Environmental geochemistry and marine (hydrocarbon) resources offshore Victoria and New South Wales: proposal for Rig Seismic Survey 126

by D T Heggie and G P Bickford

Record 1994/15

AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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Australian Geological Survey Organisation

Projects 121.37 and 121.40

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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. David Beddall, MP
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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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ISSN: 1039-0073
ISBN: 0 642 20228 1

Executive Summary

AGSO will undertake a multidisciplinary survey to south eastern Australia during April 1994. New initiatives will be conducted to expand the analytical capability of the AGSO continuous geochemical tracer (CGT) apparatus and hence demonstrate its application to both offshore resources and environmental monitoring. In particular the Marine Science Laboratories of the Victorian Department of Fisheries and Conservation will bring to Rig Seismic new technology to continuously profile seawater nutrients, chlorophyll and fluorescence (an empirical indicator of petroleum hydrocarbons). The NSW Environment Protection Authority, Marine and Estuarine waters section, will integrate a high precision CTD (conductivity. temperature/depth) unit into the AGSO DHD tow-fish for high precision tracer analyses of freshwater (ocean outfall) discharge. The main elements of the program include.

1. During the transit (Yarra River entrance to Point Lonsdale) of Port Phillip Bay, total hydrocarbons, seawater nutrients and hydrographic parameters will be measured. This work will complement the seafloor survey of Port Phillip Bay conducted by AGSO and colleagues earlier during the year. A transit past the Barwon Water (Geelong) ocean outfall at Barwon Head may be made, outside of Port Phillip Bay, to test if this discharge can be detected via multi-tracer techniques.

2. A survey will be conducted in the vicinity of a naturally occurring hydrocarbon seep site in the Torquay Embayment. Light hydrocarbons in bottom-waters and sediments will be measured and the physical environment around the seep will be documented. This work will be conducted with cooperation from Shell Australia and will complete the DHD evaluation of surface geochemical methods for application to offshore hydrocarbon resources in this area. The data collected also have environmental

application by documenting environmental conditions around a natural hydrocarbon seep site.

3. A survey will be conducted around select Bass Strait oil fields to test the Direct Hydrocarbon Detection (DHD) apparatus in tracing formation water discharge from petroleum platform installations. This work will be conducted with cooperation from Esso Australia.

4. A survey between Lake Illawarra and Sydney of the far-field distributions of ocean outfall discharge will be made. The ocean outfall at Billambi will be investigated and runoff from Lake Illawarra documented. Far-field observations of the Sydney ocean outfall discharges to the south will be made.

Near -field observations of the ocean outfall dispersion around Malabar (and perhaps North head) will be made. A variety of samples will be collected fro subsequent shore-based analyses. Similar observations will be made at an offshore reference station. This work will be conducted with cooperation from the NSW Environment Protection Authority and the Water Board.

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Introduction

The Australian Geological Survey has been conducting a variety of marine (hydrocarbon) resource and also environmental surveys from Rig Seismic over the past few years in south east Australia (e.g. Heggie & O'Brien, 1988; O'Brien et al., 1992; Bishop et al., 1992; Bickford et al., 1992; Heggie et al., 1993a,b). These surveys have utilised both seafloor sampling techniques for hydrocarbons, and continuous underway profiling in bottom-waters (Direct Hydrocarbon Detection), to assist in offshore petroleum exploration as part of the Continental Margins Program.

The potential application of continuous geochemical tracer (CGT) technology to a wide range of other resource and environmental issues in the marine environment was recognised, and during 1991 AGSO conducted a pilot survey to test if DHD technology could detect the ocean outfalls offshore Sydney. The results of this pilot study were successful and during 1992, AGSO conducted a survey with the Water Board (Sydney) to trace ocean outfall discharges in the coastal zone. This survey also conducted marine resource (hydrocarbons and seafloor minerals) observations offshore New South Wales with the University of Sydney (Dept. of geology and Geophysics) and the New South Wales Geological Survey (Bickford & Heggie et al., 1992).

The current program continues this work, and addresses some of the outcomes of these earlier surveys in some more detail, but also addresses additional marine environmental projects offshore Victoria. The continuous geochemical tracer technology utilised as part of the AGSO Continental Margins Program will be expanded in the current survey to include other oceanographic parameters to demonstrate the potentially wide range of measurements that can be conducted with this capability, and which have application to a wide range of marine environmental

and resource (both renewable and non-renewable) issues. To this end the Victorian Dept. of Fisheries and Conservation, Marine Science Laboratories at Queenscliff will be installing on Rig Seismic, for the duration of the survey, continuous seawater nutrient and chlorophyll profiling apparatus to document marine productivity, and other instrumentation which may be used to measure empirical indicators of petroleum in seawater.

