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The petroleum potential of onshore Tasmania: a review

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Summary

Onshore exploration for petroleum hydrocarbons in Tasmania has continued intermittently for nearly a century. Despite this exploration there has been no production of hydrocarbons, other than from small-scale retorting of oil shale.

Historically, exploration interest has been driven by the reported presence of oil and gas seeps; very few of over a hundred reports of seeps may be regarded as genuine. However, onshore Tasmania remains under-explored for hydrocarbons, and there has been almost no application of modern exploration methods such as seismic reflection.

Broadly speaking, there are two sedimentary rock successions that are potentially prospective for hydrocarbons:

- a folded lower Palaeozoic succession, the Wurawina Supergroup; and
- a flat-lying Carboniferous to Triassic succession, the Parmeener Supergroup, that comprises the sedimentary fill of the Tasmania Basin.

Small onshore Tertiary basins lack sufficient thickness of sediment to have attained hydrocarbon maturation temperatures.

Two corresponding petroleum play concepts have been the subject of recent exploration interest in onshore Tasmania. Firstly, a hypothesised Ordovician carbonate source may have charged lower Palaeozoic reservoirs during a mid-Devonian thermal maximum, and possibly also sub-unconformity traps and Permo-Carboniferous reservoirs in the overlying Tasmania Basin after later migration or during a second, post-Permian period of deep burial. Ordovician carbonate rocks have reached oil and gas-window temperatures under parts of southern Tasmania and are overmature in western Tasmania. The carbonates locally contain pyrobitumens but viable source rocks have yet to be identified.

The second, wholly intra-Tasmania Basin play, involves a lower Permian source charging lower Permian to lower Triassic sandstone reservoirs during maximum burial in the Jurassic–Cretaceous. Potential source rocks comprise tasmanite (an oil shale rich in the fossil alga *Tasmanites*) and the enclosing, moderately organic-rich mudstone of the Woody Island Formation and correlates. The tasmanite is an exceptionally rich, oil-prone potential source rock, but is thin and limited in areal distribution. One oil seep has been geochemically linked to a *Tasmanites*-rich source.

New Rock-Eval data from the Woody Island Formation shows it to be a lean, gas and liquid prone, potential source rock. The Woody Island Formation correlative is immature in the northern part of the basin, but has attained oil- and early gas-window temperatures in the central and southern parts of the basin. Recent apatite fission track analysis suggests a Cretaceous thermal maximum. Burial history modelling shows that the lateral variation in thermal maturity is consistent with known variation in original thickness of the basin fill, which is now largely eroded.

Virtually every part of the Tasmania Basin has been intruded by at least one, and up to three, thick (ca. 400 m) Jurassic dolerite sheets. The dolerite intrusions may have locally matured host rocks to within or past the ‘oil window’. The sheets may act as a semi-regional seal. Complex intrusion forms, combined with Jurassic to Early Tertiary normal faulting, result in considerable structural complexity in the Tasmania Basin. The younger faults pose a risk to seal integrity.

The depth of erosion of the Tasmania Basin, and the presence of widespread dolerite, mean that the design and location of future prospect generation seismic surveys will probably rely on surface mapping and modelling of subsurface intrusions from magnetics and gravity data, to a much greater degree than is the general case for Australian onshore basins.

