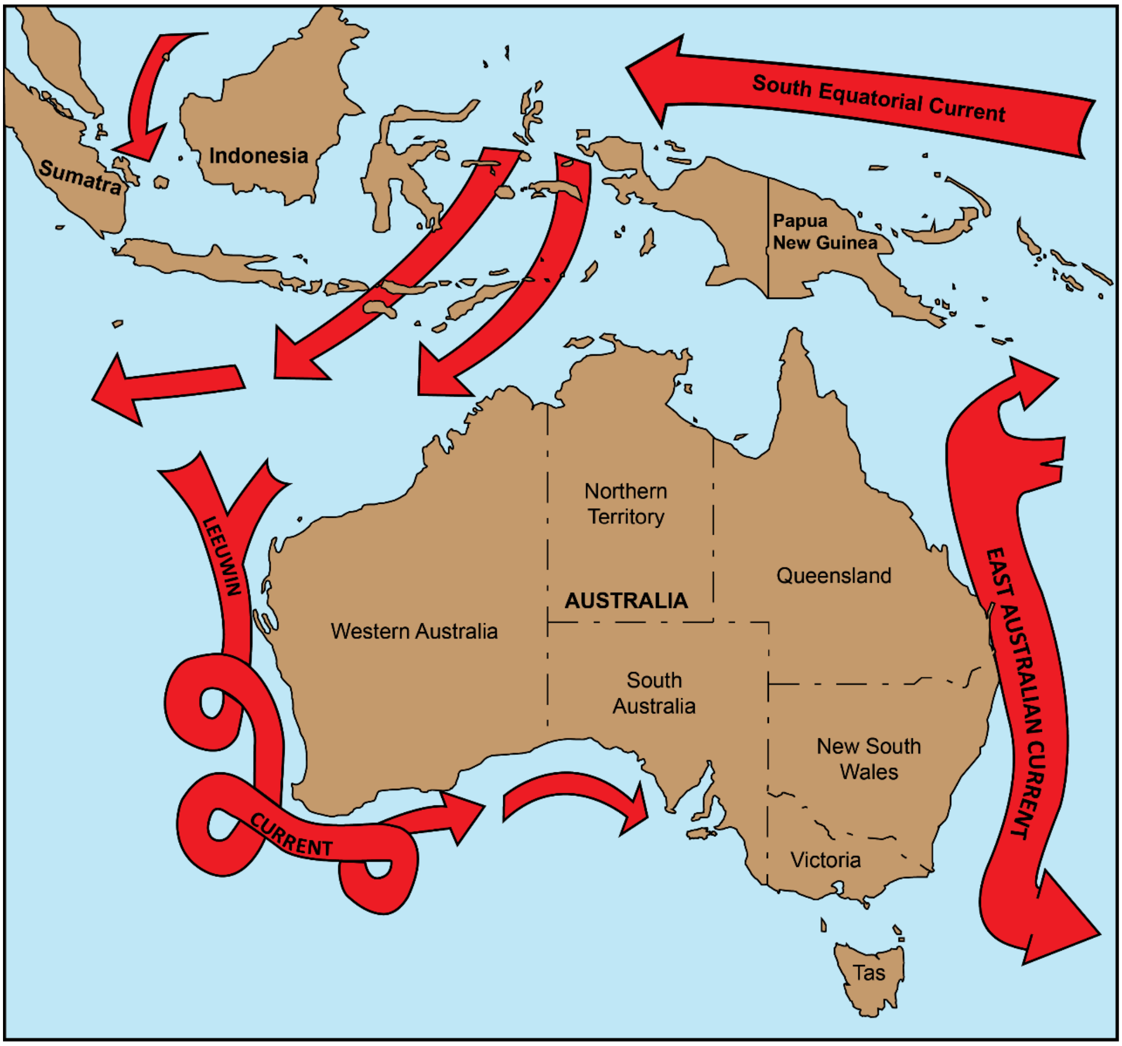


**Figure 11: Surface ocean currents responsible for the transport of coastal bitumen from Southeast Asia to southern Australia (after Edwards** et al., **2016; Padley 1995).**

During these winter storms the open ocean surface waters of the GAB experience large swells, waves and high winds (see Part 4 Oceanography below) which are likely to disperse oil slicks before they were able to amalgamate into semi-solid tar patties. It is therefore unlikely that under these conditions the asphaltites collected along the South Australian coastline can be attributed to the operation of this process during winter. However, at other times of the year, including between storm events, the offshore marine environment can be relatively benign and semi-solid tar patties may be able to form. However, there is only limited evidence from SAR studies (see Box 2 above) to suggest that these slicks are extensive or frequent in the GAB.

Alternatively, Hall et al., (2014) proposed that the asphaltites were the product of subsurface tar mats formed during the migration of petroleum. These subsurface tar accumulations were then exposed to the seafloor due to submarine canyon incision along Australia's southern margin (Figure 12).

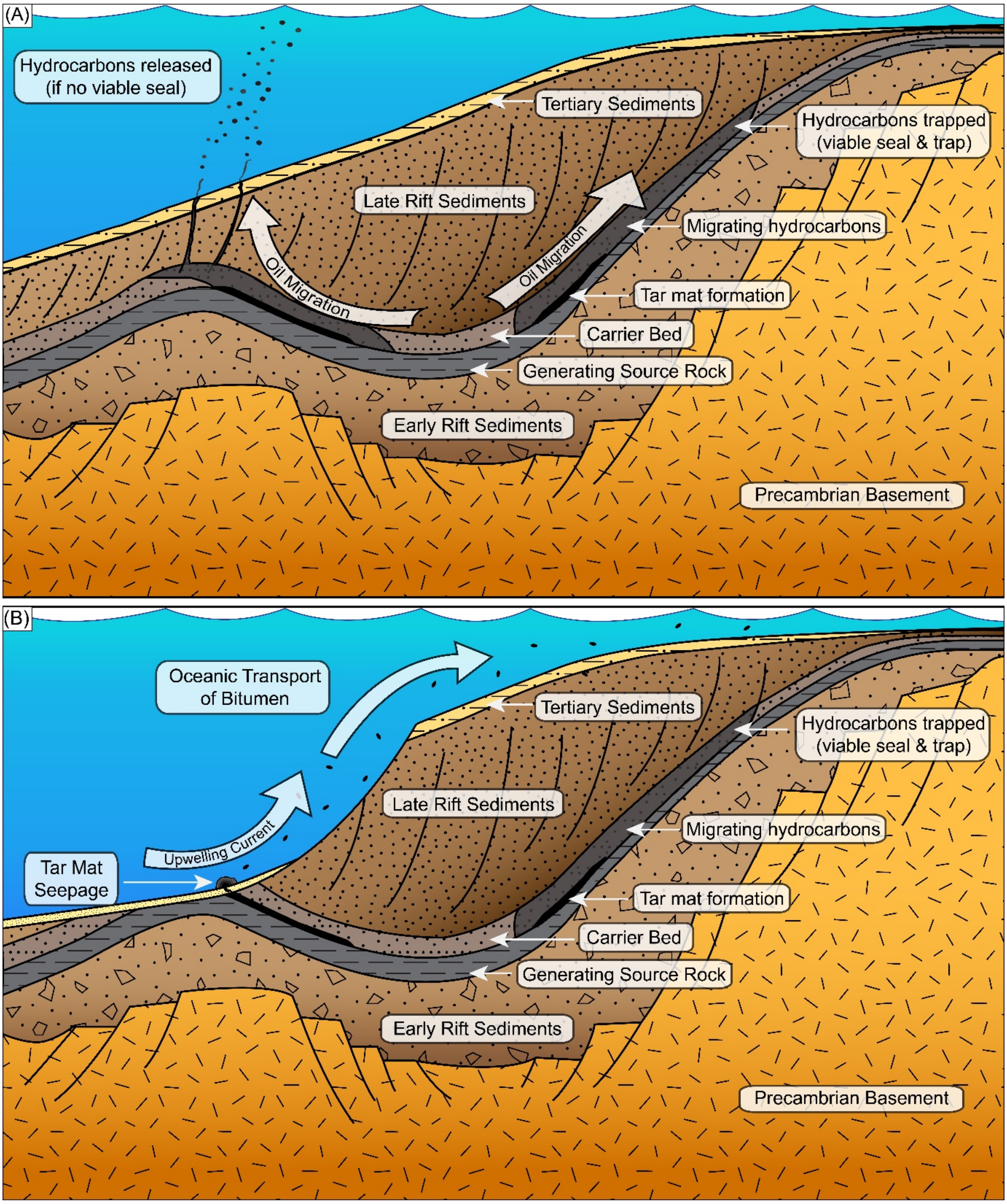


**Figure 12: Simplified model for submarine canyon incision resulting in lateral bituminous seeps from subsurface tar mats. (A) Source rocks deposited in the basin are buried at sufficient depth to generate hydrocarbons which migrate along a carrier bed. Asphalts precipitated from produced oils due to pressure changes during migration (Wilhelms & Larter, 1995), forming viscous sub-surface tar mats, while the oil charge either migrates to a viable trap or is lost due to a lack of a sealing unit. (B) Slumping at the shelf edge results in submarine canyon incision, exposing the subsurface asphaltic tar mats. After the bitumen has become fragmented, upwelling currents which travel up the submarine canyon are then able to entrain pieces of this bitumen resulting in their transportation to the shallower regions of the shelf.**