Survey areas and primary objectives

The survey will collect data from the areas below to achieve the following overall objectives.

1. Port Phillip Bay

To determine the processes controlling the concentrations of extractable volatile hydrocarbon, dissolved nutrients oxygen and other oceanographic parameters in Port Phillip Bay. This is an opportunity basis survey to be conducted on the transit of Rig Seismic through Port Phillip Bay, and will be done in conjunction with the Victorian Dept. of Fisheries and Conservation. This work complements that conducted earlier during the year by AGSO and colleagues (Berelson, et al, 1994).

2. Torquay Embayment.

To examine processes controlling the light hydrocarbon concentrations and distributions in bottom waters and surface sediments at a known hydrocarbon seep site in the Torquay Embayment. This work has implications for using surface geochemical techniques as a hydrocarbon exploration tool to document hydrocarbon seepage from the seafloor. The work conducted here will also document the environmental effects

of natural hydrocarbon seepage from the seafloor. This work is being conducted with cooperation from Shell Australia..

3. Bass Strait oil fields.

To document the concentrations of light hydrocarbons around a petroleum production platform as a result of the discharge of formation water co-produced during the production process. A survey will also be made about a production platform which is currently not discharging formation water. The data collected will be compared to 'background' oceanic conditions. This work is being conducted with cooperation from Esso Australia.

4. Ocean outfall discharge offshore Wollongong and Sydney.

(i) To conduct pilot studies of ocean outfall discharge from Wollongong.
(ii) To test the far-field dispersion of the ocean outfall discharge from Sydney.
(iii) To conduct near-field dispersion experiments of the ocean outfall discharge from Malabar.

The survey is a multidisciplinary effort with cooperation from the following external Agencies including: the Victorian Dept. of Fisheries and Conservation, Marine Science Laboratories at Queenscliff; Esso Australia; Shell Australia; the Environment Protection Authority (New South Wales) Marine and Estuarine Waters Section and the Clean Waterways Unit of the Water Board (Sydney); the Universities of Sydney and New South Wales, and the Bureau of Resource Sciences.

Port Phillip Bay

The Port Phillip Bay is the subject of a interdisciplinary survey being conducted by the Melbourne Water Corporation to evaluate the potential impact of increased nutrient discharge to the bay. As part of this work the Victorian Dept. of Fisheries and Conservation have been monitoring the concentrations and distributions of dissolved nutrients in the bay. AGSO also contributes to this project and has been involved in an evaluation of the sediments and the role that the sediments play in regulating the concentrations of dissolved nutrients in the water column (Berelson et al., 1994).. The mini-survey to be conducted as the Rig Seismic transits Port Phillip Bay will complement this work.

Work program:

1. Dissolved nutrients (nitrate, nitrite, phosphate and ammonia and silicate), oxygen and hydrographic parameters (temperature and salinity) and light hydrocarbons (potential tracers of anthropogenic inputs into Port Phillip Bay) will be measured in the bay between the Yarra River (Victoria Dock area) and south channel and Bass Strait.. This transect will survey the salinity gradient between the riverine end-member and the oceanic source water for the bay.

2. When Rig Seismic leaves Port Phillip Bay, the ocean outfall operated by Barwon Water, and discharging into Bass Strait south of Barwon Head will be briefly surveyed for seawater nutrients and organics, en route to the Torquay.

Equipment required includes AGSO continuous geochemical profiling apparatus (DHD and CGT) combined with the MSL continuous nutrient profiler. All geochemical systems in the shipboard laboratory will be operating with samples

simultaneously being collected for subsequent shore-based analyses. The way -points for the survey are summarised in Table 1.

Table 1. Port Phillip Bay transit and beyond.

Way point	Lat. deg S	Long. deg E	Location
#1			Victoria dock
#2	38 02.3	144 13.00	SW PPB off Werribee
#3	38 09.2S	145 02.50	eastern PPB
#4			South channel and exit to Bass Strait
#5	38 17.908	144 25.243 (WGS 84)	Black Rock (Geelong) outfall