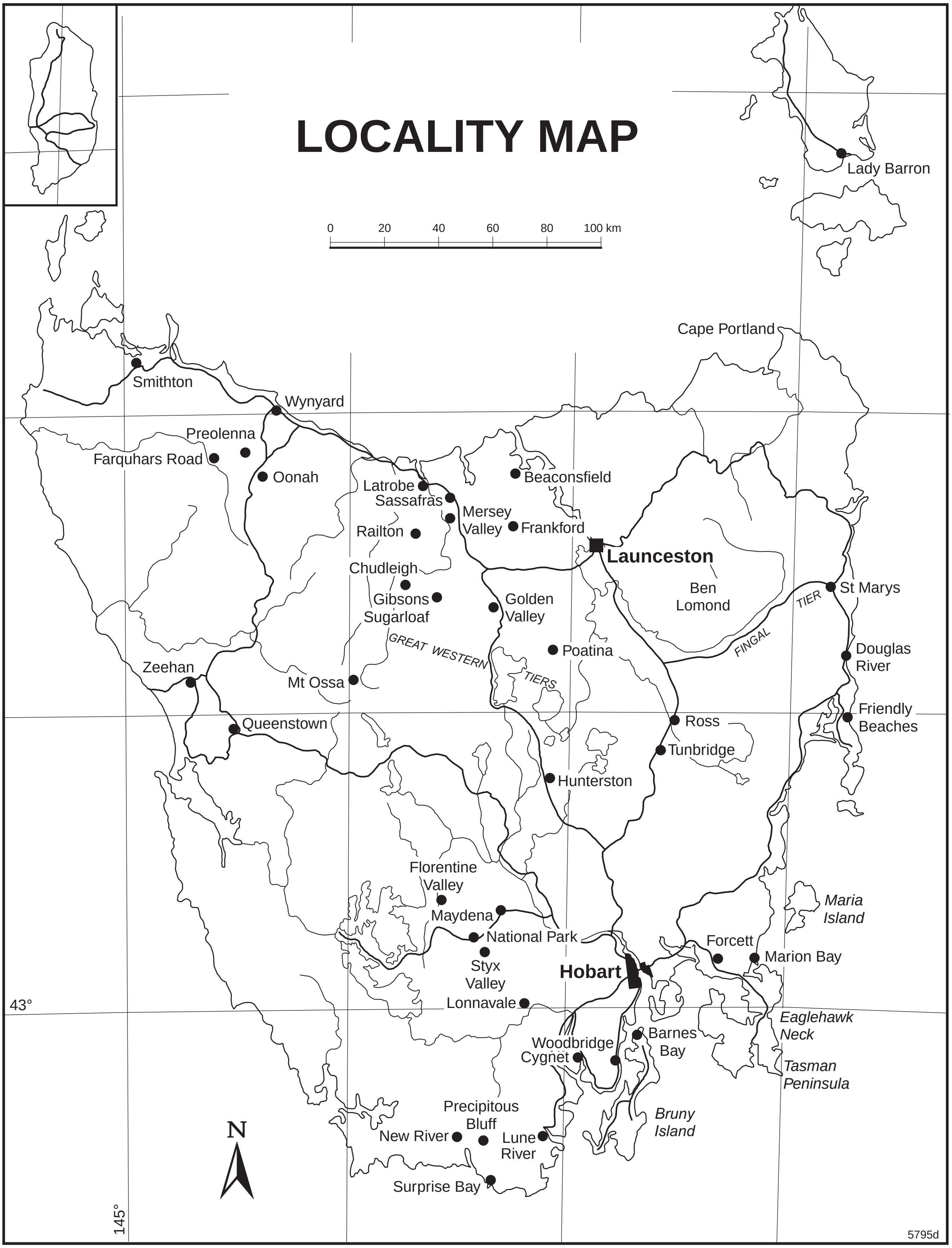
LOCALITY MAP
0 20 40 60 80 100 km
Lady Barron
Cape Portland
Smithton
Wynyard
Preolenna
Farquhars Road
Oonah
Latrobe
Sassafras
Beaconsfield
Mersey Valley
Frankford
Railton
Launceston
Chudleigh
Gibsons
Sugarloaf
Golden Valley
Ben Lomond
St Marys
TIER
FINGAL
GREAT WESTERN
TIERS
Poatina
Douglas River
Zeehan
Mt Ossa
Queenstown
Ross
Friendly Beaches
Tunbridge
Hunterston
Florentine Valley
Maydena
Maria Island
National Park
Forcett
Marion Bay
Styx Valley
Hobart
43°
Lonnavale
Eaglehawk Neck
Woodbridge
Cygnet
Barnes Bay
Tasman Peninsula
Precipitous Bluff
Bruny Island
N
New River
Lune River
Surprise Bay
145°
5795d

Figure 1

Introduction

This bulletin is the first review of the petroleum prospectivity of onshore Tasmania to be undertaken by the Tasmanian government in nearly eighty years. In this bulletin, the history of the search for oil is outlined, followed by a review of the geological setting and distribution of potential source and reservoir rocks, the geochemistry of source rocks, and the timing and level of maturation. Exploration issues pertaining to the Tasmanian environment are discussed.