## Potential Analogues

### The Gulf of Mexico

The continental margins of the Gulf of Mexico host some of the most well-studied and widespread examples of natural asphalt seepage in the world (e.g. MacDonald et al., 2004; Talukder et al. 2013; Schubotz et al., 2007, 2011a, b; Bruning et al., 2010; Sahling et al., 2016). Here heavy hydrocarbons escape a shallow reservoir with a thin (ca. 100–200 m) seal (Ding et al., 2008) to episodically produce large (ca. 2000 $m^2$) asphaltic flows on the seafloor (Figure 13: Bruning et al., 2010). These asphalt seeps remain active today, with fresh asphalt exhibiting flow structures and hosting chemosynthetic communities such as bacterial mats, bivalves and tube worms (MacDonald et al., 2004; Sahling et al., 2016). Although the asphalt flows are the most studied component of the seafloor seeps in the Gulf of Mexico, in deeper sites the asphalt flows may also be accompanied by liquid oil in the form of whips or sheets, gas emissions and gas hydrates (Sahling et al., 2016). Methane captured as hydrate in the vicinity of the seeps has been attributed to biological methanogenesis occurring several meters below the seafloor by the local hydrocarbon-degrading bacteria (Schubotz et al., 2011a).

The presence of flow structures led MacDonald et al., (2004) to propose the asphalt flows were the result of 'asphalt volcanism', where hot asphalt erupted from the seafloor in a manner comparable to traditional lava flows. The hypothesis was refined by Hovland et al., (2005), who attributed the mechanism of heating to supercritical water. In this scenario, hydrothermal fluids heated at depths > 10 km carried the asphalt in solution through the subsurface to the seafloor, thermally buffered from cooling during migration through the subsurface by local salt diapirs. Upon reaching the seafloor, cooling from seawater resulted in the precipitation of the asphalt, producing lava-like flows away from the seep site until the hot asphalt cooled and solidified.

Alternatively, the flow structures may not have required heating. Brüning et al., (2010) proposed the asphaltic flows may be the result of an already viscous (biodegraded) petroleum further increasing in viscosity upon release to the seafloor due to loss of volatile components. As the asphalt loses these volatile components the remaining material becomes increasingly brittle, eventually leading to fragmentation of the asphalt (Figure 14).

While fresh asphalt flows commonly host a wide range of organisms, older generations do not typically host significant chemosynthetic communities (Sahling et al., 2016). The older asphalts also develop widespread fissures. Whilst this may be comparable to the shrinkage cracks observed in the South Australian coastal asphaltites, the fissures which occur in the asphaltic flows in the Gulf of Mexico appear to have a highly consistent fracture orientation (Figure 15A, B). By comparison, the asphaltites often show multiple fracture orientations within an individual sample (Figure 15C, D) which although they are not being assessed in situ, appear much less systematic in nature.

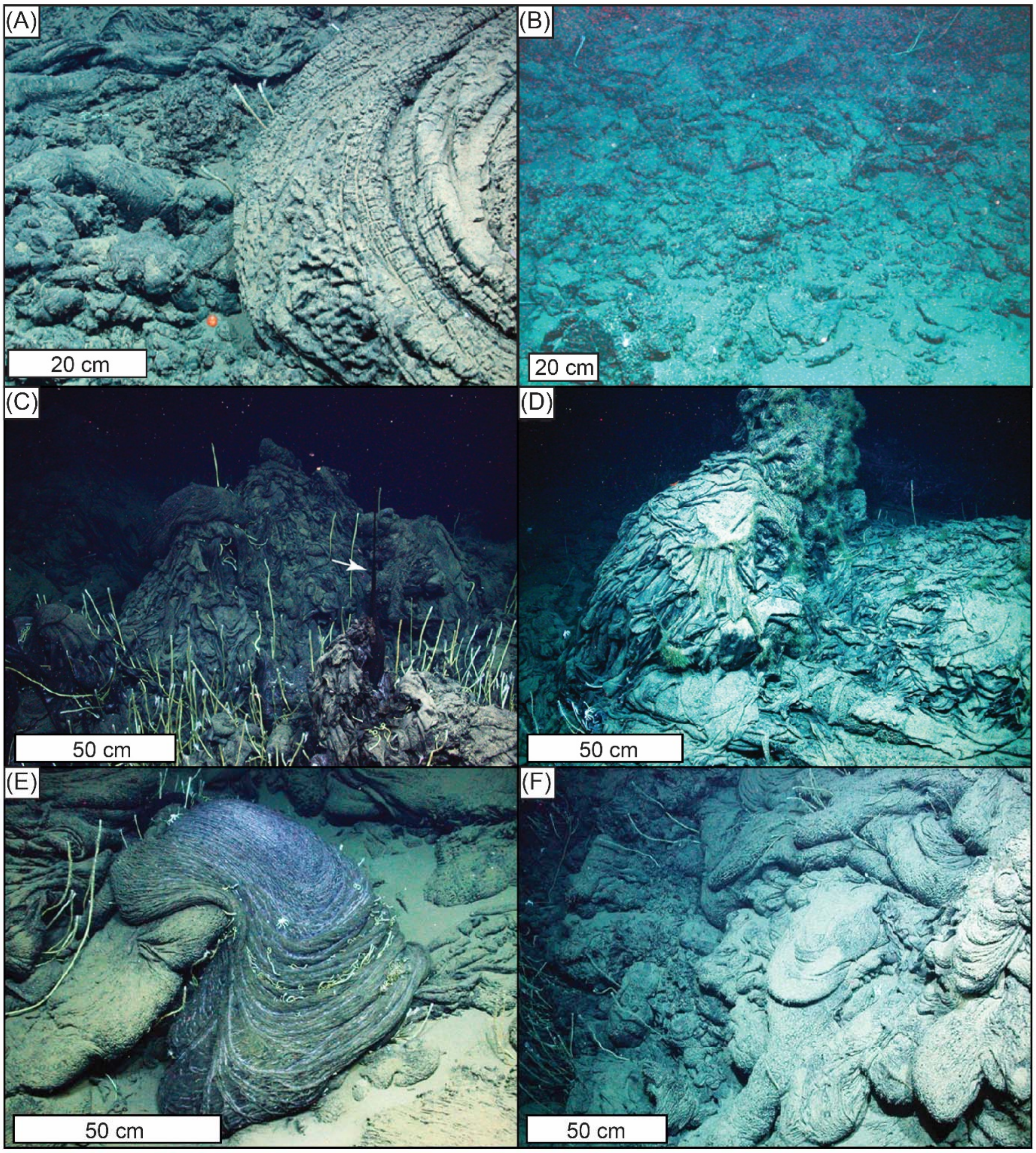


**Figure 13: Examples of seafloor expressions of asphaltic bitumen from the Gulf of Mexico. (A) Seafloor asphalt mounds and flows from Chapopote Knoll, Southern Gulf of Mexico after Brüning et al., (2010). (B) Fragmented seafloor asphalt from Chapopote Knoll, Southern Gulf of Mexico after Brüning et al., (2010). (C) – (F) Examples of seafloor expression of hydrocarbon seeps in the Gulf of Mexico after Sahling et al., (2016).**

