Understanding the Geographical Distribution of Historical and Modern Asphaltite Strandings along the South Australian Coastline*

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Abstract

The coastal asphaltites of South Australia have source and age-specific biomarker signatures suggestive of an origin from a Cretaceous marine shale deposited under sulfidic conditions during an oceanic anoxic event (Edwards et al., 1998; Boreham et al., 2001). They are very likely to be of local origin in the offshore Ceduna or Otway basins, although the exact location of their parent petroleum system has yet to be established (Edwards et al., 1998, 1999; Totterdell et al., 2008; Hall et al., 2014). The process of stranding has been postulated to involve leakage of hydrocarbons onto the seafloor (possibly as asphaltic volcanoes, or via exposure of tar mats: Hall et al., 2014) followed by entrainment in the prevailing oceanic currents and eventual deposition on the shoreline by surface wave and wind forcing of seasonally variable strength and direction. The asphaltites typically have quasi-neutral buoyancy (4-18° API), implying that they were submerged or even bottom drifters. Hence, it is not surprising that their historical stranding pattern should differ markedly from that of the pelagic tar balls (waxy bitumens) also found along the coastline (McKirdy et al, 1994; Padley, 1995). An informed understanding of their journey from low-intensity seafloor seep(s) to the shoreline therefore requires a detailed knowledge of the stranding distribution and both the surface and deepwater currents which traverse the continental margin of South Australia, including zones of upwelling (Middleton and Bye, 2007; Middleton et al., 2007). Whilst historical standings of asphaltites have been reported from southeastern South Australia, western Victoria and southern Tasmania, there are significant lengths of the South Australian coastline which have not been surveyed, particularly along the Eyre Peninsula. Therefore, a more comprehensive understanding of the potential geographical origin of the asphaltites has not been possible. This paper outlines the preliminary findings of beach surveys recently conducted along 31 beaches of South Australia, from the Western Australian border to the Victorian border. We compare the spatial distribution and abundance of both asphaltite and waxy bitumen on different beaches with the results of previous surveys, and review our findings in the light of differences in seasonal oceanic conditions.

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Great Australian Bight Research Program

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What is asphaltite?

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Distinctive features

- 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 Padley's 1991–92 survey

Potential importance

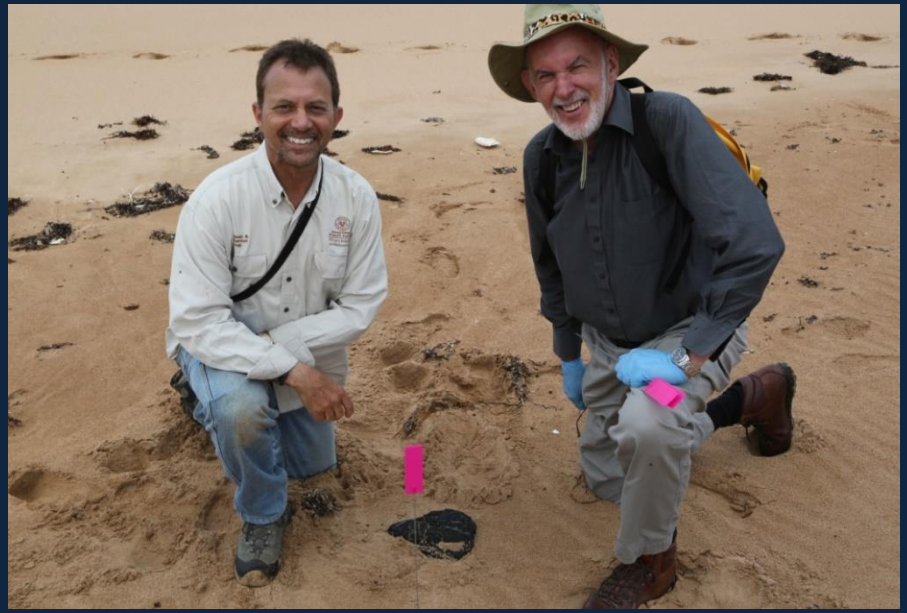
Petroleum Exploration

Indicative of an unidentified petroleum system, thereby enhancing the prospectivity of the Bight Basin & perhaps the western Otway Basin

Environmental Conditions

Contributes to the natural hydrocarbon loading of the South Australian coastline, which needs to be characterised & quantified ahead of the next phase of offshore drilling

Where do we find it?