Twelvetrees (1917) was the first government geologist to review Tasmania's oil potential. He noted that while there were no undoubted surface indications of oil or gas, there was a chance of finding oil in the onshore Tertiary basins and in the 'Gondwanaland beds' (i.e. Parmeener Supergroup) of the Midlands. Prospecting for surface seeps followed by 'geologically correct' drilling was recommended. In contrast, Hills (1921*a*, 1922) was emphatic that there was no possibility of finding liquid oil over most of Tasmania (including the Tasmania Basin). This was because of a perceived absence of compressional tectonism in the Tasmania Basin rocks, which was then thought to be a pre-requisite for both the generation and storage of hydrocarbons.

Within the last twenty years, there has been a renewed interest in onshore Tasmanian petroleum prospectivity, and exploration licences for petroleum have been held almost continuously over parts of the Tasmania Basin. During this time a number of assessments of petroleum prospectivity have been undertaken, nearly all in the form of unpublished company reports or university theses (Summons, 1981*a*; Wiltshire, 1980; Mulready, 1987; 1995; Leaman, 1990; Bendall *et al.*, 1991; Carne, 1992; Woods, 1995; Young, 1996; Burrett, 1996; 1997*b*). It is therefore timely to publish a collation and review of current information pertaining to the search for hydrocarbons in onshore Tasmania.

History of Petroleum Exploration Onshore Tasmania

INTRODUCTION

Traces of petroleum hydrocarbons have been found in a number of rock types in Tasmania for over a century and this has led to some optimistic efforts to search for economic oil accumulations onshore. Many surface seeps of oil and gas have been reported, although subsequent investigation has usually shown that the reported observations are not indicative of petroleum hydrocarbons. Pieces of transported asphaltum have also been found at various localities around the Tasmanian coastline. Gas shows have recently been reported from exploratory drill holes in southern Tasmania.

Apart from the retorting of oil shale, petroleum has never been produced in Tasmania, but it is known to occur in the offshore Bass Basin, where exploration commenced in 1961. Appendix 3 lists offshore wells drilled in Tasmanian waters to date.

Small deposits of Late Carboniferous oil shale (tasmanite) in northern Tasmania have been investigated on several occasions as a potential source of hydrocarbons or road bitumen, and the shale has been mined intermittently since the 1860s. During the 1930s a number of experimental retorts were used by different companies to produce a variety of fuels and fuel products, although none of the retorts operated as a commercial success.

The oil in the shale is derived from microfossil algal cysts or algal bodies, which release hydrocarbons when heated. Recent exploration has indicated *in situ* resources of 40 million tonnes of oil shale near Latrobe, although no commercial application exists for the products which can be produced. A detailed history of the search for oil shale is given in Bacon (1986), and photographs of various distilling works are shown in Plates 1 to 7.

Given an appropriate thermal history, many source rocks may eventually yield some petroleum hydrocarbons. Traces of oil have been reported in a number of Tasmanian rocks such as Gordon Group limestone, the Woody Island Siltstone and the tasmanite, which sometimes smells petroliferous when pieces are freshly broken.

There is, however, no essential link between recognition of trace quantities of petroleum hydrocarbons in a rock and establishing a commercially viable oil/gas field. Many factors must first be assessed and confirmed.

In this section the historical reports of occurrences of oil and gas in onshore Tasmania are reviewed and some explanations are offered for the various historical observations.

SEEPS AND GAS SHOWS: HISTORICAL SIGNIFICANCE

The existence of petroleum deposits has been noticed in many places by individuals first finding petroleum or gas oozing from the earth as a 'seep'. Natural seeps have been used as a source of bituminous materials for building purposes, medicine and lighting for millennia[1].