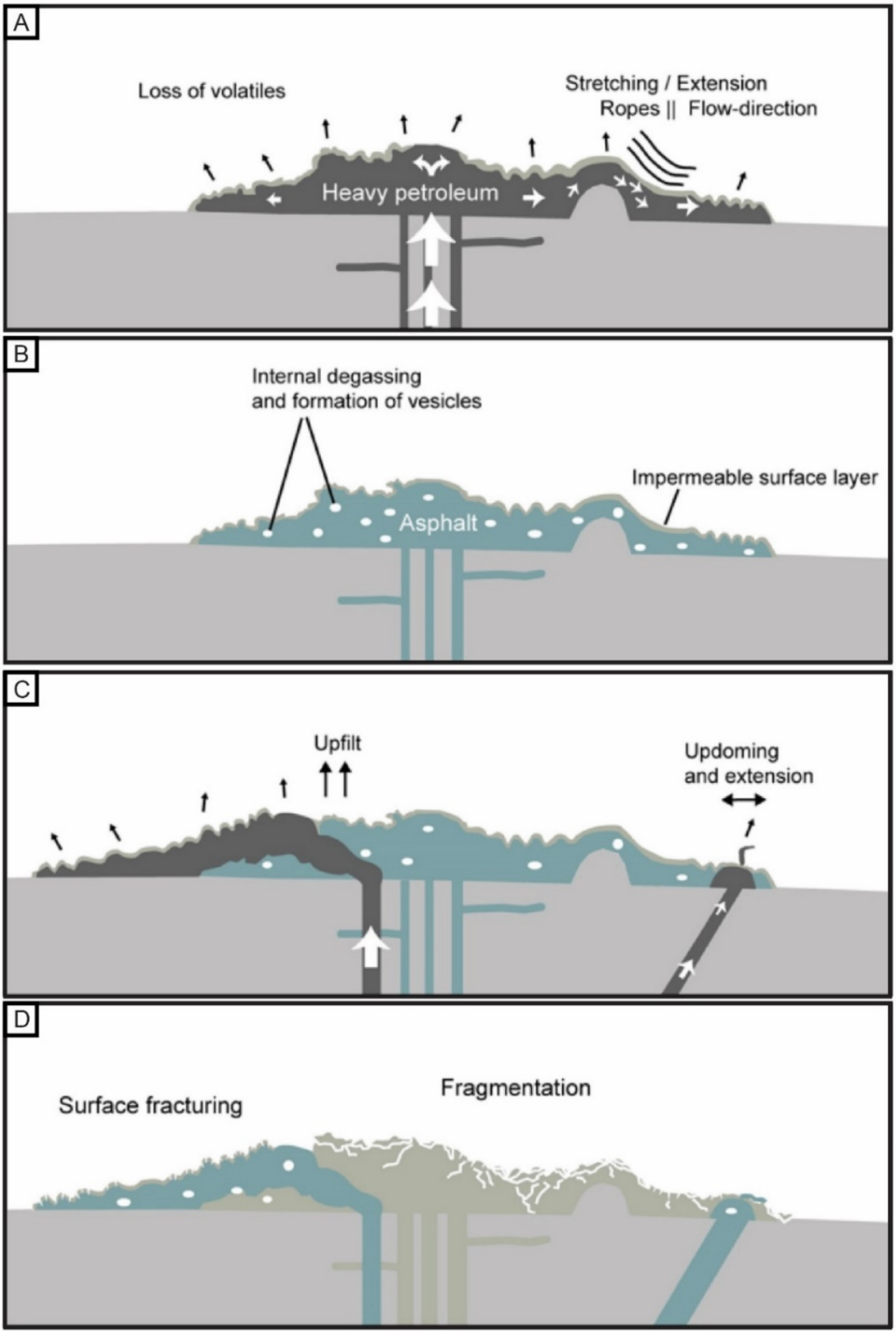


**Figure 14: Overview of asphaltic bitumen spreading and fragmentation based on studied sites at Chapopote Knoll after Brüning et al., (2010). Continual weathering and loss of volatiles results in surficial cracking and asphalt fragmentation.**

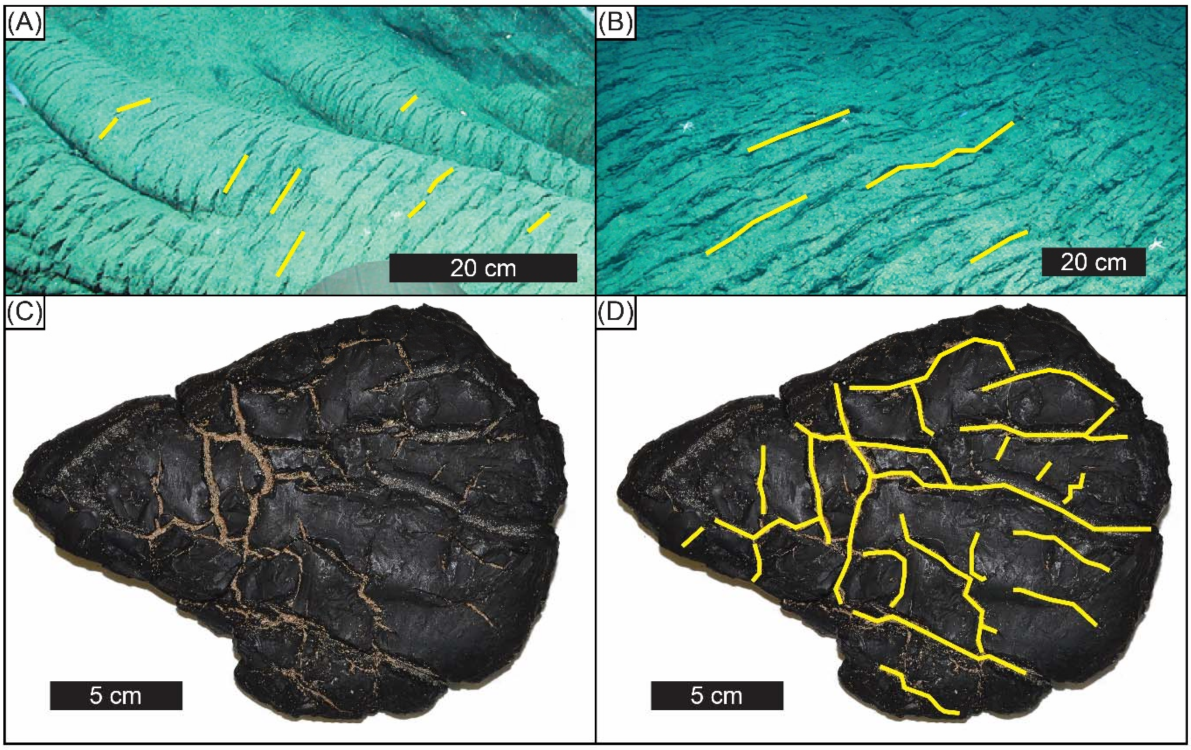


**Figure 15: Comparison of fracture patterns in asphaltic flows in the Gulf of Mexico and the South Australian coastal asphaltites. (A+B) ROV QUEST images of fractured asphalt at Chapopote Knoll modified after Brüning et al., (2010). Yellow annotation lines highlight the clearly preferred fracture orientation. (C) South Australian asphaltite sample W13/007507, an example of the highly fractured asphaltite surface. (D) Asphaltite sample W13/007507 with fracture orientations annotated in yellow lines.**

## Santa Barbara Channel, offshore California

The Santa Barbara Channel hosts many extremely active natural hydrocarbon seeps. This area has been studied extensively as part of a multi-year study by the U.S. Geological Survey (USGS), which assessed seafloor seeps, produced oils from the region and the hydrocarbon loading of the coastline between 2001 and 2003. As oil extraction and shipping also occurs in the region, the ability to characterise natural hydrocarbon seepage products from any possible anthropogenic spills is extremely important from an environmental management perspective. For a comprehensive review see Lorenson et al. (2009).

These natural tar seeps originate from leaking petroleum systems in the offshore southern Santa Maria Basin and the Santa Barbara Basin. Here the tar seepage and sea-surface oil slicks have been well documented, with geochemical analyses correlating tars to local production oils. In addition, USGS surveys have documented the occurrence of sea-surface oil slicks/tars and the hydrocarbon loading along the California coastline (Lorenson et al., 2009). Unlike the continental margins of the Gulf of Mexico, where asphalt expelled from seeps forms large-scale flows, the seeps in the Santa Barbara Channel primarily produce positively buoyant ‘tar whips’ and surface oil slicks which may strand along the coastline as liquid droplets of oil or amalgamate on the sea surface to form tar patties (Figure 16). Most, though not all seep oils were found to be heavily biodegraded, having undergone significant or complete loss *n*-alkanes and isoprenoids pristane and phytane. By

comparison, these compounds were present in all samples of produced oils. This formed the basis for a tentative method for distinguishing seep and produced oils. However, in some cases the produced oils were clearly derived from the same petroleum systems with natural seeps, making definitive geochemical differentiation between the two inconclusive.