Along strandlines on south or west-facing ocean beaches following winter storms

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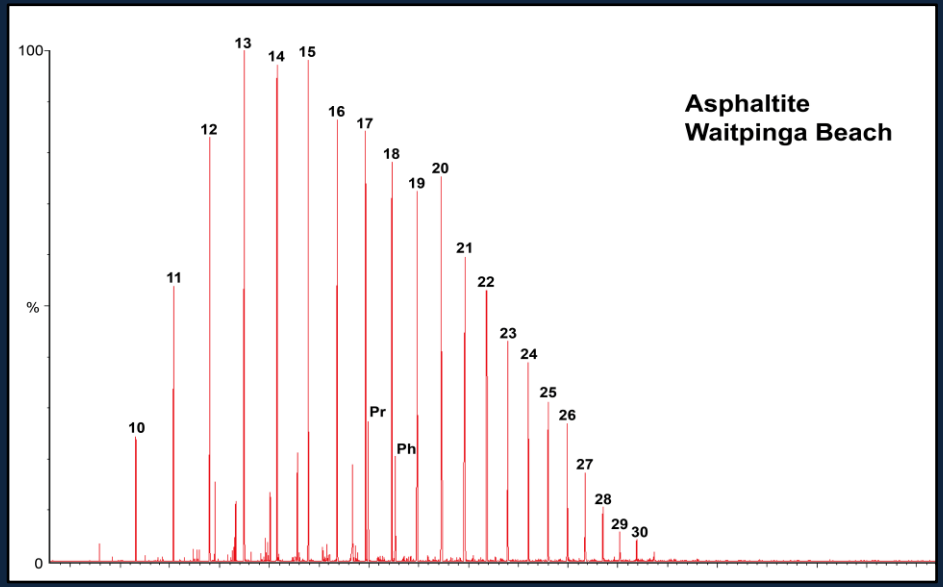
Asphaltite stranding locations

- Asphaltite typically strands along Australia's southern coastline
- Reports date back to the mid-1800s
- All exploration efforts have failed to locate its point(s) of origin

Asphaltite geochemistry

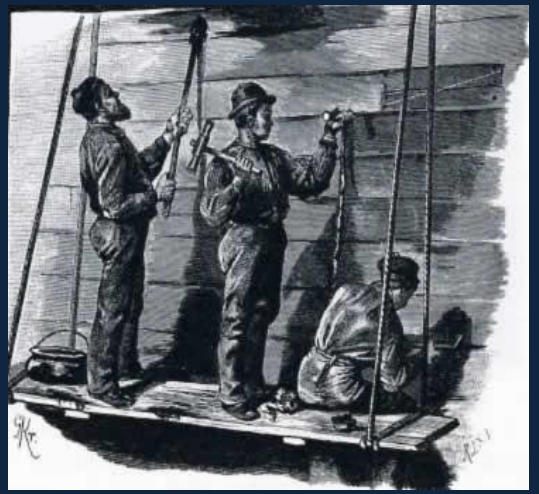
- Sulphur-rich (3 - 4 %)
- Low pristane/phytane ratio (1.1–1.3)
- High V/Ni ratio (≈ 22 : 1)
- Belong to a single family of aromatic-asphaltic crude oils
- Maturity within the early oil window (VR_{calc} = 0.68–0.75%)



Source affinity: Mid-Cretaceous marine shale containing Type II-S kerogen deposited under anoxic/sulphidic conditions (Edwards *et al.*, 1998; Boreham *et al.*, 2001)

Hypothesis #1 : Anthropogenic

- Pitch imported by early European settlers for caulking boats was improperly stored on beaches or eroded from shipwrecks

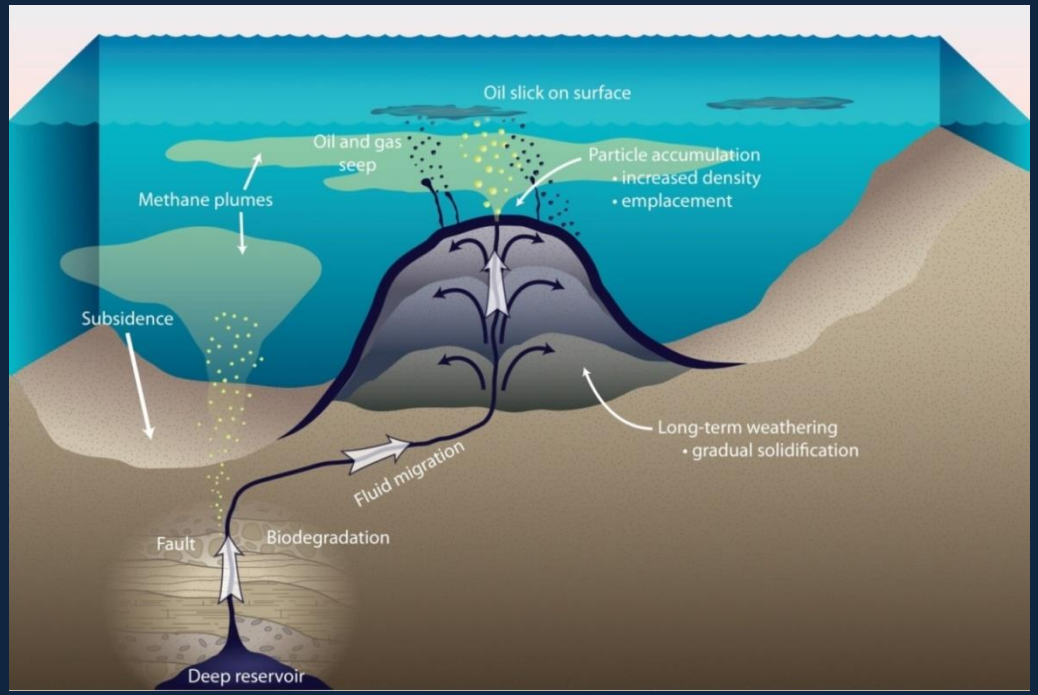


- Analysis of pitch recovered from local 19th Century shipwrecks reveals no correlation with Australian asphaltite (Smart, 1999)

