Perth Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled. NSW-6A is a redrill of the plugged and abandoned petroleum well Houtman-1. The upper section are Tertiary carbonates. The top of the Cretaceous is at 713 mbdf. Shows of hydrocarbons occur in the marine and marginal marine sequence above, within and below the Jurassic Cadda Formation (3342-3500 mbdf: Gas) and in the Cattamarra Coal Measures (3378.5 mbdf: Oil).

### All commercial drilling in this area that produced or yielded significant hydrocarbon shows.

### Indications of gas hydrates at this location.

No

### Are there reasons to expect hydrocarbon accumulations at this site?

Not at depths to be drilled

### What “special” precautions will be taken during drilling?

### What abandonment procedures need to be followed?

### Natural or manmade hazards which may effect ship’s operations.

Possibility of shallow gas

### Summary: What do you consider the major risks in drilling at this site?

Possibility of shallow gas
<table>
<thead>
<tr>
<th>Subbottom depth (m)</th>
<th>Key reflectors, Unconformities, faults, etc</th>
<th>Age</th>
<th>Assumed velocity (km/sec)</th>
<th>Lithology</th>
<th>Paleo-environment</th>
<th>Avg. rate of sed. accum. (m/My)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>seafloor</td>
<td>5.33</td>
<td>3.2</td>
<td>Calcarenites and calcilutites</td>
<td>Shelfal</td>
<td>62</td>
<td>Pliocene to Pleistocene record down dip of Houtman Abrolhos Reef complex</td>
</tr>
<tr>
<td>328</td>
<td>Base Pliocene/Top Miocene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposal #:</td>
<td>Site #:</td>
<td>Date Form Subm.:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>807</td>
<td>NWS-6A</td>
<td>2012-09-03 09:02:47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Site Summary

**Figure Comment**

**Table:**

<table>
<thead>
<tr>
<th>Key reflectors, Unconformities, faults, etc</th>
<th>Age Assumed velocity (km/sec)</th>
<th>Lithology</th>
<th>Paleo-environment</th>
<th>Avg. rate of sed. accumulation (m/My)</th>
<th>Comments</th>
</tr>
</thead>
</table>

**Proposal #:** 807  
**Site #:** NWS-6A  
**Date Form Subm.:** 2012-09-03 09:02:47
Site summary Form 6: NWS-6A (Houtman-1 Redrill):

SSDB Details for proposed site:

(1) Location map from regional Geoscience Australia bathymetric grid,
(2) Wireline log for Houtman-1.
(3) A-A' Seismic line: a89-010ar.
(4) B-B' Seismic line: a76a-29r.
(5) A well completion report for Houtman-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.
**IODP Site Summary Forms:**

**Form 1 – General Site Information**

### Section A: Proposal Information

**Title of Proposal:** Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

**Date Form Submitted:** 2012-10-04 04:43:58

**Site Specific Objectives with Priority**

A Southern record of latitudinal tropical to subtropical carbonate deposition and Leeuwin Current (Drilling Objective 1). A Plio-Pleistocene record of southwest Australian climate (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (drilling objective 3).

**List Previous Drilling in Area:** This is a redrill of a plugged and abandoned petroleum well: Morangie-1 and Morangie-ST1.

### Section B: General Site Information

<table>
<thead>
<tr>
<th>Site Name:</th>
<th>NWS-5A</th>
</tr>
</thead>
<tbody>
<tr>
<td>If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#</td>
<td></td>
</tr>
<tr>
<td>Latitude:</td>
<td>-27.375</td>
</tr>
<tr>
<td>Deg:</td>
<td>112.925</td>
</tr>
<tr>
<td>Longitude:</td>
<td>112.925</td>
</tr>
<tr>
<td>Coordinate System:</td>
<td>WGS 84</td>
</tr>
<tr>
<td>Priority of Site:</td>
<td>Primary: yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area or Location:</th>
<th>Northwest Shelf Australia, Perth Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jurisdiction:</td>
<td>Australia</td>
</tr>
<tr>
<td>Distance to Land: (km)</td>
<td>100</td>
</tr>
<tr>
<td>Water Depth (m):</td>
<td>214</td>
</tr>
</tbody>
</table>
# Section C: Operational Information

**Proposed Penetration (m):**

<table>
<thead>
<tr>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>336</td>
<td>0</td>
</tr>
</tbody>
</table>

**Total Sediment Thickness (m):** 336 m

**General Lithologies:**

Calcarenites and calcilutites

**Coring Plan:**

- Triple APC to refusal (200 m)/XCB to total depth

**Wireline Logging Plan:**

**Standard Measurements:**
- Magnetic Susceptibility
- Magnetic Field
- Formation Image (Acoustic)
- Borehole Temperature
- Formation Fluid Sampling
- Nuclear Magnetic Resonance
- Formation Temperature & Pressure
- Geochemical
- VSP
- Side-Wall Core Sampling

**Special Tools:**
- Sonic (Δt)
- Check-shot (upon request)
- Others:

**Max. Borehole Temp.:** 336 °C

**Mud Logging:**

(Riser Holes Only)

**Cuttings Sampling Intervals:**
- from m to m m intervals
- from m to m m intervals

Basic Sampling Intervals: 5m

**Estimated Days:**

| Drilling/Coring: | 3.5 | Logging: | 1.4 | Total On-site: |

**Observatory Plan:**

Longterm Borehole Observation Plan/Re-entry Plan

**Potential Hazards/Weather:**

- Shallow Gas
- Complicated Seabed Condition
- Hydrothermal Activity
- Preferred weather window
- Hydrocarbons
- Soft Seabed
- Landslide and Turbidity Current
- Shallow Water Flow
- Currents
- Gas Hydrate
- Abnormal Pressure
- Fracture Zone
- Diapir and Mud Volcano
- Man-made Objects (e.g., sea-floor cables, dump sites)
- Fault
- High Temperature
- H₂S
- High Dip Angle
- Ice Conditions
- CO₂
- Sensitive marine habitat (e.g., reefs, vents)