Ancient peoples referred to the products from oil seeps as bitumen, slime or pitch. The Bible records that the

Vale of Siddim was full of slime pits (i.e. bitumen deposits) and that the Kings of Sodom and Gomorrah fled and fell there (*Genesis* 14:10). The basket in which Moses lay among the bulrushes was waterproofed with bitumen (*Exodus* 2:3), as was Noah's Ark which was "pitched within and without" (*Genesis* 6:14). Centuries later Columbus waterproofed his ships with pitch from Trinidad. The crew of *Beagle* used finds of bitumen to waterproof their ship in 1839, after finding fragments of bitumen while drilling for water in the tidal reaches of the Victoria River, Northern Territory[2].

The famous Greek historian Herodotus (circa 484–424 BC)[3], known as the 'Father of History', recorded the existence of oil pits near Babylon. Even earlier, the Pharaoh Thothmes III exacted a tribute of bitumen from cities in Mesopotamia. Around 500 BC Alexander the Great was welcomed to Persia by people lighting oil in the street[4].

The epic poet Homer (circa 850 BC) described in the *Illiad* how "the Trojans cast up upon the swift ship unwearied fire, over her forthwith with streamed a flame that might not be quenched". The Greek historian Diodor wrote of the presence of bitumen: "whereas many incredible miracles occur in Babylonian country there is none such as the great quantity of asphalt found therein"[5].

Pliny, the Greek naturalist (circa 100 AD), described the pharmaceutical value of bitumen in glowing terms. The substance was thought to check bleeding, heal wounds, treat cataracts, relieve shortness of breath, cure diarrhoea, relieve rheumatism and fever, could be used to join severed muscles, served as a liniment for gout, and was also used for "straightening the eyelashes which inconvenience the eyes"![6] This list of wonder cures was echoed centuries later in other countries.

The ancient Chinese used natural gas from seeps to heat pans of brine and so produce salt, and also used oil for heating. Marco Polo, the famous Venetian traveller (1256–1323 AD) recorded oil at Baku on the Caspian Sea (now a major oil province), noting that "the oil was not good to use with food but it is good to burn" and that it also cured camels of the mange. Gas from seeps at Baku fuelled "Eternal Fires". Thousands of pilgrims flocked to worship at temples built around these fires[7].

In the 7th century the Byzantines used 'Greek Fire' (*oleum incendiarum*) which was a mixture of bitumen of petroleum and lime, which could be ignited by wetting. The Byzantines used the mixture on the tip of flaming arrows, in crude grenades, and tossed lumps into attacking ships. The composition was a closely guarded secret and the material was considered to be more powerful than gunpowder[8].

The Peruvians used natural bitumen as a mortar, as did the builders of Babylon and Jericho. The Mexicans made chewing gum from it, and the North American Indians use it as a medicine. The Indians collected bitumen from pools, where it was found floating on water, by lowering blankets carefully into the pools and then squeezing the oil out into bowls. This oil was called 'Seneca Oil' after the local Indian tribe, who supposedly revealed the curative secrets of the oil to white man. The oil was supposed to cure headache, toothache, deafness, worms, rheumatism and dropsy, and to heal wounds on the backs of horses and mules[9, 10]. Oil found during a water boring operation in 1848 in Pennsylvania was sold as a medicine by Samuel Kier[11].

The earliest mechanical extraction of oil was made around 300 AD by the Chinese, who sometimes found oil when drilling for salt water with a crude drilling rig. This consisted of a chisel-shaped metal tool hung from a platform of poles, taking the rope attached to the tool over a roller. The tool was jolted up and down by means of a spring board, and the rope on the roller gradually released as the tool dug into the earth. By this means wells of up to 2000 feet deep were dug[12]. This technology was imported into Europe around 1830[13].