Torquay Embayment

AGSO has earlier conducted work with Shell Australia to survey a naturally occurring hydrocarbon seep site in the Torquay Embayment (O'Brien & Heggie, 1989; Bishop et al., 1992). That earlier work documented the occurrence of the seep location via high resolution seismic methods, side scan sonar, and bathymetric observations of the seafloor and DHD analyses of light hydrocarbons in the bottom-waters overlying the sediments. The thermogenic nature of the seep was confirmed from analyses of both the carbon isotopic composition and the radiocarbon composition of the methane. Other geochemical analyses conducted include the molecular compositions of light hydrocarbons separated from the top 1-4 m of sediments. These observations suggested that the molecular compositions of the light hydrocarbons in the sediments were distinctly different from those compositions measured in most other areas of the Australian continental margin surveyed as part of the Continental Margins Program. The significance of this result is that these parameters, notably the C2+ hydrocarbon compositions ethane/ethylene ratio and the propane/propylene ratio may be the only reliable indicators of migrated light thermogenic hydrocarbons in near-surface sediments. The isotopic composition of methane in bottom-waters of this area was indicative of migrated thermogenic hydrocarbons. However, this parameter is subject to potential artefacts, notably aerobic and anaerobic oxidation and the extent of this reaction (if it is occurring) in Torquay Embayment sediments is unknown.

Objectives:

1. To test if the isotopic and molecular compositions of light hydrocarbons in sediments of the Torquay Embayment are reliable indicators of migrated thermogenic hydrocarbons.

2. To test if the isotopic composition of digenetic carbonate in the sediments of the seep site are sensitive indicators of migrated thermogenic hydrocarbons.

3. To assess the environmental effects of natural hydrocarbon seepage on the immediate seafloor and water column environment.

4. To determine the Quaternary stratigraphy of the offshore Torquay Embayment.

Work program.

To achieve these objectives the work plan includes up to two days in this area.

1. Deploy DHD equipment into bottom-waters and also the high resolution seismic reflection equipment south of Barwon Head and survey to the seep location in the Torquay.

2. Collect a series of approximately 4-6 vibrocores from within the identified seep location and process and analyses these cores in the shipboard laboratory for light hydrocarbon geochemistry. Collect samples for methane isotope studies from the sediments. Collect samples for carbon isotopic compositions of dissolved carbon dioxide in pore waters. Collect samples for physical properties of sediments.

3. Collect cores from outside of the hydrocarbon seep site in an area of probable net Quaternary sedimentation for studies of stratigraphy and modern sedimentation processes (Sydney University).

4. Collect surficial sediment samples and photographs of the seafloor both within and outside of the hydrocarbon seep site and compare and contrast these sediments for environmental parameters.

Equipment required includes: DHD profiling, high resolution seismic, vibrocoring equipment, Van Veen grab, bottom-camera, other continuos profiling apparatus, sample collection apparatus in the geochemical laboratory, high speed centrifuge.

The way points for the survey and sampling in the Torquay are summarised in Table 2.

Table 2. Torquay Embayment sampling. Coordinates are relative to the ANS unless otherwise noted.

Way point	Lat. deg S	Long. deg E	Location
#1	38 28.00	144 25.00	north Torquay embayment
#2	38 40.328	144 07.333 (WGS-72	pock-mark
#3	38 40.288	144 07.375WGS-72	100 m NE of wp#2
#4	38 40.369	144 07.368WGS-72	100 m SE of wp#2
#5	38 40.356	144 07.281WGS-72	100 m SW of wp#2
#6	38 40.281	144 07.294WGS-72	m NW of wp#2
#7	38 40.00	144 25.00	central Torquay

Pilot study of Formation Water plumes in the Bass Strait

As the petroleum production from existing fields in Bass Strait declines, the amount of formation water produced with the petroleum is increasing. Today, the volumes of petroleum and formation water are about equivalent at 50-70 megalitre per day total. Discharge of formation water from Halibut is between 5-15 megalitre/day while that from Kingfish is about 8 megalitre/day. The formation water is discharged into the marine environment at relatively shallow depths of between about 10 and 30 metres water depths (depending upon the platform).

Modelling of the discharge from the Halibut Platform indicates that under prevailing oceanographic conditions, the concentrations of total aromatic hydrocarbons are diluted from concentration of about 15 mg/l at the platform to about 10 µg/l at a distance of about 1 km from the platform and to 1 µg/l at a distance of 6 km from the platform. The plumes, because of their relatively high temperature (up to about 90 degree C) and low salinity [<10 ppt to 35 ppt (typical seawater concentrations)] have been predicted to be buoyant and rise rapidly to the sea surface (<40 m from the platform), where they are dispersed by tidal currents and flow through the Bass Strait.

Some studies have been conducted by Esso and the Marine Science Laboratories of the Marine Resources Management Branch of the Victorian Dept. of Conservation and Fisheries (Queenscliff), and these are summarised in Terrens and Tait (1993). The findings of this work suggest that because of the high dilutions predicted from the model of plume dispersion, that the expected concentrations of (i) water soluble organic acids (ii) light aromatic hydrocarbons (dissolved and suspended) (iii) trace metals (iv) napthalenes and PAH's (polycyclic aromatic hydrocarbons) would not be high enough to be toxic to marine organisms.