Results from the 2001–2003 coastal surveys demonstrated that the stranding of tars varies seasonally, with greater accumulation rates or preservation potential during summer and autumn. This was tentatively attributed to variation in prevailing wind direction, ocean currents and calmer sea-surface conditions promoting preservation on beaches, in contrast to high-energy wave action during winter months which may prompt the removal of material from the coastline (Lorenson et al., 2009). A seasonal control is also recognised when assessing the stranding of bitumen along the coastline of South Australia, where waxy bitumen preferentially strand in winter months (Padley, 1995; Edwards et al. 2016). This suggests that the high-energy sea surface conditions thought to disperse or remove material may be less relevant than the prevalent wind/wave direction and general ocean current trends.

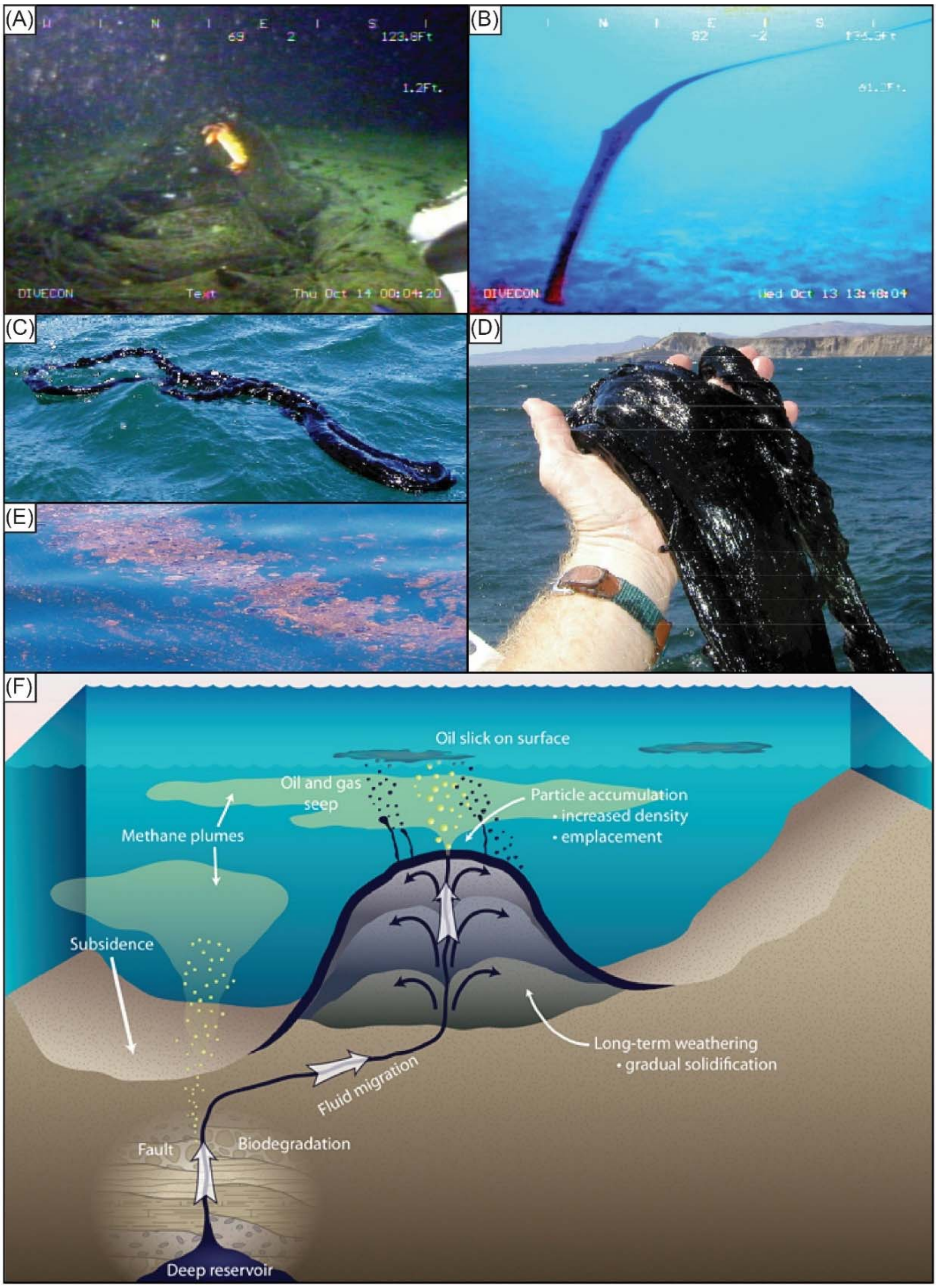


**Figure 16: Examples of seafloor tar seepage and sea surface tar formation from offshore California. Photographs A-E after Lorenson et al., (2009). (A) Remotely operated vehicle (ROV) image of extruding tar mound. (B) A 'tarwhip' extruding from a seafloor tar mound. (C) Viscous tar floating on the sea surface offshore from Point Conception on the southern coast of Santa Barbara, California. (D) Collected viscous tar from sea surface from Point Conception on the southern coast of Santa Barbara, California. (E) Natural oil slick forming tar patties observed on the sea surface offshore from California. (F) Overview of tar mound formation for offshore California after Woods Hole Oceanographic Institution <http://www.whoi.edu/oilinocean/page.do?pid=51880&tid=441&cid=107898&ct=61&article=73026>.**

# Part 2 Beach survey data

# BEACH SURVEY DATA

## Historical sites studied

In 1983 the South Australian Department of Mines and Energy (SADME) conducted a major survey of stranded bitumen along the South Australian and western Victorian coastline, involving the collection of new samples for geochemical analysis (McKirdy, 1984a, b). The study area extended from Bridgewater Bay, Victoria to Encounter Bay, South Australia, and included Kangaroo Island and the southern coastlines of the Yorke and Eyre Peninsulas (Figure 7). The results of the survey showed that coastal bitumen was stranded along the entire length of coastline surveyed, although the greatest quantities were collected from the western side of Kangaroo Island at Sandy River Beach and Hanson Bay. These collections are summarised in Padley, (1995).

During 1990 and 1991, a series of new surveys continued the systematic sampling of stranded bitumen along the coastline of southeastern South Australia between Goolwa and Bridgewater Bay (Figure 7). The study area also included Kangaroo Island, but not the Yorke and Eyre Peninsulas (Padley, 1995; Edwards et al., 2016).

This investigation employed a nested survey approach involving, in the first instance, regular bimonthly monitoring of all the accessible beaches in the field area for a period of one year. Along with the volume of stranded bitumen, the abundance of ocean flotsam and the local coastal geomorphology were recorded; and representative samples of bitumen were collected for analysis. Bitumen samples were also retrieved intermittently from various coastal localities between Point Addis, near Geelong and the Eyre Peninsula during October 1989 to August 1993. On Kangaroo Island the accessible beaches are generally small coves, as opposed to the kilometres of open beach typical of the southeastern Australian mainland (Padley, 1995; Edwards et al., 2016).

The second survey approach selected six individual beaches within the survey area along the mainland coast for detailed documentation of their bitumen strandings. These sites are listed in Table 2 and shown in Figure 7. Every two months at each of these localities all petroleum substances (coastal bitumen, asphaltite, and oil) were removed from a marked 200 m length of beach. This work began on the 26 September 1990 and was completed on the 27 of September 1991. Prerequisites for the choice of these sites were that the beaches be;

- sandy, with a wide tidal range,
- exposed, with no offshore reefs or kelp beds to hinder the stranding of flotsam,
- backed by sand dunes, and hence relatively stable, and
- seldom visited by people so that the strandlines were undisturbed.

In addition, all the chosen beaches had a moderate gradient that allowed storm debris to collect at the top of the beach.

In addition, several opportunistic collections were made from farther afield during visits to sites between Torquay, west of Melbourne, and Anxious Bay on western Eyre Peninsula (Figure 7:, Edwards et al., 2017).