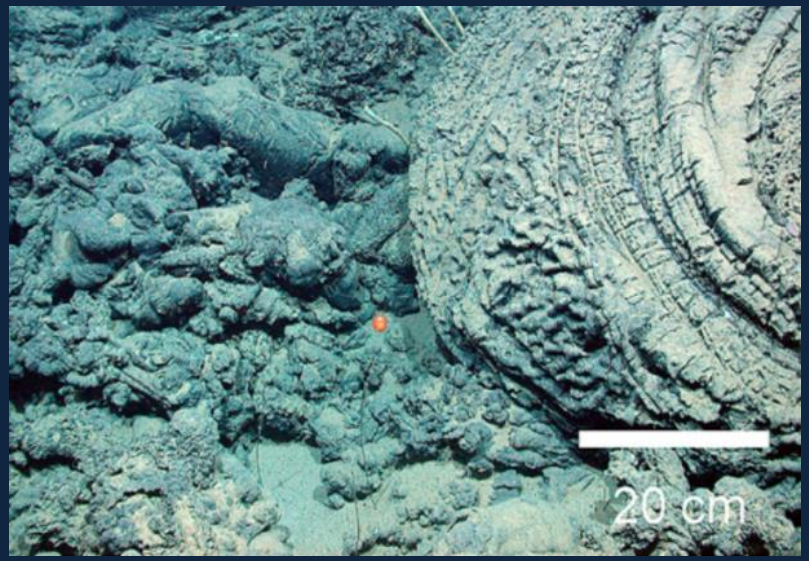
Perhaps a leaking petroleum system?

- Likely hydrocarbon kitchens are located in the Ceduna (GAB) & Morum (Otway) sub-basins
- Both contain potentially oil-prone Mid-Cretaceous marine source rocks (Boult *et al*., 2005; Totterdell *et al*., 2008)

Hypothesis #2 : Vertically migrating oil

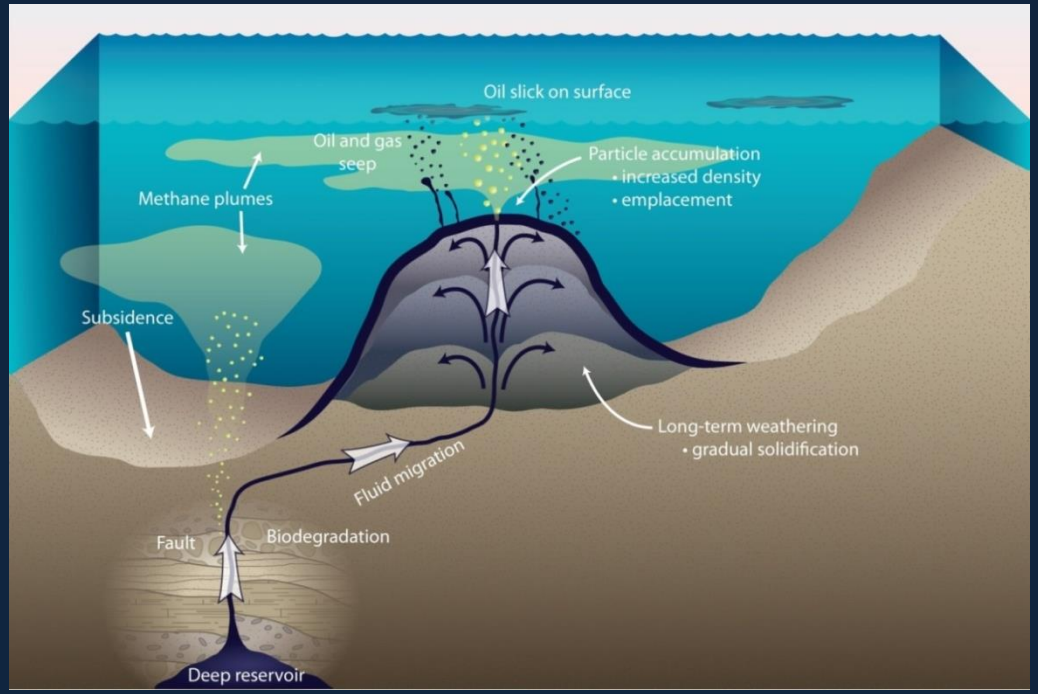


Example based on the Santa Barbara Basin asphalt volcanoes after Jack Cook, Woods Hole Oceanographic Institution
< *http://www.whoi.edu/oilinocean/page.do?pid=51880&tid=441&cid=107898&ct=61&article=73026* >



Seafloor asphalt mounds of Chapopote Knoll after Brüning *et al.*, 2010.