Other:
### IODP Site Summary Forms: Form 2 - Site Survey Detail

**Proposal #:** 807  
**Site #:** NWS-5A  
**Date Form Submitted:** 2012-10-04 04:43:58

*Key to SSP Requirements*

- X = required; X* = may be required for specific sites; Y = recommended; Y* = may be recommended for specific sites; R = required for re-entry sites; T = required for high temperature environments; † = Accurate velocity information is required for holes deeper than 400m.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>In SSDB</th>
<th>SSP Req.</th>
<th>Details of available data and data that are still to be collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a High resolution seismic reflection (primary)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>1b High resolution seismic reflection (crossing)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
</tbody>
</table>
| 2a Deep penetration seismic reflection (primary) | no | | Line A-A' (shown on site summary form 6) seismic line = s93-601 (strike section Northwest-Southeast)  
Location: a93-601 |
| 2b Deep penetration seismic reflection (crossing) | | | Line B-B' (shown on site summary form 6) seismic line = s93-608r (dip section East-West)  
Location: s93-608r |
| 3 Seismic Velocity | | | Velocity survey in submitted Morangie-1 well completion report |
| 4 Seismic Grid | | | |
| 5a Refraction (surface) | | | |
| 5b Refraction (bottom) | | | |
| 6 3.5 kHz | | | |
| 7 Swath bathymetry | | | |
| 8a Side looking sonar (surface) | | | |
| 8b Side looking sonar (bottom) | | | |
| 9 Photography or video | | | |
| 10 Heat Flow | | | |
| 11a Magnetics | | | |
| 11b Gravity | | | |
| 12 Sediment cores | None | | |
| 13 Rock sampling | | | Cutting every ca. 10 m in Morangie-1 described in submitted well completion report |
| 14a Water current data | | | Information in published literature |
| 14b Ice Conditions | | | |
| 15 OBS microseismicity | | | |
| 16 Navigation | | | |
| 17 Other | | | Wireline logs (gamma) to 265 mbdf in Morangie-1 and well completion report |
IODP Site Summary Forms: Form 3 – Detailed Logging and Downhole Measurement Plan

<table>
<thead>
<tr>
<th>Proposal #:</th>
<th>807</th>
<th>Site #:</th>
<th>NWS-5A</th>
<th>Date Form Submitted:</th>
<th>2012-10-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Depth (m):</td>
<td>214</td>
<td>Sed. Penetration (m):</td>
<td>336</td>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 1.4

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
<th>Relevance (1=high, 3=low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>VSP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other (SET, SETP, ...)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
### Pollution & Safety Hazard

<table>
<thead>
<tr>
<th><strong>Pollution &amp; Safety Hazard</strong></th>
<th><strong>Comment</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Summary of Operations at site.</td>
<td>Triple-APC to 200 mbsf (or to refusal), XCB to 336 mbsf</td>
</tr>
<tr>
<td>2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.</td>
<td>The Perth Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled. NSW-5A is a re-drill of Morangie-1 and Morangie-ST1. In Morangie-1 the base of the Tertiary carbonates is at 738 mbdf. Cretaceous strata comprise a series of calcarenites. These are underlain by Jurassic sandstones and shales from 879.5 mbdf. Residual oil is present from 2097 m to 2155 mbdf in Morangie-1. There were no hydrocarbon shows in Morangie-ST1.</td>
</tr>
<tr>
<td>3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.</td>
<td></td>
</tr>
<tr>
<td>4. Indications of gas hydrates at this location.</td>
<td>No</td>
</tr>
<tr>
<td>5. Are there reasons to expect hydrocarbon accumulations at this site?</td>
<td>Not at depths to be drilled</td>
</tr>
<tr>
<td>6. What “special” precautions will be taken during drilling?</td>
<td></td>
</tr>
<tr>
<td>7. What abandonment procedures need to be followed?</td>
<td></td>
</tr>
<tr>
<td>8. Natural or manmade hazards which may effect ship's operations.</td>
<td>Possibility of shallow gas</td>
</tr>
<tr>
<td>9. Summary: What do you consider the major risks in drilling at this site?</td>
<td></td>
</tr>
<tr>
<td>Subbottom depth (m)</td>
<td>Key reflectors, Unconformities, faults, etc</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>0</td>
<td>seafloor</td>
</tr>
<tr>
<td>336</td>
<td>Base Pliocene/Top Miocene</td>
</tr>
<tr>
<td>Proposal #:</td>
<td>807</td>
</tr>
<tr>
<td>------------</td>
<td>-----</td>
</tr>
</tbody>
</table>

**Site Summary Figure Comment**
Site summary Form 6: NWS-5A (Morangie-1 Redrill):

SSDB Details for proposed site:

(1) Location map from regional Geoscience Australia bathymetric grid,
(2) Wireline log for Morangie-1.
(3) A-A' Seismic line: s93-601.
(4) B-B' Seismic line: s93-608r.
(5) A well completion report for Morangie-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.
**Section A: Proposal Information**

**Title of Proposal:**
Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

**Date Form Submitted:**
2012-10-04 04:43:58

**Site Specific Objectives with Priority (Must include general objectives in proposal):**
Record of tropical to subtropical carbonate deposition, ITF and Leeuwin Current. Constraining the age and setting of the buried reef up dip and landward of section (Drilling Objective 1). Obtaining an long term orbital scale record of the Australian monsoon (Drilling Objective 2).

