GREAT AUSTRALIAN BIGHT
RESEARCH PROGRAM

Petroleum Geology & Geochemistry Theme 5
Introduction
Annual Symposium - 9th August 2017
Theme Objectives

Identify the distribution and provenance of asphaltites and undertake tar ball surveys to further delineate other possible hydrocarbon leakage points in the GAB – Project 5.2

Identify and characterise natural seepage in, and around the vicinity of, the BP permits in the Great Australian Bight (GAB) – Project 5.1

Determine palaeo-hydrocarbon charge, timing and geochemistry – Project 5.3

Why?

- Provide geochemical environmental baseline information
- Develop a more detailed understanding of the processes and geological framework of the GAB
- Enhance the prospectivity by providing proof of an active petroleum system
AN INTRODUCTION TO THE HISTORY OF THE GREAT AUSTRALIAN BIGHT AND THEME 5 ACTIVITIES

Video
KEY GEOLOGICAL CONCEPTS
The Petroleum System

The goals of the theme aim to deliver understandings on many of these elements and the processes of generation, migration and accumulation are necessary for hydrocarbons to accumulate and be preserved. (Schlumberger Oilfield Glossary)
Project 5.2: Asphaltites and tarballs

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GAB Science Symposium, 9\textsuperscript{th} August 2017
Project objectives:

1) Collect coastal bitumen from the SA coastline

2) Classify bitumens into oil families

3) Determine how each oil family degrades through time

4) Combine spatial distribution of fresh coastal bitumen strandings with GAB oceanography models - collaboration with Theme

5) Cross-validate with known GAB geology

Do materials occur more widely than previously reported?

Are there multiple unknown hydrocarbon sources?

How recently have they stranded on the beach?

Where are they coming from?
What is Waxy Bitumen?

- Positive buoyancy, hence surface drifters
- Surficial sand coating
- Typically form small rounded balls
  - hence ‘tarballs’
- The majority of coastal bitumen recovered along the southern coastline
- Surficial weathering may result in a hard, brown and cracked exterior
Waxy Bitumen: An Indonesian Origin?

- Waxy bitumen interpreted as products of seepage from the Indonesian Archipelago
- Transported to the GAB region via the Leeuwin Current
- Similar geochemistry to known Indonesian crude oils (e.g. Minas, Central Sumatra)

Figure modified after Edwards et al. (1998)
**What is Asphaltite?**

- Jet black, conchoidal fractures, petroliferous odour

- Quasi-neutral to negative buoyancy (4–18° API gravity), hence bottom drifters

- Some colonised by benthic marine fauna (e.g. goose barnacles, worm tubes, bryozoa)

- Typically forms the largest specimens of stranded bitumen

- Accounts for only 2% of all coastal bitumen washed ashore during 1991–92 surveys
Asphaltites: A Local Origin?

- Typically strand along Australia’s southern coastline
- Reports date back to the mid-1800s
- All exploration efforts have failed to locate asphaltite point(s) of origin
- Geochemistry not correlated to any known hydrocarbon system worldwide
- Prior authors suggest Morum basin source
Beach surveys: Study area

- 32 beaches from WA border to Victorian border
- Compare coastal bitumen distributions with previous surveys:
  1) 1990-1991 by Dianne Edwards
  2) 1983 SADME surveys

Are Asphaltites found on the Eyre Peninsular?
Beach surveys: Survey dates

- Survey 1 - November 2014: 10 asphaltites, 153 waxy bitumens*
- Survey 2 - September 2015: 16 asphaltites, 88 waxy bitumens*
- Survey 3 - October 2016: 20 asphaltites, 338 waxy bitumens*

*includes donated samples
Define Oil Families

- Asphaltite
- Waxy Bitumen also known as tarballs

Based on physical characteristics we can identify asphaltites and waxy bitumen in the field.

Cannot determine waxy bitumen sub-families without geochemistry.
Define Oil Families: Analytical program

- Sequential approach
- Samples eliminated at each step
Bitumen Breakdown: Finding fresh samples

- Each oil family degrades differently, variations may be subtle
  - *biodegradation*: progressive removal of light compounds
  - *water washing*: overall drawdown of all compounds

- Differences in the degree of weathering allow us to create a ‘time series’ for each oil family, demonstrating how it breaks down over time
Define Oil Families: Whole-Oil GCMS

Asphaltite

Waxy Bitumen
No Botryococcane (low wax)

Waxy Bitumen
No Botryococcane (high wax)

Waxy Bitumen
High Botryococcane

Waxy Bitumen
Low Botryococcane

Possible GAB origin?