Hypothesis #2 : Vertically migrating oil



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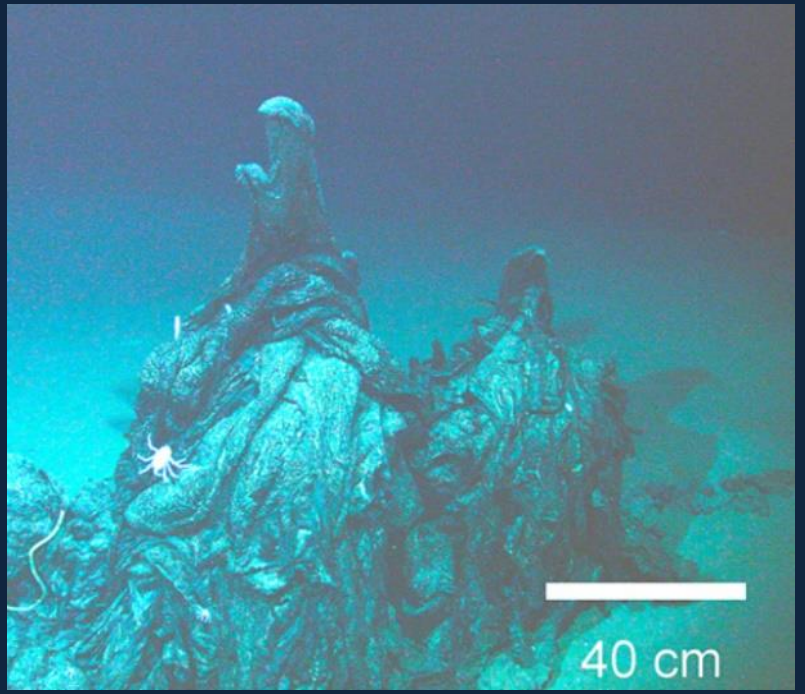
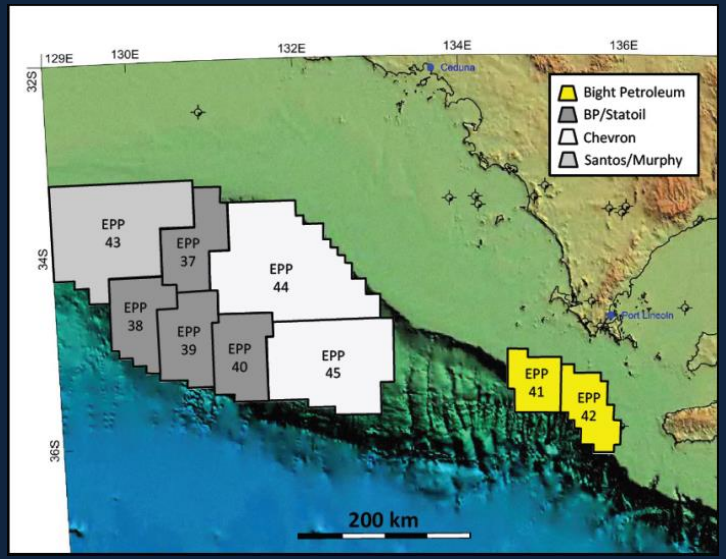


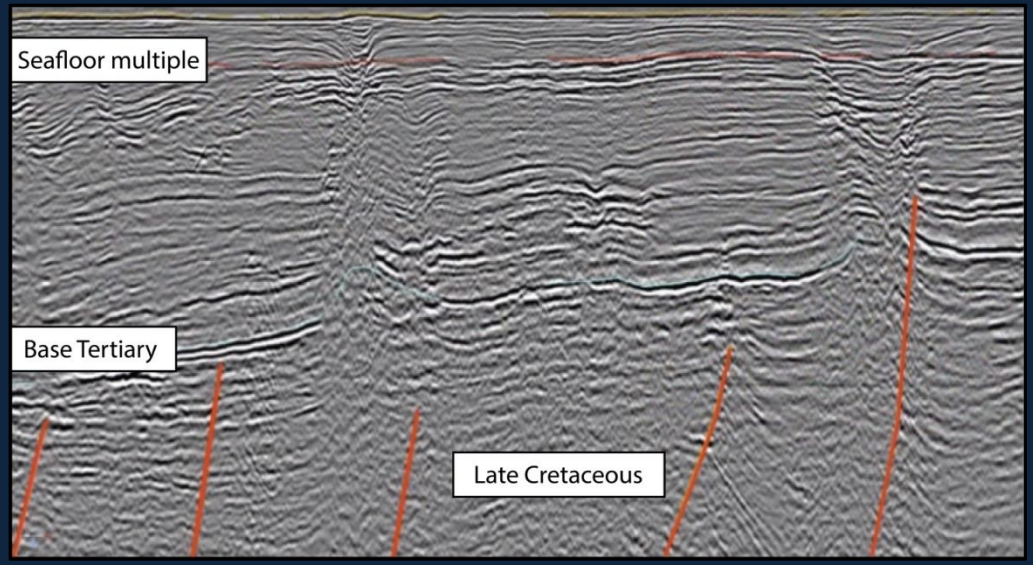
Seafloor asphalt mounds of Chapopote Knoll after Brüning *et al.,* 2010.