Objectives:

The primary objectives are:

1. To test if the CGT capability (primarily the DHD) can trace the formation water discharge from a production platform nominated by Esso.

2. To determine the distributions of benzene, toluene, ethyl benzine and xylene in the vicinity of a platform and their reactivity in the surrounding seawater.

The rationale behind the proposed program includes the following:

(i) Light hydrocarbons, notably methane and the saturated C2 through C8 hydrocarbons are probably concentrated in formation water and will be used to detect the formation water plume and trace its distribution in the surrounding seawater. Light hydrocarbons and other organic compounds are non-conservative and their distributions are controlled by mixing, transport and reaction (e.g volatilisation and for the heavier aromatic compounds, perhaps concentration and removal by settling particles).

(ii) Hydrographic parameters (salinity and temperature) are conservative (ie controlled by mixing processes) and may be used to assess both the dilution and the reactivity of organic compounds of interest. However, the expected concentration differences between the salinity and temperature of seawater and the formation water plume are not expected to be large and therefore these parameters are probably not sensitive indicators of the plumes. However, other dissolved components in the plume, notably iron and manganese may be useful pseudo conservative tracers (over relatively short time-scales), and if measured may be used to assess the reactivity of the potential toxic aromatic hydrocarbons. Based upon the possible relative concentrations of compounds in formation water and seawater, other potential conservative tracers of the formation water plume include lithium, boron, calcium, magnesium and sulphate

and, we suggest that these be measured on a select basis in some samples of collected seawater.

(iii) Thermogenic methane and biogenic methane have distinctly different carbon isotopic signatures, including the radiocarbon contents. Similarly the isotopic (and radiocarbon) compositions of inorganic carbon dioxide in seawater and formation water are expected to be distinctly different and we suggest some measurements of these parameters are potential sensitive tracers of the formation water plumes.

As part of a pilot study it is recommended that some of these noted above be determined on a limited basis to test if these can be used as conservative tracers of mixing and dilution and of the reactivity of the BTX's. (benzene, toluene, xylene and ethyl benzene).

Formation water and natural hydrocarbon seepage.

Earlier surveys in the Bass Strait found evidence of light hydrocarbon anomalies in bottom-water that may have been related to hydrocarbon seepage across the seafloor. However, because of the discharges of formation water in this area, the interpretation of bottom-water anomalies remains ambiguous.

However, formation water plumes would be expected to have a different chemical composition (other than light hydrocarbons) than natural seepage, which is probably comprised, for the most part, of light hydrocarbons only. If time permits a small survey will be conducted in an area of previously defined bottom-water anomalies (between Sunfish and Tuna and to the north towards the Wahoo exploration well), to collect seawater samples for analyses of other dissolved components. The contrasting chemical compositions of formation water (other than hydrocarbons) and natural

seepage may be useful in the application of surface geochemical techniques to offshore hydrocarbon exploration. This work will complete the evaluation of DHD techniques.

Table 3 Table 1. Potential tracers of formation water plumes.

Analyses	Rationale	Measurement Agency
Light saturated hydrocarbons C1 through C8.	Tracers of formation water plume	AGSO and CGT apparatus
Light unsaturated hydrocabns C2&C3	Tracers of biogenic activity	AGSO and CGT apparatus
Benzene, toluene, ethyl benzene and xylene (BTX'S)	Potential marine toxicants	AGSO and CGT apparatus
Temp, salinity, DO, pH	Potential tracers of formation water plume	AGSO and CGT apparatus
Seawater nutrients	Ammonia may be a tracer of formation water	Vic. Conservation MSL
Seawater fluorescence	Potential empirical tracer of 'total oil'	Vic. Conservation MSL
Fe, Mn, Li, B, Ba, Mg, Ca, S,	Potential 'pseudo-conservative' tracers of formation water plume	By contract and analyses of discrete seawater samples collected from the CGT apparatus.

Isotopic and radiocarbon contents of methane and carbon dioxide	Tracers of formation water plumes	NIWAR in New Zealand. by contract

Work program.

The final work program will be decided in consultation with Esso Australia, and will include some combinations of the following. The survey will be conducted in the vicinity of Kingfish B and West Tuna.

Vertical profiles of hydrocarbons

1a To determine the vertical distributions of light hydrocarbons (and hydrographic parameters temperature, salinity, oxygen, pH and turbidity) in seawater at a distance of approximately 500 m radially from the platform in that direction predicted by the dispersion model used by Esso under the prevailing oceanographic conditions.