**List Previous Drilling in Area:**
This section is 2 km northeast from the petroleum well West Tryal Rocks-1

**Section B: General Site Information**

| Site Name: NWS-4A |
|------------------|----------------|
| If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#: |
| Latitude: Deg: -20.216 |
| Longitude: Deg: 115.083 |
| Coordinate System: WGS 84 |
| Priority of Site: Primary: yes Alt: |

| Area or Location: Northwest Shelf Australia, Carnarvon Basin |
| Jurisdiction: Australia |
| Distance to Land: (km) 100 |
| Water Depth (m) 138 |
### Section C: Operational Information

<table>
<thead>
<tr>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1122</td>
<td>0</td>
</tr>
</tbody>
</table>

**Proposed Penetration (m):**

- Total Sediment Thickness (m): 1122
- Total Penetration (m): 1122

**General Lithologies:**

- Calcarenites and calcilutites

**Coring Plan:**

- Triple APC to refusal (200 m)/XCB to total depth

**Standard Measurements**

- Magnetic Susceptibility
- Magnetic Field
- Formation Image (Acoustic)
- Borehole Temperature
- Formation Fluid Sampling
- Nuclear Magnetic Resonance
- Formation Temperature & Pressure
- Geochemical
- VSP
- Side-Wall Core Sampling
- Others:

**Wireline Logging Plan:**

- WL
- LWD
- Sonic (∆t)
- Porosity
- Density
- Gamma Ray
- Resistivity
- Formation Image (Res)
- Check-shot (upon request)

**Max. Borehole Temp.:**

- °C

**Cuttings Sampling Intervals**

- from m to m m intervals
- from m to m m intervals

**Mud Logging:**

- (Riser Holes Only)
- Basic Sampling Intervals: 5m

**Estimated Days:**

- Drilling/Coring: 5.5
- Logging: 2.3
- Total On-site: 

**Observatory Plan:**

- **Longterm Borehole Observation Plan/Re-entry Plan**

**Potential Hazards/Weather:**

- Shallow Gas
- Hydrocarbon
- Shallow Water Flow
- Abnormal Pressure
- Man-made Objects (e.g., sea-floor cables, dump sites)
- H₂S
- CO₂
- Soft Seabed
- Currents
- Fracture Zone
- Fault
- High Dip Angle
- High Temperature
- Diapir and Mud Volcano
- Landslide and Turbidity Current
- Gas Hydrate
- Ice Conditions
- Sensitive marine habitat (e.g., reefs, vents)

**Preferred weather window**

**Other:**

---

*Page 2 of 2*
<table>
<thead>
<tr>
<th>Data Type</th>
<th>In SSDB</th>
<th>SSP Req.</th>
<th>Details of available data and data that are still to be collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a High resolution seismic reflection (primary)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>1b High resolution seismic reflection (crossing)</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>2a Deep penetration seismic reflection (primary)</td>
<td></td>
<td></td>
<td>Line A-A' (shown on site summary form 6) seismic line = 136_07 (dip section Northwest-Southwest) Location:</td>
</tr>
<tr>
<td>2b Deep penetration seismic reflection (crossing)</td>
<td></td>
<td></td>
<td>Line B-B' (shown on site summary form 6) seismic line = 93_106 (strike section Northeast-Southwest) Location:</td>
</tr>
<tr>
<td>3 Seismic Velocity</td>
<td></td>
<td></td>
<td>From submitted West Tryal Rocks-1 well completion report</td>
</tr>
<tr>
<td>4 Seismic Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a Refraction (surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5b Refraction (bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 3.5 kHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Swath bathymetry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8a Side looking sonar (surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8b Side looking sonar (bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Photography or video</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Heat Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11a Magnetics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11b Gravity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Sediment cores</td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>13 Rock sampling</td>
<td></td>
<td></td>
<td>Cuttings from 420 m to 1160 m in West Tryal Rocks-1 as described in well completion report</td>
</tr>
<tr>
<td>14a Water current data</td>
<td></td>
<td></td>
<td>Information in published literature</td>
</tr>
<tr>
<td>14b Ice Conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 OBS microseismicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Navigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Other</td>
<td></td>
<td></td>
<td>Wireline logs (gamma) to log level 395 m in West Tryal Rocks-1 and well completion report</td>
</tr>
</tbody>
</table>
IODP Site Summary Forms: Form 3 – Detailed Logging and Downhole Measurement Plan

<table>
<thead>
<tr>
<th>Proposal #:</th>
<th>807</th>
<th>Site #:</th>
<th>NWS-4A</th>
<th>Date Form Submitted:</th>
<th>2012-10-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Depth (m):</td>
<td>138</td>
<td>Sed. Penetration (m):</td>
<td>1122</td>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 2.3

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
<th>Relevance (1=high, 3=low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>VSP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other (SET, SETP, ...)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
**Summary of Operations at site:**
(Example: Triple-APC to 200 mbsf, XCB to 1122 mbsf)

**All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.**
The Carnavon Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled.
NSW-4A is 2km northeast of the West Tryal Rocks gas field that was intersected by West Tryal Rocks-1, 2 and 3. The wells sampled a thick Cenozoic carbonate sequence (>2000m) unconformably overlying early Cretaceous and Triassic strata. Gas and condensate were intersected in Triassic Mungaroo Beds from 3225-3321 mbd. Close by Goodwyn 7: Interval 2810-2881 mbd (late Triassic terrigenous sandstones, siltstones and claystones) was shown to be gas bearing. Production test over 2812-2834 mbd perforated interval yielded flow rates of 1.08 MMSCM/D gas and 763 CMPD condensate. TD 3429 m, (Triassic siliciclastic sediments.)