Evidence in the eastern Bight Basin

- A series of upturned reflectors at depth, depressed shallow reflectors, and a possible seafloor mound in EPP 41 & 42



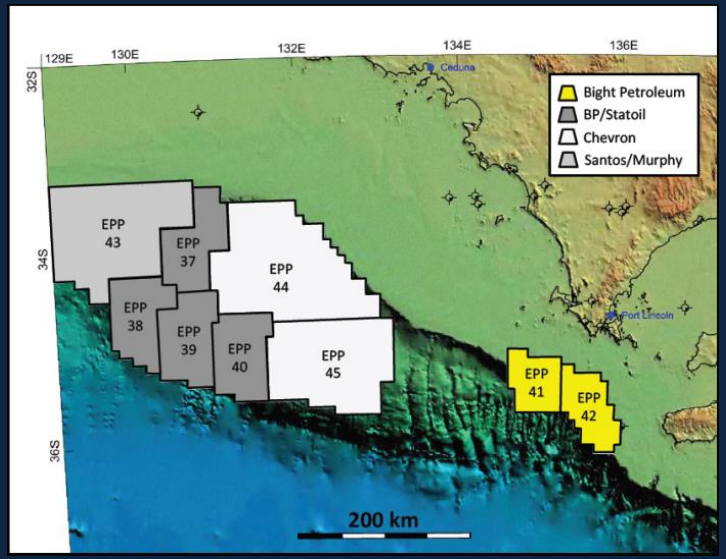
Images after Peter Boult (Bight Petroleum)

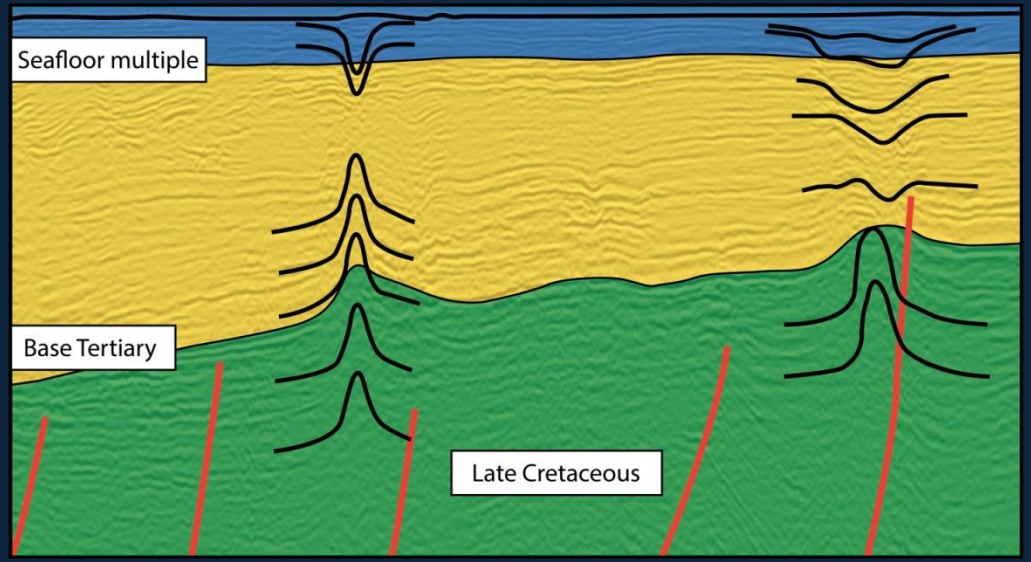


http://www.bightpetroleum.com/14862/Review-of-geochemistry-and-maturation-of-the-Bight-Basin.htm

Evidence in the eastern Bight Basin

- Characteristic fluid escape structures which may mark the site of heavy oil seepage





Images after Peter Boult (Bight Petroleum)