1b. To determine the vertical distribution of parameters noted above at distances of approximately 100m, 500 m, and 1 km downstream of the platform in the direction predicted by Esso under the prevailing oceanographic conditions or otherwise determined.

Horizontal profiling of light hydrocarbons

To determine the concentrations and distributions of those parameters noted radially around nominated platforms at distances of about 1 km. These radial distributions of light hydrocarbons will be collected at the surface and also at mid-water depths.

To determine the concentrations and distributions of those parameters noted above along a line downstream (up to about 6 km) of the predicted direction of plume dispersion under the prevailing oceanographic conditions. The tow-fish would be set at the depth of maximum hydrocarbon concentrations found in the vertical profiles. Model predictions suggest this would be a surface water transect.

Other data collection

To collect from each of these vertical profiles and transects discrete water samples for subsequent laboratory analysis of other potential conservative tracers of formation water plumes (shown in Table 1), that assist in quantitatively determining dispersion of the plume and the reactivate of BTX compounds in the plume.

Equipment required includes all DHD apparatus and other continuous profiling equipment installed for this survey.

Ocean outfall discharges offshore New South Wales

This survey will continue that work conducted earlier on Rig Seismic surveys 104 (september 1991) and 112 (september 1992). However, this new study will expand the scope of the original work by conducting preliminary observations of outfall discharge from outfalls at Wollongong, and the possibility of outflow from Lake Illawarra. New observations of far-field dilution will be made of the Sydney ocean outfall discharges and some detailed experiments focussed on near-field dispersion around the Malabar (an perhaps the North Head) outfalls will also be made. These are documented below. These experiments will be conducted jointly with the NSW Environment Protection Authority (Marine and Estuarine Waters Section) and the Water Board (Clean Waterways Unit), and one part of the work described here forms part of a Joint AGSO/WB project into the effects of organic enrichment on the sediments offshore Sydney.

Far-field observations of ocean outfall discharge.

Earlier work on the ocean outfall discharges offshore Sydney documented the light hydrocarbon concentrations and distributions as potential tracers of the effluent discharge into the sea. The outfall discharge from Malabar (or the collective discharge from the three outfalls offshore Sydney) were detected off Port Hacking, some seven nautical miles south of the Malabar outfall. The survey during 1992, was not intended to trace this discharge further south, but rather to test and quantify, using geochemical tracers, how the effluent could be traced. The far-filed discharge from Sydney will be examined as part of this survey.

Objective: 1. To make a preliminary examination of the dispersion of surface runoff form Lake Illawarra and the ocean outfall discharges in the Wollongong area.

2. To test if light hydrocarbons, notably the methane concentration and distributions are sensitive tracers of the far-field dispersion of the sewage outfall discharge off Sydney, and if dispersion from the outfalls is reflected in the dissolved nutrient concentrations of near shore oceanic waters.

Work program

1. Near Lake Illawarra, and around the Wollongong area, preliminary observations of surface water runoff from Lake Illawarra will be made and a zig-zag survey pattern will be begun to make preliminary observations of ocean outfall discharge from those outfalls in the Wollongong area (Table 4).

2. Using the DHD continuous geochemical profiler in a pogo fashion, between water depths of 0-60 m, test for if far-field dispersion of outfalls from Sydney is evident in the light hydrocarbon distributions. Dissolved seawater nutrients will also be monitored during this survey to test if outfall discharge is detectable in the dissolved nutrient inventory in seawater. Shown in Figure 2 is a proposed cruise track between Lake Illawarra and Manly, including the transit over the three Sydney discharges. The way points for this survey are summarised in Table 4. Vertical profiles of hydrographic parameters salinity and temperature, dissolved oxygen will be made with the EPA high precision CTD unit.

Near-field observations of ocean outfall discharge.

Objective: To examine the near-field reactivity and hence dispersion of a variety of constituents discharged into the sea off Sydney.

Work Program

To examine the reactivity of primarily nutrients (i) vertical profiles will be conducted in the immediate vicinity of the Malabar outfall, and (ii) a tightly gridded contour will be conducted at two water depths (surface and mid-water) around the Malabar outfall, at km scales.

This work will be conducted around at the Malabar ocean outfall and if time permits similar experiments will be conducted at North Head.

Vertical profiles of dissolved and suspended particulates in the water column.

A vertical profile will be conducted directly over one of the diffuser outlets. The positions of these are summarised in Table 5. The vertical profile will be conducted using the AGSO CGT continuous profiler, and this will include the EPA high precision CTD. The outcome of this experiment depends upon sampling within the salinity gradient near the ocean outfalls where the freshwater effluent is mixed with seawater. The Water Board Clean Waterways Unit will be beginning a study to document the concentrations of a variety of elements in the effluent and these data will be one important end-member for this work. At closely spaced intervals (5 or 10 m) seawater samples will be collected in the ship laboratory and filtered and both the filtrate and suspended particulates analysed for nutrients. Hydrographic parameters will be measured and the light hydrocarbon distributions and nutrient distributions (on unfiltered samples) will be continuously monitored.