Correlate with fluid inclusion oils

Likely Indonesian Archipelago

Attributed to hydrocarbon seepage in the Indonesian Archipelago

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Family stranding locations
Oceanographic modelling

Forward models with offshore seeding locations (ROMS/BRAN)

Back track models from stranding beaches (BRAN)

ROMS surface drifters with no effect of waves

BRAN surface drifters with effects of waves
Oceanographic modelling

Forward models with offshore seeding locations (ROMS/BRAN)

Back track models from stranding beaches (BRAN)

ROMS surface drifters with no effect of waves

BRAN surface drifters with effects of waves
Oceanographic modelling: Generalized pattern

Possible origin of new tar ball family and asphaltites

Unlikely that bitumens sourced east of this location can travel west
Possible fluid/gas escape structures
Duntroon sub-basin

Possible seafloor expression
Conclusions:

1) Collect coastal bitumen from the SA coastline

2) Classify bitumens into oil families

3) Determine how each oil family degrades through time

4) Combine spatial distribution of fresh coastal bitumen strandings with GAB oceanography models - collaboration with Theme 1

5) Cross-validate with known GAB geology

- Wider spatial distribution of Asphaltites than previously reported
- New tar ball family defining a hitherto unknown petroleum system, with correlation to GAB fluid inclusion oils
- Tar balls more severely weathered than in previous surveys
- A more westerly origin for the asphaltites and the new tar ball family, with a Limestone Coast origin unlikely
- Candidate seepage indicators identified in the Duntroon sub-basin
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Project 5.1: Hydrocarbon seeps

Andrew Ross¹, Laurent Langhi¹, Asrar Talukder¹, Christine Trefry¹, Charlotte Stalvies¹, Se Gong¹, Julian Strand¹, Manzur Ahmed¹, Emma Crooke¹, Xiubin Qi¹, Mike Gresham¹ + Theme 3 team

¹CSIRO
Project objectives:

1) Collection of water and sediments for geochemical analysis

What are baseline hydrocarbon concentrations in the GAB?

2) Seafloor and water column characterisation for hydrocarbon seeps

Is active hydrocarbon seepage present?

3) Geological evidence for seepage and fault seal relationships

Has hydrocarbon seepage occurred in the past?

How do hydrocarbons migrate in the subsurface?
Seepage indicators - Synthetic Aperture Radar
Reconnaissance & baseline: SS2013_c02

2375 samples collected on voyage
146 water, 82 sediment geochemistry
37 water, 27 sediment analyzed
No seep hydrocarbons detected
Potential seepage indicators?

- Low confidence acoustic contact
- Pock marks
- Canyon area
Seismic seepage indicators

Seabed morphologies showing possible pockmarks
Associated with deeper faulting
Synthetic Aperture Radar anomalies
Potential leakage indicator - subsurface features

Related to fault reactivation between 65-40 Ma

Possible mound complex

Many mound complexes hydrocarbon seeps
e.g. GOM, Atlantic, NWS
Interpreted seismic anomalies underlying mounds

(Totterdell et al 2008)

Line S215-06
Geological modeling of subsurface migration
Geological model populated with sedimentary model outputs

Percentage of shale rocks

~10% mean VSH

~14%

~19%

~30%
Shale rock sealing ability
SGR – Green no sealing – red sealing

~10% mean VSH
~14%
~19%
~30%
Conclusions:

1) Collection of water and sediments for geochemical analysis

No seep hydrocarbons detected in baseline water and sediment samples areas

2) Seafloor and water column characterisation for hydrocarbon seeps

A number of low confidence leakage indicators observed during reconnaissance survey

Top Hammerhead mounds over faults are potential paleo-leakage indicators

3) Geological evidence for seepage and fault seal relationships

Modelled Trim 3D Hammerhead shales have high sensitivity between sealing faults and non-sealing faults
Challenge

Petroleum system - was there a source rock(s) that led to the generation of oil and gas?
**Project objectives**

1. DETECT presence of oil (and gas) in rocks from the GAB

2. CHARACTERISE the molecular fingerprints of the ancient oil.

3. TIMING of oil and gas entrapment

- Is there hidden evidence for hydrocarbons trapped in the rocks?
- What are the source characteristics of these hydrocarbons?
- When in time did the hydrocarbons move through the system?
1. Detection
Evidence for oil & gas: Gnarlyknots-1A

- Potoroo
- Wigunda - Potoroo
- Upper Cretaceous
  - Maastrichtian
  - Campanian
  - Coniacian
  - Santonian

- GOI (%)
- Oil Shows
- 100 Oil Shows
- 0 Oil Shows
- M-C
- S-C
- H-C
- Coniacian – Sant.
- Coniacian
- Tiger
- M-D
- Oil
- Gas-condensate