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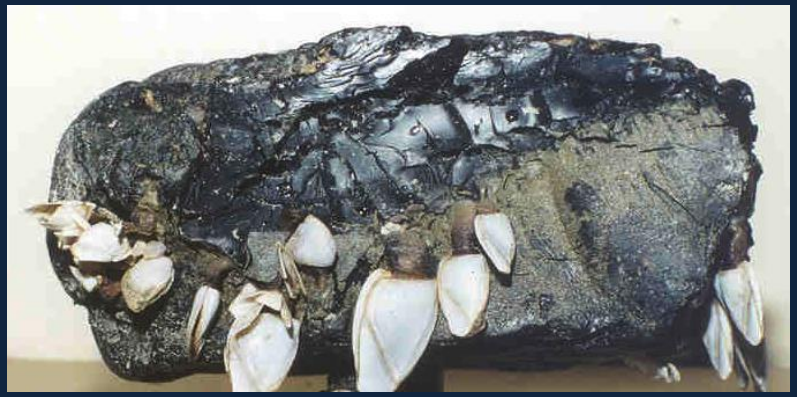
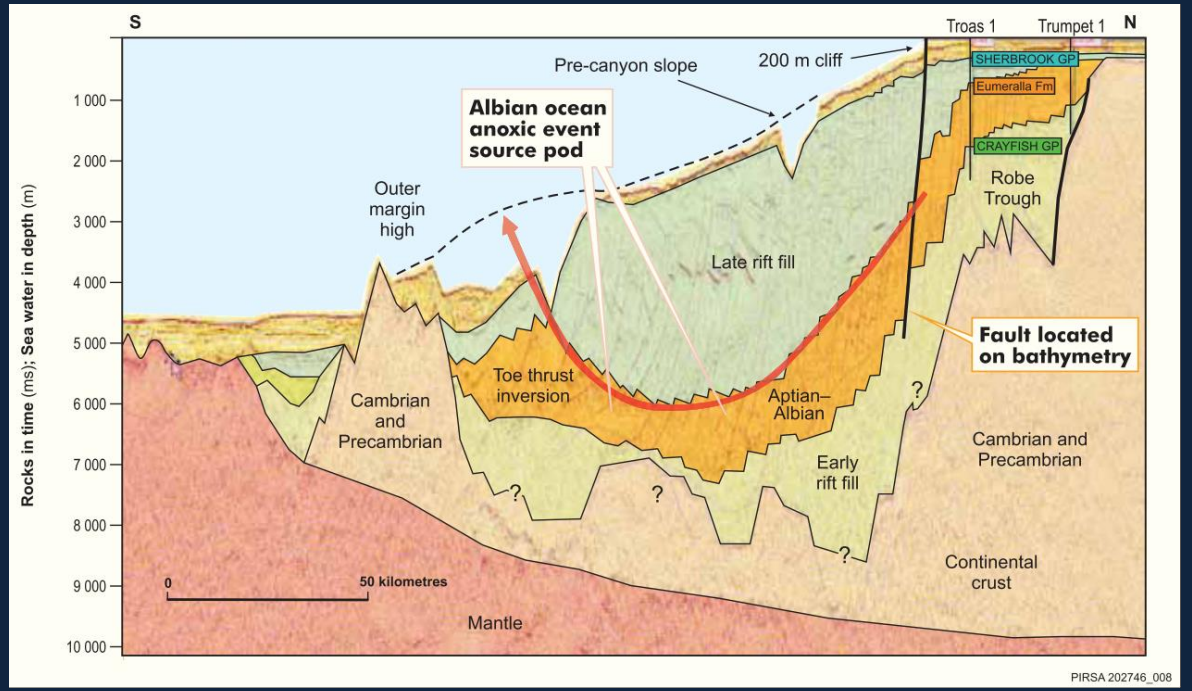
Fatal flaws?

- Detailed molecular analyses of the asphaltites revealed no evidence of water-washing or biodegradation (Volkman *et al*., 1992; Edwards *et al*., 1998)
- The model of an oil slick mousse devolatilising at the ocean surface prior to stranding (Logan *et al*., 2010) is inconsistent with flow structures & laminations
  - Goose barnacles can colonise flotsam



Hypothesis #3 : Subsurface tar mats

- Asphaltite originated from tar mats formed along sub-horizontal secondary migration pathways of the parent oil, or via deasphalting following gas invasion of the reservoir
- Exposure by submarine canyon incision creates low-intensity seeps, possibly in form of asphalt volcanoes (Hall *et al*., 2014)



Interpreted seismic section across the Morum sub-basin after Boult *et al*. (2005)

Other types of coastal bitumen

Waxy bitumen

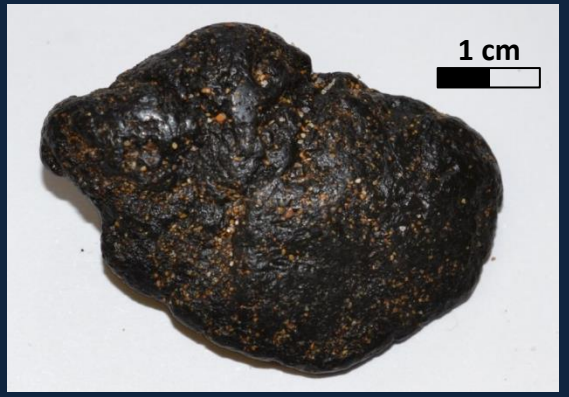
Greasy bitumen

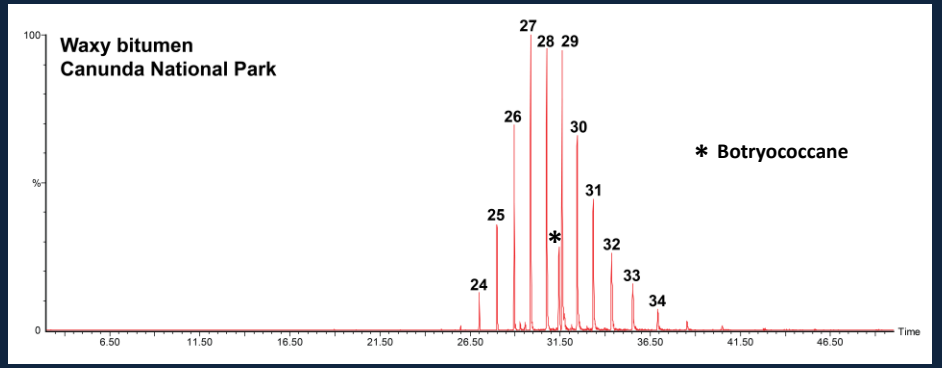
Oil slick (liquid droplets)