Two vertical profiles will be occupied near Malabar - one directly over the outfall while the other will be approximately 200- 500 m downstream of the outfall (optional). An offshore station will be occupied to document 'background' concentrations of all species measured.

Similar experiments will be conducted at the North Head ocean outfall if time permits, notably the vertical profile directly over the outfall.

Near-field Horizontal contouring.

As part of the near-field dispersion experiment some horizontal contouring will be conducted, probably in the vicinity of Malabar. Rather than try to document the down-stream dispersion of the effluent, this experiment will focus on the onshore/offshore component, as these gradients, because of lateral, rather than longitudinal dispersion, might be expected to be more contrasted over relatively short distances than gradients downstream of the outfall. The proposed sampling grid is shown in Table 5. We propose a grid of survey lines 4 nm in an onshore/offshore direction spaced 0.25 nm apart. We propose to survey at about 3 knots. Light hydrocarbons, hydrographic parameters(Yeo-Kal CTD) and dissolved seawater nutrients will be measured, and seawater samaples will be collected for subsequent shore-based analyses.

Estuarine runoff into the coastal zone.

As part of our initial work offshoe Sydney, the runoff from estuarine areas, Botany Bay and Port Jackson, could be distinguished from the ocean outfall discharge on the basis of the different light hydrocarbon compositions. To continue to test this idea select vertical profiles of light hydrocarbons, and oceanographic parameters, will be collected at sites previously occupied.

Offshore NSW work program summary

1. Conduct DHD observations between Lake Illawarra and Manly using the DHD towfish in pogo mode.

2. Conduct near-field observations around the Malabar ocean outfall by horizontal profiling (surface and mid-water depths) the DHD tow-fish and collecting water samples in the laboratory for subsequent shore-based analyses. Detailed nutrient and chlorophyll analyses will be conducted on this survey.

3. Transit to an offshore station and en-route install the EPA high precision CTD unit into the DHD tow-fish.

4. Conduct a vertical profile of light hydrocarbons and nutrients at the offshore location collecting samples for shore-based analyses of particulates, and also samples for isotopic compositions. A vertical cast for zooplankton populations will be conducted at this site from the hydro-wire (UNSW/WB cast).

5. Transit to Malabar ocean outfall and locate Rig Seismic directly above an outfall diffuser. Conduct a vertical profile for light hydrocarbons, nutrients and hydrographic parameters and collect seawater samples for shore-based analyses. Conduct a similar vertical profile approx 250 m south of the Malabar outfall, or see item 6 below (optional).

6. Transit to the North Head ocean outfall and conduct a detailed vertical profile as outlined in 5 above.

7. Conduct vertical profiles of light hydrocarbons at sites previously occupied near the entrances to estuaries and offshore Kurnell, namely AGSO sites 18, 17, 4 from Rig

Seismic survey 112.

Table 4 List of proposed way-points for the transit between Lake Illawarra and Manly for the far-field observations.

WP#	LAT degS	LONG deg E	LOCATION and WATER DEPTH
#1	34 32.5	150 53.40	Lake Illawarra entrance; approx 20 m
#2	34 24.5	151 04.50	offshore Wollongong; approx 100 m.
#3	34 22.0	150 56.80	Bellambi outfall; approx 16 m
#4	34 17.5	151 07.2	offshore Scarborough; approx 100 m
#5	34 14.2	151 07.00	Stanwell Par; approx 20 m
#6	34 10.0	151 09.80	offshore Wattamolla; approx 100 m
#7	34 05.0	151 11.60	Port Hacking entrance; approx 30 m
#8	34 03.0	151 16.20	offshore Kurnell; approx 100 m
#9	33 58.5	151 17.85	Malabar outfall; approx 80 m
#10	33 53.5	151 20.00	offshore ORS; approx 80 m
#11	33 49.4	151 20.30	Nth Head outfall; approx 60 m

Table 5. Way points for the near-field observations around the Sydney outfalls.