**Table 2: South Australian beaches monitored in detail for the stranding of coastal bitumen during the 1990-1991 Coastal Bitumen Survey.**

| Site No. | Location | Description |
|---|---|---|
| 1 | Nene Valley, S. A. | Extending 200 m along the coast from the bay in front of the shacks, east to the last track entering the beach. |
| 2 | Admella Dunes, near Cape Banks Lighthouse, S. A. | Extending 200 m along the beach east from the Lake Bonney sluice gate. |
| 3 | Number Two Rocks, Canunda National Park, S. A. | The whole bay (300 m long) northwest of Jennings Shack. |
| 4 | Three Mile Rocks, Beachport Conservation Park, S. A. | The whole of the northern beach (300 m long). This site is not ideal as there are offshore reefs. |
| 5 | Long Gully, Little Dip Conservation Park, S. A. | Extending 200 m along the beach from the southern rocky headland. |
| 6 | The Granites, S. A. | Extending along the beach 50 m to the north and 150 m to the south of the granite outcrop. |

Prior to the present investigation, analyses of coastal bitumen samples from the SADME (1983) and Padley (1995) studies constituted the largest geochemical database of sea-borne petroleum stranded in southern Australia. This database was therefore used to guide the development of the survey plans for GAB Project 5.2. In designing its three beach surveys, historical stranding sites were considered for revisitation to extend the long-term record of coastal bitumen data. Other recent beach survey designs and methods were also considered, including those associated with shoreline assessment and cleanup (SCAT: Santner et al., 2011; NOAA, 2013) and those recently used for surveying anthropogenic marine debris (Hardesty et al., 2017; Van der Velde et al., 2017).

Beaches along the coastline of South Australia visited as part of these marine debris surveys numbered 27, of which 15 were outside the Spencer Gulf, Gulf St Vincent and Investigator Strait. Where possible, beaches that had been visited during these marine debris surveys were revisited, partially to gain some temporal understanding of marine debris loadings but also because these beaches were accessible and roughly equidistant from one another.

## Beach survey rationale and hypothesis

Historical surveys of coastal bitumen stranding in South Australia are heavily weighted towards the beaches of Kangaroo Island and the Limestone Coast, augmented by informal collections from farther afield. No systematic surveys had included the beaches of Eyre Peninsula and the Head of the Bight. The lack of survey effort, and therefore collections, in these more remote locations could therefore have led to a biased understanding of the distribution and source of the bitumen strandings. In the event of an oil spill in the GAB, this gap in the survey coverage posed an additional risk, with no baseline data available to characterise the existing hydrocarbon loadings of the beaches in the far west of South Australia.

For the Gulf St. Vincent, Spencer Gulf and Investigator Strait it was anticipated that the presence of high population densities (especially in and around the Adelaide metropolitan area) and associated shipping and industry would have compromised any survey of their beaches because of a higher likelihood of instances of anthropogenic contamination. Moreover, it was considered that the beaches within the gulfs and the Investigator Strait did not have as high a catchment potential for flotsam sourced from the Southern Ocean.

The geographical extent of the asphaltite and tarball survey therefore encompassed the whole South Australian coastline, with the exception of beaches bounding Gulf St Vincent, Spencer Gulf and Investigator Strait.

Also informing the rationale for the beach surveys were the results of Padley (1995) and Edwards et al., (2016) which revealed that little or no bitumen stranded during the summer months, with the optimum stranding season being winter when storms and prevailing westerly winds drive bitumen and other flotsam ashore. This knowledge was instrumental in the decision to annually survey selected beaches in the spring quarter of the year when encounter rates were likely to be at their highest.

Other considerations in the selection of survey beaches for the study was the substrate type, aspect and slope, with a view to establishing if any of these factors had an impact on the type and quantities of materials stranded on shorelines of the South Australian coastline.

All of these considerations were important in the final selection and timing of beach surveys during the project described below.

## Beach selection approach

At the commencement of the project, the beaches and sampling locations of previous coastal bitumen surveys were collated. The beaches visited in the marine debris surveys of Hardesty et al., (2017) and Van der Velde et al., (2017) were also ascertained. These data were incorporated into a project-specific geographic information system (GIS), along with other administrative data sets such as towns, roads, administrative boundaries, parks and reserves, and locations of key infrastructure.

In addition, hard copy maps (1:50,000 scale) were purchased and, together with Google Earth™ satellite imagery and an online South Australian oblique coastal photography data set, used to aid the understanding of beach location, substrate, physiography and slope. In the selection of the beaches for study, a first order consideration was to attempt to provide equidistant survey locations along the coastline of South Australia, with second order considerations being aspect, slope, substrate and predominant wind and wave directions. The survey design also incorporated the need to revisit beaches studied in prior coastal bitumen and marine debris surveys.

Finally, once candidate survey beaches were identified they were assessed for accessibility, safety, proximity to accommodation, water, food, fuel supplies and medical facilities.

The aforementioned selection process identified 46 sites, extending from the Western Australian border in the west to the Victorian border in the east, that were then categorized as either primary or secondary priority beaches. The rationale for having primary and secondary beaches was that if,

on arrival, any primary beach was found to be inaccessible or deemed to be unsafe, a nearby secondary priority survey beach could be readily substituted.

Field dossiers of all the pertinent data required for the field surveys were compiled for all 46 beaches.

This information included:

- General description
- Beach shape, exposure, aspect, gradient, width, substrate type and backshore type
- Access point from the main road
- Permits necessary for access
- GPS waypoints from the nearest graded road
- Nearest water
- Nearest medical post
- Beach specific hazards
- Safety mitigations
- Environmental and cultural aspects
- GIS maps of topography, Landsat satellite imagery, waterways, infrastructure (roads, fuel, campsites), land tenures (aboriginal or pastoral land), protected areas, reserves plus bird and mammal breeding sites
- Oblique coastal photographs from the South Australian government collection
- Google Map images of access roads and tracks with the access track indicated

Based on the information in the compiled dossiers, the shortlist of 46 beaches was further narrowed down to 29 priority one beaches (Figure 17). This final list of beaches was considered to provide the best coverage of the coastline with reasonably easy access and which had an orientation suited to tarball strandings, plus a few alternative orientations for comparison. Two priority two beaches were added to the list when they were close to another beach for a short survey. The beach dossiers from the 31 beaches visited are included in APPENDIX 5: BEACH DOSSIERS.

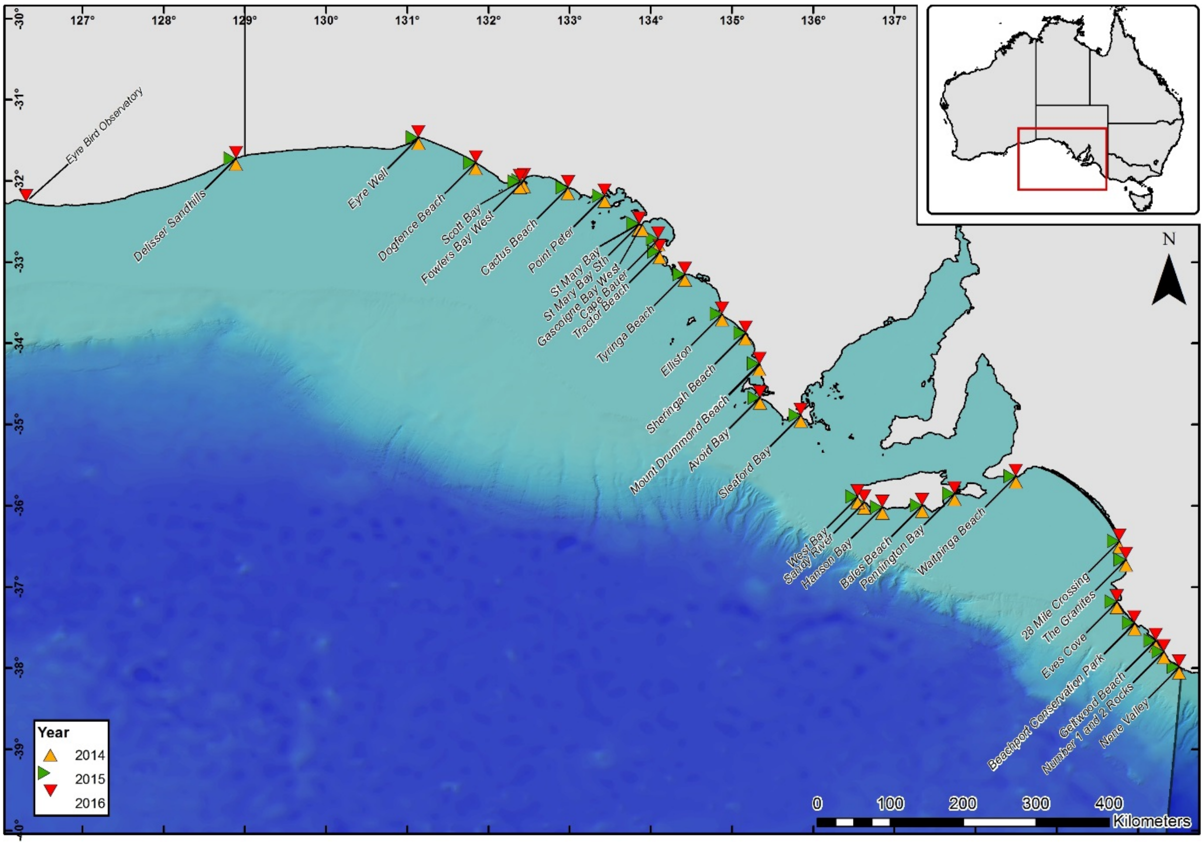


**Figure 17: Beaches visited during the 2014 / 2015 / 2016 seasons.**

## Beach visit seasons

To gain an understanding of annual stranding patterns, and to collect every stranded bitumen specimens for photography, weighing and subsequent geochemical analysis, beach surveys were conducted in consecutive years between 2014 and 2016. Information for each beach visit is tabulated below (Table 3-5).