Sooty bitumen

Waxy bitumen

- Most common variety of South Australian coastal bitumen
- Positive buoyancy (floats on seawater)
- Assigned to five different oil families on basis of their elemental, isotopic & biomarker compositions (Padley, 1995)
- Molecular signatures similar to those of Indonesian crude oils generated from Cenozoic lacustrine-deltaic source rocks





Oil slicks

- Refined & crude oil stranded as
  - sooty bitumen
  - greasy bitumen
  - liquid droplets
  - solid oil melted on to rocks
- Spillage or tanker washings from local maritime traffic (Padley *et al*., 1993)
- Less prominent in 2014
  - no notable oil spills found

Oil slick droplets (top) and greasy bitumen (right) after Padley (1995)

Long-distance transport of waxy bitumen

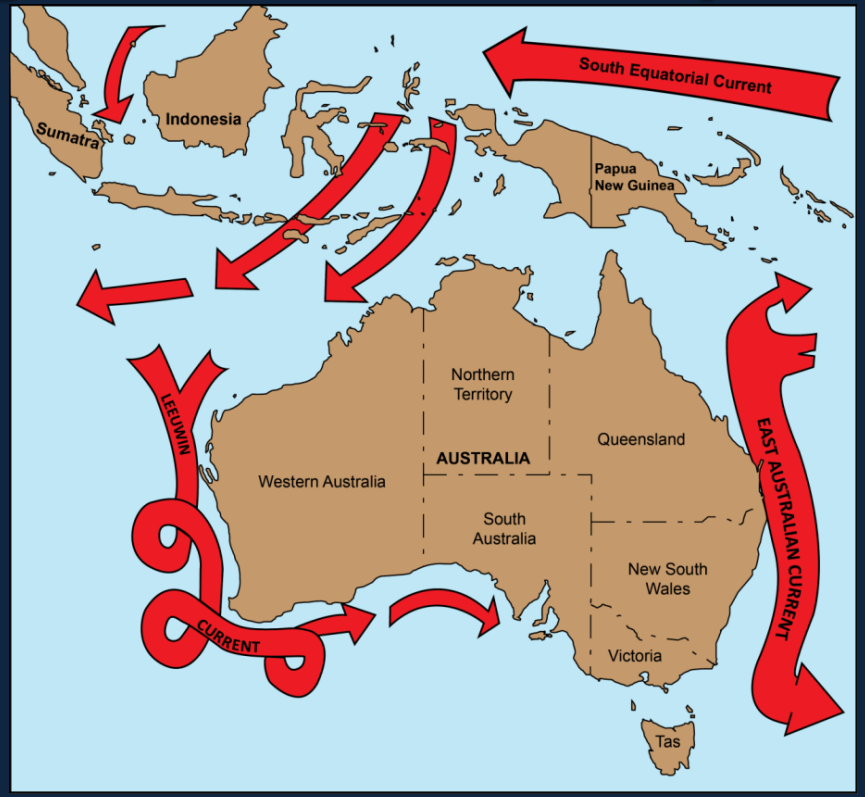
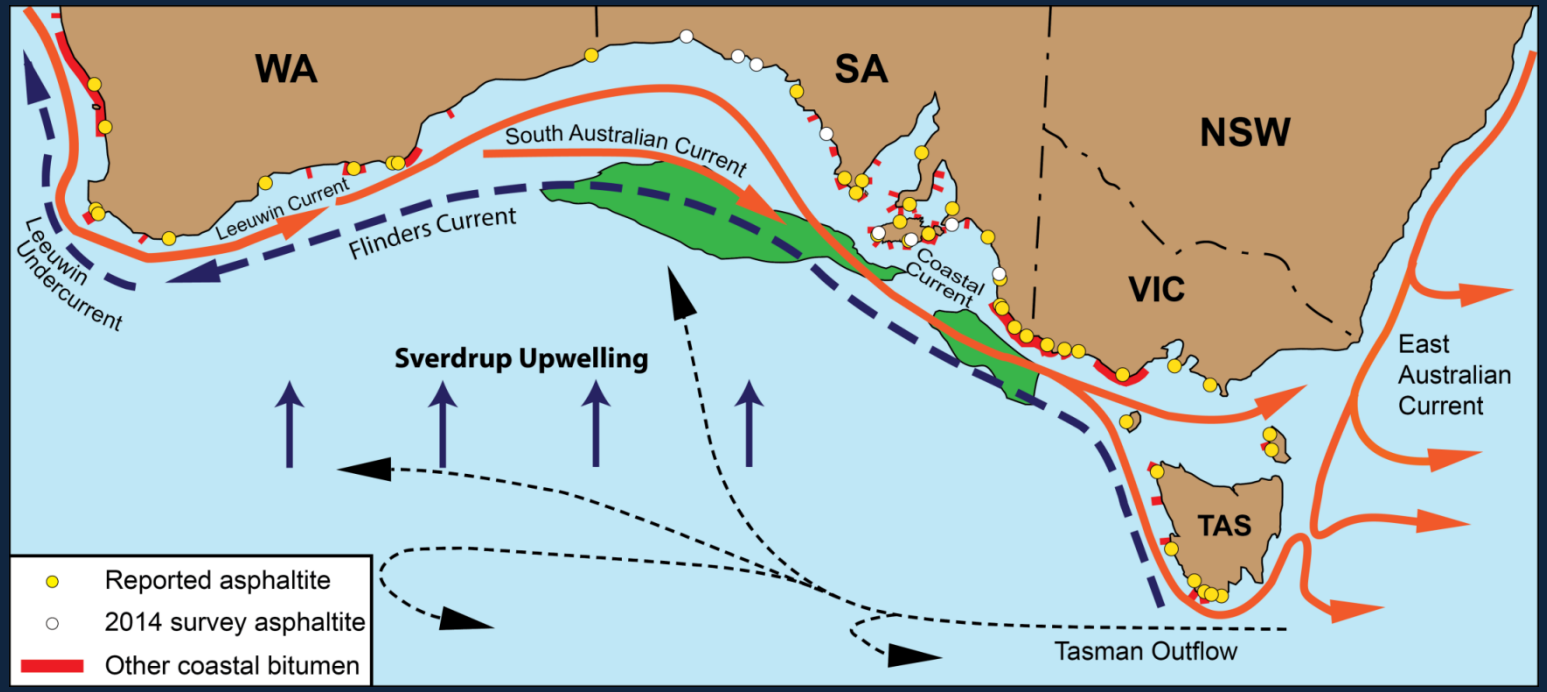