Line #	Latitude deg S	Longitude deg E
LINE 1 SOL	-33 57 36.0156	+151 17 20.4101
LINE 1 EOL	-33 58 45.6939	+151 21 56.6094
LINE 2 SOL	-33 57 50.3967	+151 17 15.1775
LINE 2 EOL	-33 59 00.0781	+151 21 51.3882
LINE 3 SOL	-33 58 04.7776	+151 17 09.9440
LINE 3 EOL	-33 59 14.4625	+151 21 46.1665
LINE 4 SOL	-33 58 19.1585	+151 17 04.7100
LINE 4 EOL	-33 59 28.8465	+151 21 40.9443
LINE 5 SOL	-33 58 26.3489	+151 17 02.0926
LINE 5 EOL	-33 59 36.0385	+151 21 38.3332
LINE 6 SOL	-33 58 33.5393	+151 16 59.4755
LINE 6 EOL	-33 59 43.2305	+151 21 35.7216
LINE 7 SOL	-33 58 47.9201	+151 16 54.2405
LINE 7 EOL	-33 59 57.6144	+151 21 30.4984
LINE 8 SOL	-33 59 02.3011	+151 16 49.0051
LINE 8 EOL	-34 00 11.9982	+151 21 25.2747
LINE 9 SOL	-33 59 16.6817	+151 16 43.7691
LINE 9 EOL	-34 00 26.3820	+151 21 20.0506
LINE 10 SOL	-33 59 31.0622	+151 16 38.5327
LINE 10 EOL	-34 00 40.7657	+151 21 14.8264
LINE 11 SOL	-34 01 11.7244	+151 16 01.8645
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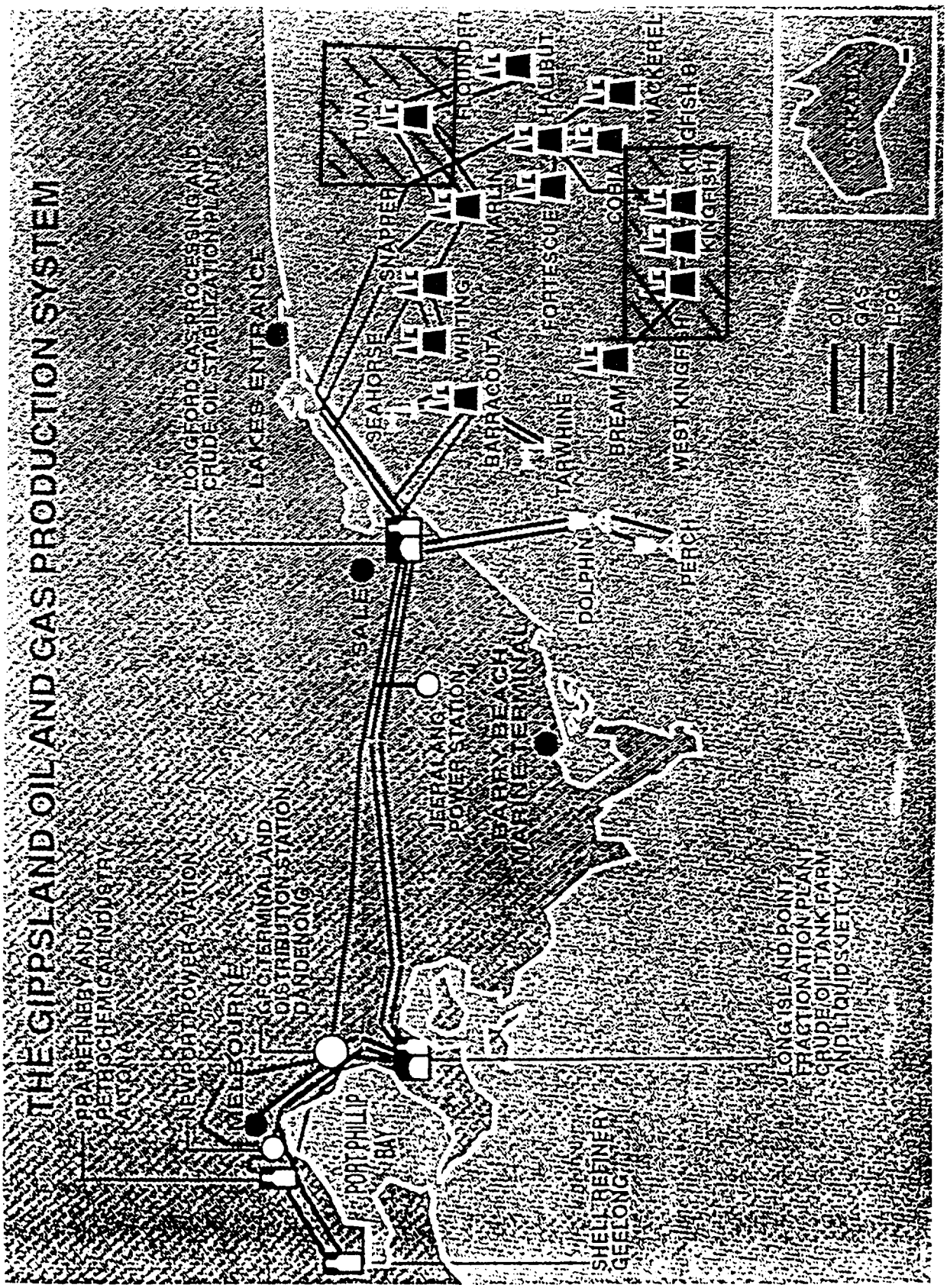

Figure 1. Map of the Gippsland oil-fields and proposed location of survey.