### *Beach survey season 1 – November 2014*

A total of 31 beaches were visited in late spring between November 5$^{th}$ and 27$^{th}$. A six-person survey team travelled 5,880 km and collected 97 asphaltite and tarball samples. The numbers of survey personnel completing each beach survey varied, as some members of the team were required to move ahead to set up camp or procure supplies. On a few of the beaches we were joined by additional volunteers who helped conduct the surveys (Table 3).

The survey began on the western-most beaches and travelled east, with a short pause between the western and eastern legs in Adelaide to exchange one of the field team and resupply. Field conditions for the western leg of the survey were very hot, and were mitigated through the use of a two-beach-per-day survey strategy, one early in the morning and another in the late afternoon after travel between the sites.

Weather during the second, eastern leg was more favourable and permitted the survey to proceed as per plan. No days were lost due to poor weather. However, the survey of Eve's Cove was cut short due to unexpected rain and wind. At The Granites the survey team was gifted a large sample collected by the local station owner who regularly cleaned up the beach.

**Table 3: Beaches visited 2014.**

| Area | Beach Name | Survey Length (km) | People Searching | Survey Duration (hrs) |
|---|---|---|---|---|
| East | 28 Mile Crossing | 1.02 | 6 | 0.68 |
| East | Beachport Conservation Park | 1.06 | 5 | 1.90 |
| East | Eves Cove | 0.46 | 8 | 1.23 |
| East | Geltwood Beach | 1.01 | 5 | 10.13 |
| East | Nene Valley | 0.67 | 5 | 0.60 |
| East | Number 1 and 2 Rocks | 0.31 | 5 | 2.70 |
| East | The Granites | 1.52 | 6 | 1.63 |
| East | Waitpinga Beach | 1.20 | 8 | 2.65 |
| KI | Bales Beach | 1.02 | 6 | 1.43 |
| KI | Hanson Bay | 0.94 | 6 | 2.17 |
| KI | Pennington Bay | 0.59 | 6 | 0.80 |
| KI | Sandy River | 0.19 | 6 | 0.40 |
| KI | West Bay | 0.38 | 6 | 0.82 |
| West | Avoid Bay | 1.17 | 6 | 0.90 |
| West | Cactus Beach | 2.04 | 6 | 1.53 |
| West | Cape Bauer | 1.33 | 4 | 0.83 |
| West | Delisser Sandhills | 1.74 | 6 | 1.58 |
| West | Dogfence Beach | 2.03 | 4 | 5.02 |
| West | Elliston | 0.99 | 4 | 0.85 |
| West | Eyre Well | 2.00 | 4 | 1.45 |
| West | Fowlers Bay West | 1.59 | 6 | 0.85 |
| West | Gascoigne Bay West | 0.50 | 4 | 0.23 |
| West | Mount Drummond Beach | 1.95 | 6 | 1.72 |
| West | Point Peter | 0.83 | 6 | 2.10 |
| West | Scott Bay | 2.04 | 4 | 1.38 |
| West | Sheringah Beach | 1.65 | 6 | 1.23 |
| West | Sleaford Bay | 0.73 | 6 | 1.67 |
| West | St Mary Bay | 0.84 | 4 | 0.65 |
| West | St Mary Bay Sth | 0.77 | 5 | 0.90 |
| West | Tractor Beach | 0.77 | 4 | 0.85 |
| West | Tyringa Beach | 0.58 | 6 | 0.82 |

***Beach survey season 2 – September 2015***

The same 31 beaches as 2014 were visited in early spring 2015 between September 4th and October 1st. The timing of this survey was partly determined by team availability, but also by the need to establish if delaying the visits closer to the end of winter would lead to higher sample recoveries. As before, the survey team travelled a distance of ~5,800 km, this time collecting 125 samples. A further 74 specimens were gifted to CSIRO by a beachcomber based in Coffin Bay, bringing the total number of tarballs and asphaltites collected during the 2015 field season to 197. As in the previous season, the number of team members completing each beach survey varied as some were required to move ahead of the group to set up camp or procure supplies (Table 4).

The survey direction was the reverse of that in 2014, with the eastern leg completed before the western leg. Although the prevailing weather conditions were cold, windy and rainy during the eastern leg, all beaches were visited as per plan. The Granites beach survey was cut a little short due to lack of time and failing light conditions. Two of the team were swapped out before commencement of the western leg of the 2015 survey. Weather during this leg was drier, though still cold at times, and all beaches were completed as planned.

Gascoigne Bay West, first surveyed in 2014 was checked for samples in 2015 but not properly logged. No samples were found. A section south of the jetty in Elliston was also checked, which resulted in a sample being found and post-logged. A section to the north of the surveyed part of Eyre Well was also checked and resulted in two samples being found and post-logged.

**Table 4: Beaches visited in 2015.**

| Area | Beach Name | Survey Length (km) | People Searching | Survey Duration (hrs) |
|---|---|---|---|---|
| East | 28 Mile Crossing | 0.91 | 6 | 1.45 |
| East | Beachport Conservation Park | 0.74 | 5 | 1.72 |
| East | Eves Cove | 0.77 | 5 | 1.78 |
| East | Geltwood Beach | 0.96 | 5 | 1.80 |
| East | Nene Valley | 0.68 | 4 | 1.28 |
| East | Number 1 and 2 Rocks | 0.42 | 5 | 2.05 |
| East | The Granites | 1.32 | 4 | 2.33 |
| East | Waitpinga Beach | 1.13 | 6 | 2.18 |
| KI | Bales Beach | 0.93 | 6 | 1.93 |
| KI | Hanson Bay | 0.80 | 6 | 2.30 |
| KI | Pennington Bay | 0.48 | 6 | 0.77 |
| KI | Sandy River | 0.38 | 6 | 1.92 |
| KI | West Bay | 0.37 | 6 | 1.48 |
| West | Avoid Bay | 0.89 | 6 | 1.85 |
| West | Cactus Beach | 1.95 | 6 | 1.75 |
| West | Cape Bauer | 1.25 | 5 | 1.03 |

| | | | | |
|---|---|---|---|---|
| West | Delisser Sandhills | 1.79 | 5 | 1.48 |
| West | Dogfence Beach | 2.04 | 6 | 3.33 |
| West | Elliston | 1.00 | 4 | 1.27 |
| West | Eyre Well | 1.99 | 6 | 2.77 |
| West | Fowlers Bay West | 1.68 | 4 | 1.02 |
| West | Gascoigne Bay West | 0.00 | 0 | 0.33 |
| West | Mount Drummond Beach | 0.99 | 5 | 1.80 |
| West | Point Peter | 1.91 | 6 | 1.47 |
| West | Scott Bay | 2.02 | 6 | 1.32 |
| West | Sheringah Beach | 1.53 | 6 | 1.75 |
| West | Sleaford Bay | 0.93 | 6 | 2.32 |
| West | St Mary Bay | 0.87 | 5 | 0.80 |
| West | St Mary Bay Sth | 0.81 | 5 | 0.78 |
| West | Tractor Beach | 0.82 | 6 | 1.43 |
| West | Tyringa Beach | 0.58 | 6 | 1.08 |

***Beach survey season 3 – October 2016***

The same 31 beaches as the prior years were once again revisited between October 4$^{th}$ and October 22$^{nd}$ 2016. October was chosen for its better weather and to fit team availability. The western leg was again undertaken first, with the addition of a new West Australian site (Eyre Bird Observatory) at the beginning of the survey to test if strandings occurred on southeastern facing beaches at the western end of the Bight coastline. As with prior years, the survey team travelled a distance of ~5,800 km, this time collecting 289 samples. A further 74 specimens were gifted to CSIRO by a beachcomber based in Coffin Bay, bringing the total number of tarballs and asphaltites collected during the 2016 field season to 363. As in the previous season, the numbers of team members completing each beach survey varied as some were required to move ahead of the group to set up camp or procure supplies (Table 5).