Figure modified after Edwards *et al.* (1998)

- South Equatorial Current & Leeuwin Current combine to transport waxy bitumen & other flotsam (e.g. dammar resin) from the Indonesian Archipelago into the Great Australian Bight (Murray *et al.*, 1994)
- Local currents carry them on to South Australian & Victorian beaches

Spatial distribution & oceanography

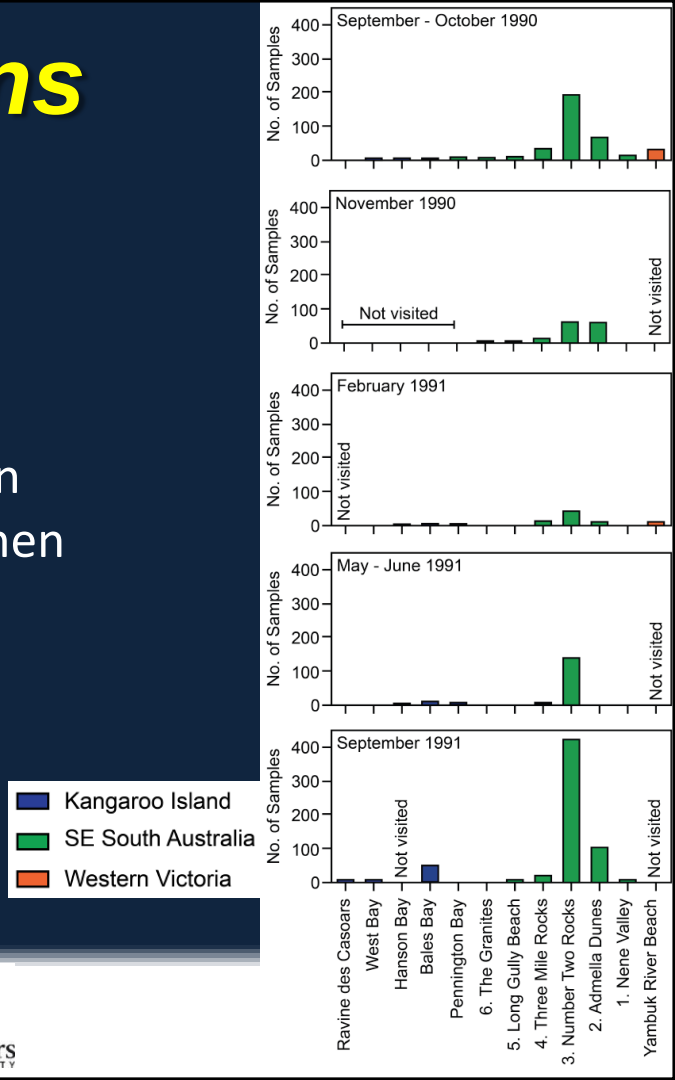


Winter ocean currents compiled from Cirano & Middleton (2004) and Middleton & Bye (2007)

- Asphaltites likely to be of local origin, offshore South Australia

Environmental implications

- Asphaltite is a minor contributor to the natural hydrocarbon loading of South Australian beaches
- Although of distant Indonesian origin, the more abundant waxy bitumens entering South Australian waters comprise the majority of its stranded bitumen (maximum loading 2 kg per 100 m)
- Winter is the optimum stranding season for both bitumen types



Summary

- Asphaltite is one of several varieties of bitumen that strand along Australia's southern coastline
- Its unique isotopic & biomarker signatures point to an origin from a mid-Cretaceous distal marine anoxic/sulphidic organic facies
- Lacking evidence of water-washing or biodegradation, this heavy oil likely seeps from exposed tar mats within the offshore Ceduna or Morum sub-basins
- The more abundant waxy bitumens likely originate from the Indonesian Archipelago

Acknowledgements

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