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Evidence for oil: Greenly-1

GoI (%)

<0.1
<0.1
<0.1
<0.1
0.0
0.0
<0.1
<0.1
<0.1
0.2
0.2
0.1
0.1
0.1
0.1
0.6
0.6
0.6
0.6
1.1
0.7

Wigunda
Platypus
Upper Cretaceous
Cenomanian - Santonian
Dugong
GoI (%)

<0.1
<0.1
<0.1
<0.1
0.0
0.0
<0.1
<0.1
<0.1
0.2
0.2
0.1
0.1
0.1
0.1
0.6
0.6
0.6
0.6
1.1
0.7

Dugong
Wobbygong
Nullabor
Wilson Bluff
Pidinga

2000
2500
3000
3500
4000
4500
mMD

Lisk et al. (2001)
Abundance

- Grains with Oil Inclusion (GOI) abundance = low
  - But oil/gas inclusions are there!

Implications

- Migration h/c
- Generation h/c
- Effective source rocks

Includes data from Lisk et al (2001)
Petroleum systems: hydrocarbon migration

Fluid inclusions reveal hidden evidence for movement of oil & gas in the Bight Basin
2. Molecular Fingerprints
Alkanes

- **Greenly-1** → terrestrial plant inputs
- **Gnarlyknots-1A** → mixed algal & terrestrial plant inputs

*Artefacts of alkene based drilling fluid*
Other source parameters

The message is the same…

- **Greenly-1** → higher terrestrial plant input
- **Gnarlyknots-1A** → mixed algal & terrestrial plant inputs
Petroleum systems: source(s)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Potential source rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gnarlyknots-1A</td>
<td>1 + 2</td>
</tr>
<tr>
<td></td>
<td>• Sub-oxic depositional environment</td>
</tr>
<tr>
<td></td>
<td>• Mixed algal and terrestrial plant inputs</td>
</tr>
<tr>
<td></td>
<td>• Marine shale</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Potential source rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenly-1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• Oxic depositional environment</td>
</tr>
<tr>
<td></td>
<td>• Significant terrestrial plant inputs and minor bacteria</td>
</tr>
<tr>
<td></td>
<td>• Clay-rich source rocks</td>
</tr>
<tr>
<td></td>
<td>• Fluvial-deltaic environment</td>
</tr>
</tbody>
</table>

First evidence for algal (co)sourc in Bight Basin

buried organic matter converted to oil and natural gas
3. Timing
**PVT: Gnarlyknots-1A**

**Coniacian sample**
- Oil entrapped “earlier” in the PT evolution
- Gaseous h/c entrapped “later” in the history.

**Quartz precipitation threshold**
- Oil trapped
  - Oil (phase separation)
- Gaseous hydrocarbon trapped
  - Gas + CO₂

**P/T curve 1D extract from 3D burial model (BP)**
Petroleum systems: timing basin depocenter

Earlier oil entrapment in the Late Cretaceous

Later gaseous h/c entrapment in the Oligocene - Miocene
Petroleum systems: timing basin margins

Later oil (gas) entrapment in the Oligocene - Miocene
### Key findings – what did we learn?

<table>
<thead>
<tr>
<th>Before study</th>
<th>As a result of Project 5.3: Fluid Inclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limited evidence for h/c. Minor oil shows.</td>
</tr>
</tbody>
</table>
| 2 | Source-rock character based on Greenly-1 (suspect correlation) | - Ceduna Sub-basin: algal and terrestrial co-sourcing of oil  
| | | - Duntroon Sub-basin: terrestrial source |
| 3 | Timing of h/c generation based on models | - Ceduna Sub-basin (depocenter): earlier oil entrapment (Late Cretaceous) then later gaseous hydrocarbon entrapment (Oligocene-Miocene)  
| | | - Ceduna and Duntroon sub-basins (margins): later oil (gas) entrapment (Oligocene - Miocene) |

Strong evidence for petroleum systems (source, generation and migration) in the Bight Basin
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Petroleum Geology & Geochemistry Theme 5 Wrap-up

Annual Symposium - 9th August 2017
Key achievements

Established geochemical baseline loadings of hydrocarbons on the beaches and in the deep water of the Great Australian Bight

Developed an understanding of potential natural seepage mechanisms over geological time in the Great Australian Bight

Identification of several new hydrocarbon sources in the Bight Basin both through the tar ball study as well as fluid inclusion study

First evidence and characterisation of oil in the Ceduna sub-basin
IMPLICATIONS

Enhanced hydrocarbon prospectivity in Bight Basin

Reduced exploration risks in this frontier basin

Hydrocarbon loading observed on beaches around the GAB is a natural baseline condition