All western leg beach surveys were successfully undertaken (Table 5), with the exception of Dogfence Beach where the beach survey was curtailed due to very hot conditions and Mt Drummond where the beach was rendered inaccessible. Passage of a very large storm system in the preceding month had a large impact on many beaches, particularly on the Mt Drummond beach where erosion had removed sand from the beach and the back-beach dune system exposing a rocky beach substrate and leaving a large unstable cliff which could not afford safe access to the beach below. Several other beaches were also affected by waves cutting into back-beach dunes and/or the loss of sand from the beaches, exposing rocks and rocky substrates.

As noted above and as with the previous year, the survey team acquired a number of samples from a local Coffin Bay resident who regularly combed the beaches in the vicinity. A section south of the jetty in Elliston was again checked, which resulted in three more samples being found and post-logged.

The Kangaroo Island and eastern mainland leg was surveyed after two of the team were swapped out. Although the weather was colder and wetter than the western leg, all its beaches were surveyed as planned. The aforementioned storm had also significantly eroded many beaches and affected access in places. Samples were also found on the walk back to the car at West Bay and The Granites, while two more samples were found in the car park area well above the beach at Number 1 and 2 rocks.

**Table 5: Beaches visited in 2016.**

| Area | Beach Name | Survey Length (km) | People Searching | Survey Duration (hrs) |
|---|---|---|---|---|
| East | 28 Mile Crossing | 1.07 | 5 | 1.02 |
| East | Beachport Conservation Park | 0.88 | 5 | 1.72 |
| East | Eves Cove | 0.76 | 5 | 2.60 |
| East | Geltwood Beach | 1.08 | 5 | 0.77 |
| East | Nene Valley | 0.69 | 5 | 0.63 |
| East | Number 1 and 2 Rocks | 0.49 | 5 | 1.35 |
| East | The Granites | 1.01 | 5 | 1.47 |
| East | Waitpinga Beach | 1.20 | 5 | 1.83 |
| KI | Bales Beach | 1.52 | 5 | 1.20 |
| KI | Hanson Bay | 0.92 | 5 | 0.90 |
| KI | Pennington Bay | 0.46 | 5 | 0.55 |
| KI | Sandy River | 0.20 | 4 | 1.28 |
| KI | West Bay | 0.36 | 4 | 0.70 |
| West | Avoid Bay | 0.89 | 6 | 1.35 |
| West | Cactus Beach | 2.02 | 6 | 2.25 |
| West | Cape Bauer | 0.56 | 6 | 0.63 |
| West | Delisser Sandhills | 1.83 | 6 | 0.95 |
| West | Dogfence Beach | 0.25 | 6 | 1.40 |
| West | Elliston | 1.00 | 6 | 0.98 |
| West | Eyre Bird Observatory | 2.02 | 6 | 1.00 |
| West | Eyre Well | 2.48 | 6 | 1.95 |
| West | Fowlers Bay West | 1.93 | 6 | 0.92 |
| West | Mount Drummond Beach | 0.48 | 6 | 0.73 |
| West | Point Peter | 1.05 | 6 | 0.48 |
| West | Scott Bay | 1.95 | 6 | 1.28 |
| West | Sheringah Beach | 1.47 | 6 | 1.35 |
| West | Sleaford Bay | 0.95 | 6 | 1.22 |
| West | St Mary Bay | 0.52 | 6 | 0.63 |
| West | St Mary Bay Sth | 0.77 | 6 | 0.60 |
| West | Tractor Beach | 0.81 | 6 | 1.18 |
| West | Tyringa Beach | 0.58 | 6 | 0.63 |

## Survey methodologies

The survey methodology was designed to maintain rigour in data collection between beaches and years. Field collection of shoreline information has historically involved considerable effort and is subject to potential errors because of the need to initially record data by hand and transcribe it later into digital format. A better system for data capture was required to eliminate these potential errors and maximise the efficiency of beach surveys.

### Logging and sample collection

Prior to deciding on the beach survey protocols and procedures, a number of methods for doing shoreline surveys were reviewed. Principal amongst these were:

- The Shoreline Assessment Manual, 4$^{th}$ Edition August 2013 which has evolved from the Shoreline Cleanup Assessment Technique (SCAT) developed by the National Oceanic and Atmospheric Administration (NOAA) as a method for evaluating and responding to threats to coastal and marine environments (NOAA. 2013);
- The Beach Litter Survey Methodology developed by the CSIRO (Hardesty et al., 2014; van der Velde et al., 2016); and
- The Emu Parade Protocol developed by the CSIRO (Hardesty et al., 2014).

Other methods reviewed were:

- An Excel Workbook developed by CSIRO for the for Maldives community-based tarball monitoring; and
- The University of Georgia and United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) developed phone app to record marine debris (http://www.marinedebris.engr.uga.edu).

Aspects of these methodologies were analysed to determine if they captured sufficient information to effectively categorise the beaches being surveyed and record the nature and abundance of the bitumen strandings found.

The SCAT method for assessing shoreline oiling conditions was developed for that purpose alone and did not capture the degree of beach character information required for the beach survey. The SCAT method of segmenting beach morphology and detailing tidal zone widths was considered useful and was included in the beach survey protocol developed for the project (NOAA, 2013). The SCAT protocol, however relied upon the transcription of hand written data sheets post survey, which was considered inefficient.

The Excel Workbook developed for the Maldives community-based tarball monitoring surveys did not improve on the SCAT methods for a beach survey, relied on the transcription of data post survey and was not considered further.

The University of Georgia and NOAA developed app to record marine debris was limited in the information it contained, although it is a more reliable method of capturing data than transcribing hand written notes.

The CSIRO debris survey method of categorising environmental conditions, beach character, beach features and debris was considered useful and as such was also adopted, and heavily adapted for, the beach survey protocol developed in this project. The same terminology for beach gradient, substrate, backshore, beach shape and aspect, plus the same categorisation of debris type, colour and size were used to maintain a link between the two prospective debris data sets. Elements of this approach not implemented in the beach survey protocol developed for this project was the practice of surveying only a small number of transects which extended from the backshore to the water. The beach survey protocol instead used the Emu Parade method of walking the beach in a line extending from the water to the backshore and moving along the beach parallel to the water. Surveying the wider beaches was accomplished by surveying the upper-shore whilst walking along the beach, then the lower shore when walking back to the starting location. Figure 18 shows the team walking the upper beach during the survey.

**Figure 18: Project 5.2 team walking the upper-beach during the survey.**

Identification of an asphaltite, tarball or other potential sample type required a sample ID to be generated and then data to be associated with the sample ID such as the description of the location, a global positioning satellite (GPS) fix, an initial interpretation of type as well as photographic record (Figure 19). In addition this allowed the ability to generate a Chain of Custody report prior to the samples being shipped to the analysing laboratory which was required.

**Figure 19: Investigation of a bitumen sample.**

These data collection requirements for the beach survey required a more efficient method of data capture than transcribing hand-written field data sheets. In order to put all these desired aspects of a beach survey together, a Microsoft Access database application was developed to record all the various data types via a series of simple-to-use data entry form, which incorporated the ability to acquire real time GPS coordinates. This Microsoft Access database was based on a prior CSIRO data record structures and Figure 20 shows a typical data entry form for the CSIRO developed beach survey database system.

The beach survey database forms were very similar in function to those used in the Canadian personal digital assistant (PDA) system (Lamarche., 2004), but were easier to view and had the advantage of direct text entry.