**All commercial drilling in this area that produced or yielded significant hydrocarbon shows.**
Dampier-1: Hydrocarbon indications starting at 9515 ft (2900 m). Not commercial.

**Indications of gas hydrates at this location.**
No

**Are there reasons to expect hydrocarbon accumulations at this site?**
Not at depths to be drilled

**What “special” precautions will be taken during drilling?**

**What abandonment procedures need to be followed?**

**Natural or manmade hazards which may effect ship’s operations.**
Possibility of shallow gas

**Summary: What do you consider the major risks in drilling at this site?**
<table>
<thead>
<tr>
<th>Subbottom depth (m)</th>
<th>Key reflectors, Unconformities, faults, etc</th>
<th>Age</th>
<th>Assumed velocity (km/sec)</th>
<th>Lithology</th>
<th>Paleo-environment</th>
<th>Avg. rate of sed. accum. (m/My)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>seafloor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1122</td>
<td>Base Pliocene/Top Miocene base delambre fM</td>
<td>4.2</td>
<td>3.2</td>
<td>Calcarenites and calcilutites</td>
<td>Shelfal to bathyal</td>
<td>267</td>
<td>Expanded low energy Pliocene to Pleistocene record</td>
</tr>
<tr>
<td>Proposal #:</td>
<td>Site #:</td>
<td>Date Form Subm.:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------</td>
<td>-----------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>807</td>
<td>NWS-4A</td>
<td>2012-09-03 08:44:42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Site Summary Figure Comment**
Site summary Form 6: NWS-4A:

SSDB Details for proposed site:

1. Location map from regional Geoscience Australia bathymetric grid, (1) Location map from regional Geoscience Australia bathymetric grid,
2. Wireline log for West Tryal Rocks-1 (2 km along strike). Wireline log for West Tryal Rocks-1 (2 km along strike).
5. A well completion report for West Tryal Rocks-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline. A well completion report for West Tryal Rocks-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.

Wells near NWS-4A

- Au1 = Austin-1
- M1 = Maitland1
- Tr1 = Tryal Rocks1
- Wtr1 = West Tryal Rocks1

<table>
<thead>
<tr>
<th>Age of reflector in millions of years</th>
<th>Top Miocene</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>1.8</td>
<td>3.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age of reflector in millions of years</th>
<th>Top Miocene</th>
</tr>
</thead>
<tbody>
<tr>
<td>ca. 1.5</td>
<td>ca. 4.2</td>
</tr>
</tbody>
</table>

...
Section A: Proposal Information

Title of Proposal: Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

Date Form Submitted: 2012-10-04 04:43:58

Record of tropical to subtropical carbonate deposition, ITF and Leeuwin Current. Constraining the age and setting of the buried reef along strike (Drilling Objective 1). Obtaining an interglacial record of the Australian monsoon (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (Drilling Objective 3).

List Previous Drilling in Area: This is a redrill of a plugged and abandoned petroleum well: Fisher-1

Section B: General Site Information

Site Name: NWS-3A

If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#

Latitude: Deg: -19.824

Longitude: Deg: 115.709

Coordinate System: WGS 84

Priority of Site: Primary: yes Alt: 

Area or Location: Northwest Shelf Australia, Carnarvon Basin

Jurisdiction: Australia

Distance to Land: (km) 100

Water Depth (m): 88
Section C: Operational Information

<table>
<thead>
<tr>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>842</td>
<td>0</td>
</tr>
</tbody>
</table>

| Total Sediment Thickness (m) | 842 |
| Total Penetration (m)        | 842 |

**General Lithologies:**
- Calcarenites and calcilutites

**Coring Plan:**
- APC
- XCB
- MDCB
- PCS
- RCB
- Re-entry

**Wireline Logging Plan:**
- Standard Measurements:
  - WL
  - LWD
  - Porosity
  - Density
  - Gamma Ray
  - Resistivity
  - Sonic (Δt)
  - Formation Image (Res)
  - Check-shot (upon request)
- Special Tools:
  - Magnetic Susceptibility
  - Magnetic Field
  - Borehole Temperature
  - Nuclear Magnetic Resonance
  - Geochemical
  - Nuclear Magnetic Resonance
  - Side-Wall Core Sampling

**Max. Borehole Temp.:** 0°C

**Mud Logging:**
- Cuttings Sampling Intervals:
  - from m to m m intervals
  - from m to m m intervals

**Estimated Days:**
- Drilling/Coring: 4.5
- Logging: 1.4
- Total On-site: 5.9

**Observatory Plan:**
- Longterm Borehole Observation Plan/Re-entry Plan

**Potential Hazards/Weather:**
- Shallow Gas
- Hydrocarbon
- Shallow Water Flow
- Abnormal Pressure
- Man-made Objects (e.g., sea-floor cables, dump sites)
- H2S
- CO2
- Other:

- Hydrothermal Activity
- Soft Seabed
- Currents
- Fracture Zone
- Fault
- High Dip Angle
- High Temperature
- Landslide and Turbidity Current
- Gas Hydrate
- Diapir and Mud Volcano
- High Temperature
- Ice Conditions

**Preferred weather window**
<table>
<thead>
<tr>
<th>Data Type</th>
<th>In SSDB</th>
<th>SSP Req.</th>
<th>Details of available data and data that are still to be collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a High resolution seismic reflection (primary)</td>
<td>Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b High resolution seismic reflection (crossing)</td>
<td>Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a Deep penetration seismic reflection (primary)</td>
<td>Line D-D' (shown on site summary form 6) seismic line = 136_10 (dip section East-West) Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b Deep penetration seismic reflection (crossing)</td>
<td>Line C-C' (shown on site summary form 6) seismic line = 136_23 (oblique strike section Northeast-Southwest) Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Seismic Velocity</td>
<td>From submitted Fisher-1 Well completion report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Seismic Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a Refraction (surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5b Refraction (bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 3.5 kHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Swath bathymetry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8a Side looking sonar (surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8b Side looking sonar (bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Photography or video</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Heat Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11a Magnetics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11b Gravity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Sediment cores</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Rock sampling</td>
<td>28 Side wall cores ca. in Fisher-1 from 420 m to 930 m (target interval) described in submitted well completion report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14a Water current data</td>
<td>Information in published literature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14b Ice Conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 OBS microseismicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Navigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Other</td>
<td>Wireline logs (gamma) to 400 mbsf in Fisher-1 and well completion report</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## IODP Site Summary Forms:

Form 3 – Detailed Logging and Downhole Measurement Plan

<table>
<thead>
<tr>
<th>Proposal #</th>
<th>807</th>
<th>Site #</th>
<th>NWS-3A</th>
<th>Date Form Submitted:</th>
<th>2012-10-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Depth (m):</td>
<td>88</td>
<td>Sed. Penetration (m):</td>
<td>842</td>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 1.4

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>0</td>
</tr>
<tr>
<td>Geochemical</td>
<td>0</td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td>0</td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td>0</td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0</td>
</tr>
<tr>
<td>VSP</td>
<td>0</td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td>0</td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Other (SET, SETP, …)</td>
<td>0</td>
</tr>
</tbody>
</table>
### IODP Site Summary Forms: Form 4 – Environmental Protection

| Proposal #: | 807 | Site #: | NWS-3A | Date Form Submitted: | 2012-10-04 04:43:58 |

<table>
<thead>
<tr>
<th>Pollution &amp; Safety Hazard</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Summary of Operations at site.</td>
<td>Triple-APC to 200 mbsf (or to refusal), XCB to 842 mbsf</td>
</tr>
<tr>
<td>2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.</td>
<td></td>
</tr>
<tr>
<td>3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.</td>
<td>The Carnarvon Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled. Fisher-1 (NSW-3A) was a plugged and abandoned dry petroleum exploration well. The well did not encounter significant hydrocarbon shows. Minor gas was encountered in the interval 2830-2835mbdf (Upper Cretaceous). Close by Goodwyn 7: Interval 2810-2881 mbdf (Late Triassic terrigenous sandstones, siltstones and claystones) was shown to be gas bearing. Production test over 2812-2834 mbdf perforated interval yielded flow rates of 1.08 MMSCM/D gas and 763 CMPD condensate. TD 3429 m, (Triassic siliciclastic sediments.) Dampier-1: Hydrocarbon indications starting at 9515 ft (2900 m). Not commercial.</td>
</tr>
<tr>
<td>4. Indications of gas hydrates at this location.</td>
<td>No</td>
</tr>
<tr>
<td>5. Are there reasons to expect hydrocarbon accumulations at this site?</td>
<td>Not at depths to be drilled</td>
</tr>
<tr>
<td>6. What &quot;special&quot; precautions will be taken during drilling?</td>
<td></td>
</tr>
<tr>
<td>7. What abandonment procedures need to be followed?</td>
<td></td>
</tr>
<tr>
<td>8. Natural or manmade hazards which may effect ship's operations.</td>
<td>Possibility of shallow gas</td>
</tr>
<tr>
<td>9. Summary: What do you consider the major risks in drilling at this site?</td>
<td></td>
</tr>
</tbody>
</table>

The Carnarvon Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled. Fisher-1 (NSW-3A) was a plugged and abandoned dry petroleum exploration well. The well did not encounter significant hydrocarbon shows. Minor gas was encountered in the interval 2830-2835mbdf (Upper Cretaceous). Close by Goodwyn 7: Interval 2810-2881 mbdf (Late Triassic terrigenous sandstones, siltstones and claystones) was shown to be gas bearing. Production test over 2812-2834 mbdf perforated interval yielded flow rates of 1.08 MMSCM/D gas and 763 CMPD condensate. TD 3429 m, (Triassic siliciclastic sediments.) Dampier-1: Hydrocarbon indications starting at 9515 ft (2900 m). Not commercial.
<table>
<thead>
<tr>
<th>Subbottom depth (m)</th>
<th>Key reflectors, Unconformities, faults, etc</th>
<th>Age</th>
<th>Assumed velocity (km/sec)</th>
<th>Lithology</th>
<th>Paleo-environment</th>
<th>Avg. rate of sed. accum. (m/My)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>seafloor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>842</td>
<td>Base Pliocene/Top Miocene top Bare Fm</td>
<td>5.2</td>
<td>3.2</td>
<td>Calcarenites and calcilutites</td>
<td>Shelfal to upper bathyal</td>
<td>161</td>
<td>Gamma rich lower unit (Pliocene?) overlain by Pleistocene carbonates</td>
</tr>
</tbody>
</table>
IODP Site Summary Forms:

Form 5 – Lithologies

Key reflectors, Unconformities, faults, etc

Age Assumed velocity

Lithology Paleo-environment

Avg. rate of sed. accum. (m/My)

Comments

Subbottom depth (m)

Proposal #: 807 - Full 1 Site #: NWS-3A Date Form Subm.: 2012-09-03 08:34:34

Site Summary Figure Comment
Site summary Form 6: NWS-3A (Fisher-1 redrill):

SSDB Details for proposed site:

1. Location map from regional Geoscience Australia bathymetric grid,
2. Wireline log for Fisher-1.
5. A well completion report for Fisher-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.
Section A: Proposal Information

Title of Proposal:
Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

Date Form Submitted:
2012-10-04 04:43:58

Site Specific Objectives with Priority (Must include general objectives in proposal)
Part of a latitudinal shelf transect, to sample Plio-Pleistocene sub-tropical to tropical transition. Oolitic facies is expected in this section. Charting the Leeuwin current and ITF (Drilling Objective 1). Obtaining an interglacial record of the Australian monsoon (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (Drilling Objective 3).