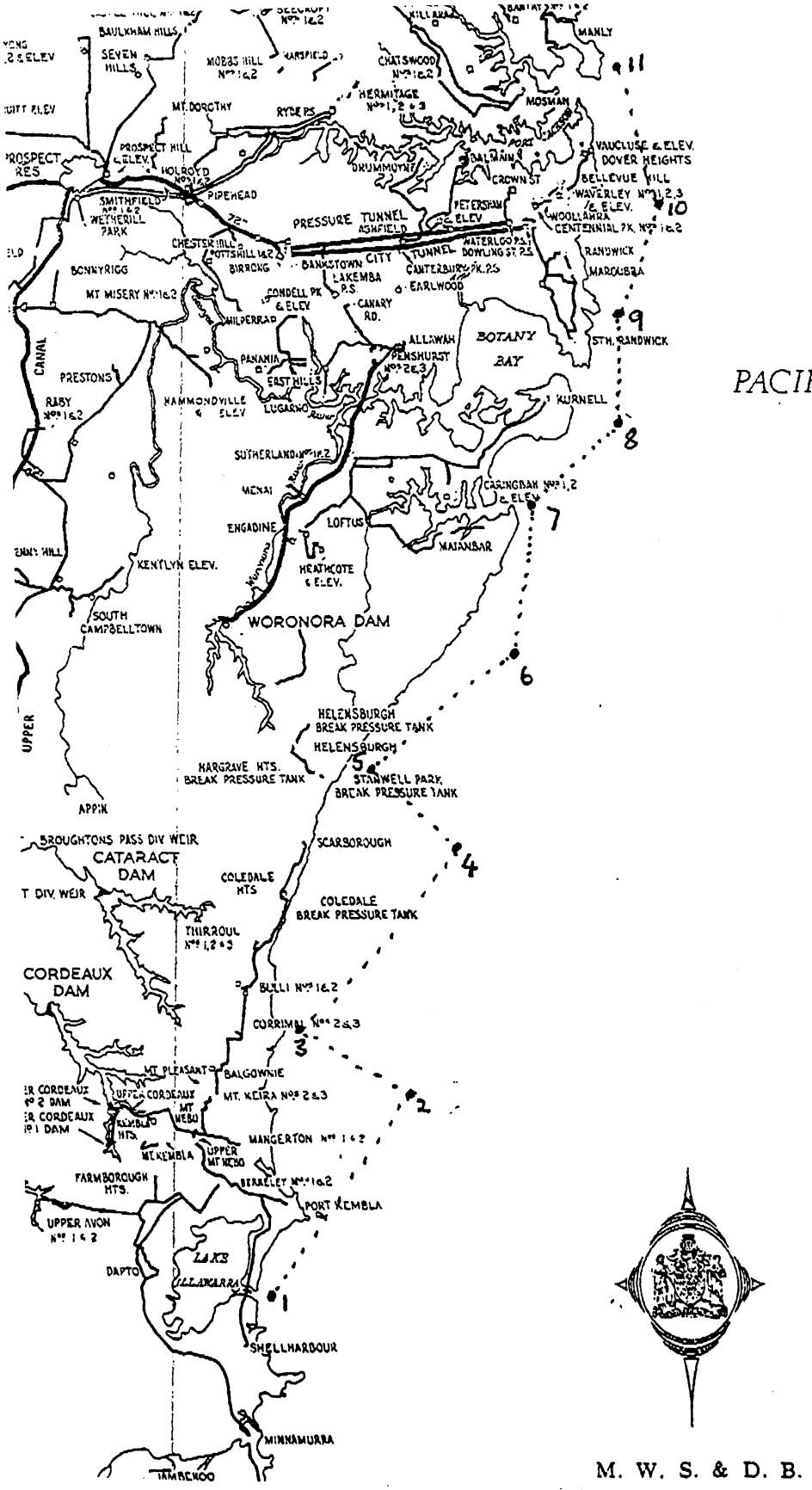

Figure 2 Map of the proposed cruise track between Lake Illawarra and Manly.

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