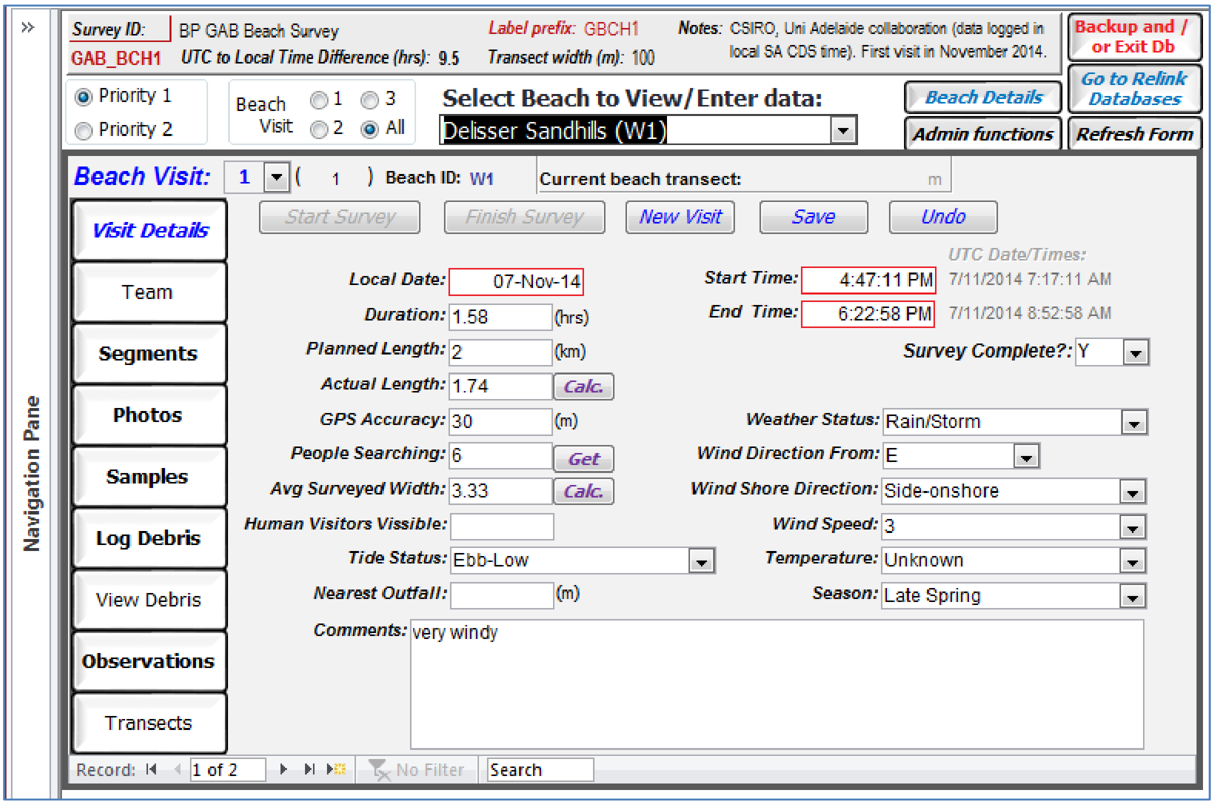


**Figure 20: Data entry form for the CSIRO developed beach survey database system.**

## Materials and metadata logged

When each beach was surveyed for a particular visit, several sets of data were entered into the database. These data sets were:

- Environmental and geological details
- Survey team members
- Photographs
- Bitumen samples
- Debris found
- Other observations
- Transects logged along the beach

For each visit, data on the environmental conditions found at the beach at the time of the survey were entered. These included:

- Date and time at the start of the survey
- Time at the end of the survey
- Planned and actual survey duration and distance
- Number of people in the survey team
- The state of the tide, weather, wind, temperature and season

For the proposed length of each beach to be surveyed, the general morphology was taken into account. If the part of the beach being surveyed comprised differing morphologies, each morphological section was deemed to be a separate "Segment" and information on each segment was entered into the database. This included:

- Date at the start of the segment
- Time plus latitude and longitude at the start and end of each segment
- Gradient of the beach
- Substrate type and colour
- Backshore type
- Beach shape and aspect
- Wave description
- Intertidal zone widths

All subsequent data entered for the beach was logged to a "Transect" along the beach. A transect ran for a set distance along the shore and extended from the water line to the back shore.

Logging to transects was not implemented for the 2014 surveys. The length of each transect was manually determined to be as close as possible to 100 m during the 2015 surveys. The transect lengths were automatically set to 100 m during the 2016 surveys. Due to time limitations in 2016, only one transect was planned to be logged for debris on each beach. However, technical issues sometimes resulted in unreliable transect lengths and some beaches were not logged for debris.

As each survey was being undertaken, data were entered for:

- Photographs at the start and end of each beach segment
- Bitumen samples found
- Debris found
- Environmental observations of interest

### *Photographs*

A set of photographs were taken for each beach segment to record any changing conditions between years. The set consisted of:

- Towards the sea
- Towards the backshore
- Along the beach
- Back along the beach at the end of the segment

### *Samples*

Date, time and location details for any bitumen samples collected were entered. Each sample was given a unique sample identification number and classified as one of the following major types:

| | | |
|---|---|---|
| Asphaltite | | Seaweed |
| Greasy Bitumen | | Sooty Bitumen |

| | | |
|---|---|---|
| Peat | | Unknown |
| Resinite/Amber | | Waxy Bitumen |

Hyperlinks to photographs taken of the sample in the field at the time of collection and later under laboratory conditions were also included.

### *Debris*

At the beginning of the project, a decision was made to log any debris encountered which had been washed up on the shore for the length of the survey as a proxy for surface drifters. Debris was logged according to type, colour and size consistent with the Beach Litter Survey methodology classes devised by CSIRO (O&A) in Hobart. All pieces for each type combination were totalled. Table 6 lists the different classes for each type that were used.

**Table 6: Classes of debris type, colour and size used to log debris encountered.**

| Debris Type | Debris Colour | Debris Size |
|---|---|---|
| **Cloth - String / Twine / Rope** | Black | 0-1 cm sq |
| **Foam - Other** | Blue/Purple | 1-2 cm sq |
| **Foam - Polystyrene** | Brown | 2-4 cm sq |
| **Glass - All** | Clear/Translucent | 4-8 cm sq |
| **Glass - Beverage Container** | Green | 8-16 cm sq |
| **Metal - Beverage Container** | Grey/Silver | >16 cm sq |
| **Metal - Fish Hook** | Orange | |
| **Metal - Hard** | Red/Pink | |
| **Metal - Soft Tinfoil** | White | |
| **Paper - Cigarette buts** | Yellow | |
| **Paper - Other** | | |
| **Plastic - Bags** | | |
| **Plastic - Beverage Container** | | |
| **Plastic - Film-like** | | |
| **Plastic - Fishing Line** | | |
| **Plastic - Hard** | | |
| **Plastic - Net** | | |
| **Plastic - Other Soft** | | |
| **Plastic - String / Twine / Rope** | | |
| **Rubber - Balloon** | | |
| **Rubber - Other items** | | |
| **Wood - Posts / Beams / Ship Hull** | | |

Consistent across all years, the most commonly encountered class of debris was varying size and colours of hard plastic and plastic rope. All types of debris listed above were seen along the beaches at some time.

During the 2014 survey, all debris counted was logged against the whole beach surveyed. No attempt was made to define where along the beach pieces were found. Most beaches were populated with debris to varying degrees, although two beaches had notably heavier numbers of debris – mostly hard plastic and rope. This may have been due to the time of year - November being three months after the major winter storms.

During the 2015 survey, a system of logging to 100 m transects was implemented, so that debris was located against separate transects. For nearly all beaches, the amount of debris seen was often two or more times what was encountered in 2014. This again could be due to the time of year – September being closer to the winter storms. A few beaches still had notably more debris than the others.

During the 2016 survey, to reduce the amount of time it took to log debris, only one randomly selected transect along each beach had debris logged. Due to technical or beach access issues, not all beaches had debris logged. Numbers of pieces encountered were mostly comparable to or more than those seen in 2015 and could have been affected by the large storm from the month before. Noticeably, some beaches had less debris and a few still had notably more debris than the others.

**Table 7: Number of pieces per 100m surveyed for hard plastic and plastic rope debris.**

| BEACH | HARD PLASTIC | | | PLASTIC ROPE | | |
|---|---|---|---|---|---|---|
| NAME | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| 28 Mile Crossing | 7 | 41 | 73 | 3 | 4 | 27 |
| Avoid Bay | 14 | 68 | 125 | 1 | 5 | 28 |
| Bales Beach | 21 | 48 | 11 | 8 | 13 | 3 |
| Beachport Conservation Park | 31 | 112 | NS | 7 | 15 | NS |
| Cactus Beach | 4 | 5 | 94 | 2 | 5 | 18 |
| Cape Bauer | | | 3 | | | 1 |
| Delisser Sandhills | 2 | 6 | 3 | 1 | 6 | 3 |
| Dogfence Beach | 26 | 11162* | NS | 11 | 211* | NS |
| Elliston | 4 | 13 | 7 | 1 | 2 | 1 |
| Eves Cove | 50 | 78 | NS | 5 | 2 | NS |
| Eyre Well | 3 | 30 | 15 | 4 | 14 | 9 |
| Fowlers Bay West | 0 | 1 | 1 | | 0 | 1 |
| Geltwood Beach | 55 | 784 | 47 | 44 | 39 | 13 |