List Previous Drilling in Area:
This is a redrill of a plugged and abandoned petroleum well: Picard-1

Section B: General Site Information

Site Name: NWS-2A
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site# Northwest Shelf Australia, Carnarvon Basin

Latitude: -18.967

Longitude: 117.622

Coordinate System: WGS 84

Priority of Site: Primary: yes

Area or Location: Northwest Shelf Australia, Carnarvon Basin

Jurisdiction: Australia

Distance to Land: 130 km

Water Depth (m): 141
## Section C: Operational Information

<table>
<thead>
<tr>
<th>Proposed Penetration (m):</th>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>579</td>
<td>0</td>
</tr>
</tbody>
</table>

| Total Sediment Thickness (m) | 579       |

| Total Penetration (m):      | 579       |

### General Lithologies:
- Calcarenites and calcilutites

### Coring Plan:
- APC
- XCB
- MDCB
- PCS
- RCB
- Re-entry

#### Coring Plan: (Specify or check)
- [ ] Triple APC to refusal (200 m)/XCB to total depth

### Wireline Logging Plan:

#### Standard Measurements
- WL
- LWD
- Porosity
- Density
- Gamma Ray
- Resistivity
- Sonic ($\Delta t$)
- Formation Image (Res)
- Check-shot (upon request)

#### Special Tools
- Magnetic Susceptibility
- Magnetic Field
- Formation Image (Acoustic)
- Borehole Temperature
- Nuclear Magnetic Resonance
- Formation Fluid Sampling
- Geochemical
- Side-Wall Core Sampling
- VSP
- Others

### Max. Borehole Temp.:

| °C |

### Mud Logging:
- (Riser Holes Only)

#### Cuttings Sampling Intervals
- from _______ m to _______ m _______ m intervals
- from _______ m to _______ m _______ m intervals

#### Basic Sampling Intervals: 5m

### Estimated Days:
- Drilling/Coring: 4.2
- Logging: 1.3
- Total On-site: __________

### Observatory Plan:
- Longterm Borehole Observation Plan/Re-entry Plan

### Potential Hazards/Weather:
- Shallow Gas
- Hydrocarbon
- Shallow Water Flow
- Abnormal Pressure
- Man-made Objects (e.g., sea-floor cables, dump sites)
- H₂S
- CO₂
- Other:

#### Preferred weather window
- [ ] Complicated Seabed Condition
- [ ] Soft Seabed
- [ ] Landslide and Turbidity Current
- [ ] Currents
- [ ] Gas Hydrate
- [ ] Fracture Zone
- [ ] Diapir and Mud Volcano
- [ ] Fault
- [ ] High Temperature
- [ ] High Dip Angle
- [ ] Ice Conditions
- [ ] Sensitive marine habitat (e.g., reefs, vents)
# Data Type | In SSDB | SSP Req. | Details of available data and data that are still to be collected
--- | --- | --- | ---
1a | High resolution seismic reflection (primary) | | Location:  
1b | High resolution seismic reflection (crossing) | | Location:  
2a | Deep penetration seismic reflection (primary) | | Line A-A' (shown on site summary form 6) seismic line = 110_02 (dip section Northwest-Southeast)  
| | | Location:  
2b | Deep penetration seismic reflection (crossing) | | Line B-B' (shown on site summary form 6) seismic line = 136_19 (strike section Northeast-Southwest)  
| | | Location:  
3 | Seismic Velocity | | From submitted Picard-1 well completion report  
4 | Seismic Grid | |  
5a | Refraction (surface) | |  
5b | Refraction (bottom) | |  
6 | 3.5 kHZ | |  
7 | Swath bathymetry | |  
8a | Side looking sonar (surface) | |  
8b | Side looking sonar (bottom) | |  
9 | Photography or video | |  
10 | Heat Flow | |  
11a | Magnetics | |  
11b | Gravity | |  
12 | Sediment cores | | none  
13 | Rock sampling | | Cutting samples ca. every 10 m in Picard-1 as listed in submitted well completion report  
14a | Water current data | | Information in published literature  
14b | Ice Conditions | |  
15 | OBS microseismicity | |  
16 | Navigation | |  
17 | Other | | Wireline logs (gamma) to sea bed in Picard-1 and well completion report  

*Key to SSP Requirements*

- X: required; X*: may be required for specific sites; Y: recommended; Y*: may be recommended for specific sites; 
- R: required for re-entry sites; T: required for high temperature environments; †: Accurate velocity information is required for holes deeper than 400m.
**IODP Site Summary Forms:**

**Form 3 – Detailed Logging and Downhole Measurement Plan**

<table>
<thead>
<tr>
<th>Proposal #:</th>
<th>807</th>
<th>Site #:</th>
<th>NWS-2A</th>
<th>Date Form Submitted:</th>
<th>2012-10-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Depth (m):</td>
<td>141</td>
<td>Sed. Penetration (m):</td>
<td>579</td>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>

Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 1.3

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
<th>Relevance (1=high, 3=low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>VSP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other (SET, SETP, …)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
### Pollution & Safety Hazard

<table>
<thead>
<tr>
<th>1. Summary of Operations at site.</th>
<th>Triple-APC to 200 mbsf (or to refusal), XCB to 579 mbsf</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.</td>
<td></td>
</tr>
<tr>
<td>3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows.</td>
<td>The Carnavon Basin is a hydrocarbon province. However, all reservoirs are in much older sediments, below the section to be drilled. Picard-1 (NSW-2A) was a plugged and abandoned dry hole petroleum exploration hole with minor gas shows in the Cretaceous and Jurassic sections. The base of the Tertiary carbonate sequence is at 1890mbdf with Cretaceous to Jurassic strata from 1890 to 4216 mbsf. The Jurassic section yielded minor gas at 3801m with minor shows from 2734.1 m to 4212.6 mbdf. The nearby non-commercial Phoenix gas field yielded significant gas shows in the Triassic Cossigny Member (carbonates and sandstones) in the interval 3786.5 to 4372.3 mbdf. The reservoir was of poor quality.</td>
</tr>
<tr>
<td>4. Indications of gas hydrates at this location.</td>
<td>No</td>
</tr>
<tr>
<td>5. Are there reasons to expect hydrocarbon accumulations at this site?</td>
<td>Not at depths to be drilled</td>
</tr>
<tr>
<td>6. What “special” precautions will be taken during drilling?</td>
<td></td>
</tr>
<tr>
<td>7. What abandonment procedures need to be followed?</td>
<td></td>
</tr>
<tr>
<td>8. Natural or manmade hazards which may effect ship’s operations.</td>
<td>Possibility of shallow gas</td>
</tr>
<tr>
<td>9. Summary: What do you consider the major risks in drilling at this site?</td>
<td></td>
</tr>
<tr>
<td>Subbottom depth (m)</td>
<td>Key reflectors, Unconformities, faults, etc</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>0</td>
<td>seafloor</td>
</tr>
<tr>
<td>579</td>
<td>Base Pliocene/top Miocene</td>
</tr>
</tbody>
</table>
Site summary Form 6: NWS-2A (Picard-1 redrill):

SSDB Details for proposed site:

(1) Location map from regional Geoscience Australia bathymetric grid,
(2) Wireline log for Picard-1.
(3) A-A' Seismic line: 110_02.
(4) B-B' Seismic line: 136_19.
(5) A well completion report for Picard-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.
**IODP Site Summary Forms:**

**Form 1 – General Site Information**

**Section A: Proposal Information**

- **Title of Proposal:** Reefs, Oceans and Climate: A 5 Million Year History of the Indonesian Throughflow, Australian Monsoon and Subsidence on the Northwest Shelf of Australia

- **Date Form Submitted:** 2012-10-04 04:43:58

- **Site Specific Objectives with Priority (Must include general objectives in proposal):**

  The most northerly of the shelfal latitudinal transect, to sample Plio-Pleistocene sub-tropical to tropical transition and date seismic reflectors and by proxy date buried reef "shoal" along strike (Drilling Objective 1). Obtaining an interglacial record of the Australian monsoon (Drilling Objective 2). Obtaining bathymetric estimates for subsidence history (Drilling Objective 3).

- **List Previous Drilling in Area:** This is a redrill of a plugged and abandoned petroleum well: Minilya-1

**Section B: General Site Information**

- **Site Name:** NWS-1A

- **Area or Location:** Northwest Shelf Australia, Roebuck Basin

- **Jurisdiction:** Australia

- **Distance to Land:** 130 km

- **Water Depth:** 146 m

- **Latitude:** -18.325

- **Longitude:** 118.732

- **Coordinate System:** WGS 84

- **Priority of Site:** Yes

---

*Page 1 of 2*
### Section C: Operational Information

<table>
<thead>
<tr>
<th>Sediments</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Penetration (m):</td>
<td></td>
</tr>
<tr>
<td>475</td>
<td>0</td>
</tr>
<tr>
<td>Total Sediment Thickness (m):</td>
<td></td>
</tr>
<tr>
<td>475</td>
<td></td>
</tr>
</tbody>
</table>

### General Lithologies:
- Calcarenites and calcilutites

### Coring Plan:
- **APC**
- **VPC**
- **XCB**
- **MDCB**
- **PCS**
- **RCB**
- Re-entry

### Wireline Logging Plan:
- **Standard Measurements**
  - Magnetic Susceptibility
  - Magnetic Field
  - Porosity
  - Borehole Temperature
  - Density
  - Nuclear Magnetic Resonance
  - Gamma Ray
  - Resistivity
  - Sonic (Δt)
  - Formation Image (Res)
  - Check-shot (upon request)
- **Special Tools**
  - Formation Image (Acoustic)
  - Formation Fluid Sampling
  - Formation Temperature & Pressure
  - Geochemical
  - Side-Wall Core Sampling
  - VSP
  - Others:

### Max. Borehole Temp.:
- °C

### Mud Logging:
- **WL**
- LWD
- **Porosity**
- **Density**
- **Gamma Ray**
- **Resistivity**
- **Sonic (Δt)**
- **Formation Image (Res)**
- **Check-shot (upon request)**

### Estimated Days:
- **Drilling/Coring:** 4
- **Logging:** 1
- **Total On-site:**

### Potential Hazards/Weather:
- **Shallow Gas**
- Hydrocarbon
- **Shallow Water Flow**
- Abnormal Pressure
- Man-made Objects (e.g., sea-floor cables, dump sites)
- **H₂S**
- **CO₂**
- Other:

### Cuttings Sampling Intervals:
- from m to m m intervals
- from m to m m intervals

### Basic Sampling Intervals: 5m
<table>
<thead>
<tr>
<th>Data Type</th>
<th>In SSDB</th>
<th>SSP Req.</th>
<th>Details of available data and data that are still to be collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a High</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>resolution seismic reflection (primary)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b High</td>
<td></td>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td>resolution seismic reflection (crossing)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a Deep</td>
<td></td>
<td></td>
<td>Line D-D' (shown on site summary form 6) seismic line = 110_05 (oblique dip section East West)</td>
</tr>
<tr>
<td>penetration seismic reflection (primary)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b Deep</td>
<td></td>
<td></td>
<td>Line E-E' (shown on site summary form 6) seismic line = JN87_07 (dip section Northwest-southeast). Line C-C' (shown on site summary form 6) seismic line = 120_04 (oblique dip section East West)</td>
</tr>
<tr>
<td>penetration seismic reflection (crossing)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Seismic</td>
<td></td>
<td></td>
<td>From submitted Minilya-1 well completion report</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Seismic Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a Refraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5b Refraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 3.5 kHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Swath bathymetry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8a Side looking sonar (surface)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8b Side looking sonar (bottom)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Photography or video</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Heat Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11a Magnetics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11b Gravity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Sediment cores</td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>13 Rock sampling</td>
<td></td>
<td></td>
<td>Cutting samples ca. every 10 m in Minilya-1 see submitted well completion report</td>
</tr>
<tr>
<td>14a Water current data</td>
<td></td>
<td></td>
<td>Information in published literature</td>
</tr>
<tr>
<td>14b Ice Conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 OBS microseismicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Navigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Other</td>
<td></td>
<td></td>
<td>Wireline logs (gamma) to sea bed in Minilya-1 and well completion report</td>
</tr>
</tbody>
</table>

* Key to SSP Requirements
X=required; X*=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.
Are high temperatures or other special requirements (e.g., unstable formations), anticipated for logging at this site?

Estimated total logging time for this site: 1

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scientific Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Shot Survey</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>0</td>
</tr>
<tr>
<td>Geochemical</td>
<td>0</td>
</tr>
<tr>
<td>Side-wall Core Sample</td>
<td>0</td>
</tr>
<tr>
<td>Formation Fluid Sampling</td>
<td>0</td>
</tr>
<tr>
<td>Borehole Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>0</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0</td>
</tr>
<tr>
<td>VSP</td>
<td>0</td>
</tr>
<tr>
<td>Formation Image (Acoustic)</td>
<td>0</td>
</tr>
<tr>
<td>Formation Pressure &amp; Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Other (SET, SETP, ...)</td>
<td>0</td>
</tr>
</tbody>
</table>

IODP Site Summary Forms: Form 3 – Detailed Logging and Downhole Measurement Plan

<table>
<thead>
<tr>
<th>Proposal #:</th>
<th>807</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site #:</td>
<td>NWS-1A</td>
</tr>
<tr>
<td>Date Form Submitted:</td>
<td>2012-10-04</td>
</tr>
<tr>
<td>Water Depth (m):</td>
<td>146</td>
</tr>
<tr>
<td>Sed. Penetration (m):</td>
<td>475</td>
</tr>
<tr>
<td>Basement Penetration (m):</td>
<td>0</td>
</tr>
</tbody>
</table>
**Pollution & Safety Hazard**  
**Comment**

1. **Summary of Operations at site.**  
Triple-APC to 200 mbsf (or to refusal), XCB to 475 mbsf

2. **All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling.**

3. **All commercial drilling in this area that produced or yielded significant hydrocarbon shows.**  
The Robuck Basin is a minor hydrocarbon province to the north of the Carnarvon Basin. However, all reservoirs are in much older sediments, below the section to be drilled. Minilya-1 (NSW-1A target) was a plugged and abandoned dry hole petroleum exploration hole that penetrated Cretaceous to Jurassic (Bajocian) strata. Only traces of gas were recorded from the Cretaceous and Jurassic section (1686 m to 2064 mbdf). The nearby non-commercial Phoenix gas field yielded significant gas shows in the Triassic Cossigny Member (carbonates and sandstones) in the interval 3786.5 to 4372.3 mbdf. The reservoir was of poor quality.

4. **Indications of gas hydrates at this location.**  
No

5. **Are there reasons to expect hydrocarbon accumulations at this site?**  
Not at depths to be drilled

6. **What “special” precautions will be taken during drilling?**

7. **What abandonment procedures need to be followed?**

8. **Natural or manmade hazards which may effect ship’s operations.**  
Possibility of shallow gas

9. **Summary: What do you consider the major risks in drilling at this site?**
### IODP Site Summary Forms: Form 5 – Lithologies

<table>
<thead>
<tr>
<th>Subbottom depth (m)</th>
<th>Key reflectors, Unconformities, faults, etc</th>
<th>Age</th>
<th>Assumed velocity (km/sec)</th>
<th>Lithology</th>
<th>Paleo-environment</th>
<th>Avg. rate of sed. accum. (m/My)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>seafloor</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>475</td>
<td>Base Pliocene/Top Miocene</td>
<td>5.33</td>
<td>3.2</td>
<td>Calcarenites and calcilutites</td>
<td>shelfal</td>
<td>106</td>
<td>Gamma rich lower unit (Pliocene?) overlain by Pleistocene gamma poor carbonates</td>
</tr>
</tbody>
</table>
IODP Site Summary Forms:

Form 6 - Site Summary Figure

| Proposal #: | 807 - Full 1 | Site #: | NWS-1A | Date Form Subm.: | 2012-09-03 05:56:22 |

### Site Summary Figure Comment

---

Page 1 of 1 - Site Summary Figure

generated: Thu Oct 4 04:45:31 2012
by if356_pdf□ / kk+w 2007 - 2012
(user 0.2258)
Site summary Form 6: NWS-1A (Minilya-1 redrill):

SSDB Details for proposed site:

1. Location map from regional Geoscience Australia bathymetric grid.
2. Wireline log for Minilya-1.
3. C-C' Seismic line: 120_04.
4. D-D' Seismic line: 110_05.
5. E-E' Seismic line: JN87_07.
6. A well completion report for Minilya-1, wireline log and seismic data will be submitted to the SSDB by Dec 1 2012 deadline.