REPORTS OF OIL AND GAS 'SEEPS' IN TASMANIA

Oil 'seeps'

An oil seep is an outcropping deposit of oil, representing either a breached seal to a trapped accumulation of oil or a migration conduit truncated by the Earth's surface. After seeping to the surface, petroleum begins to change in composition. The more volatile fractions of hydrocarbons evaporate; water soluble compounds of oxygen, nitrogen, sulphur and some of the lighter aromatics may be leached out; the oil will be eaten by bacteria and suffer microbial degradation; and exposure to sunlight will cause formation of oxidised polymers (Hunt, 1979). Although seeps often work ephemerally due to seismic re-activation of faults, evidence of a genuine seep can be easily found, sampled and confirmed. Such features are not transient; they are seen periodically or continuously.

Traditional petroleum seeps are classified (Hunt, 1979) as either:

1. Active (live) seeps of gas, oil, or mounds of sticky black asphalt; or
2. Inactive seeps, represented by piles of asphalt or bitumen; no liquid oil present.

Materials which have been mistaken for an oil seep, but which are shown to have no connection with accumulations of petroleum, are known as false seeps.

There are no known examples in Tasmania where phenomena matching these descriptions of traditional active, or inactive, oil seeps have been found. Occurrences of bitumens are, however, known from Ordovician limestone and in one case bitumen occurs in fractures in dolerite. Traces of genuine petroleum hydrocarbons have been found in a number of rock types, and in water samples from several places. There are also innumerable examples of 'false seeps', phenomena which have, upon inspection, been shown to be unconnected to any accumulation of petroleum hydrocarbons.

Reports of oil and gas seeps made to the Tasmania Department of Mines (and its successors) have been summarised and are shown in Appendix 1. The results of any investigation, where known, is included, together with reference by footnotes (listed with the references) to the relevant Departmental records. The locations of these sites are shown in Figure 2. The principal places mentioned in the text are shown in Figure 1.

To date, the Department of Mines (and its successors) has received 139 reports of oil and gas seeps. On inspection, the majority of these suspected oil seeps have been shown to be caused by agents other than natural indigenous petroleum sources, as follows:

- iron oxide films on water;
- water in clay soil;
- cannel coal (pelionite);
- heavy minerals (ilmenite) swirling in the sea;
- bat guano;
- seepage from toilets;
- road bitumen;
- decomposing vegetable matter;
- a well polluted by nearby storage of petroleum oils;
- puddles discoloured by mud;
- Tertiary lignite, peat;
- deposit of coorongite (peat-like material);
- seepage from a pile of eucalypt bark;
- manganese oxide;
- smectite clay and other minerals;
- coastal strandings of bitumen of offshore origin;
- creosote washed ashore from a shipwreck;
- fuel oil from ships at sea, washed up onto the coastline;
- resin from Grass Trees or Blackboys; *Xanthorrhoea* sp.;
- algal scum on dams or ponds or pools of water;
- sounds heard while digging a water well.

Of the 139 reports, one has been confirmed by modern analysis as migrated petroleum hydrocarbons, generated within Tasmania (at Lonnavale, where bitumen derived from *Tasmanites*-bearing source rock has been found). Of the other reports:

- Six were reports of traces of petroleum hydrocarbons, which may be expected from rocks having a suitable composition and appropriate thermal history, or from water which has been in contact with such rocks.
- Twenty-four reports relate to coastal bitumens, washed up by tides and heavy seas.
- Sixty-six reports have been shown to be not related to petroleum.
- Some 38 reports remain 'unverified' by either not being investigated or because there is no real evidence to either support or disprove the idea that the reported observations may be due to petroleum hydrocarbons.
- One is a bitumen deposit that cannot be linked to any known possible Tasmanian source rock.
- Three are of uncertain origin, possibly derived from local high temperature contact metamorphism by dolerite intrusions.

The significant number of 'reported indications' and 'historical hydrocarbon occurrences' listed by Bendall (1990) and Bendall *et al*. (1991) was based on these reports being authentic. The status of reported seeps is summarised in Appendix 1. A list of holes drilled for oil and the results obtained are given in Appendix 2, and a list of tenements held is given in Appendix 4.

The mineralogist W. F. Petterd recorded an occurrence of a bitumen-like material near Chudleigh, in northern Tasmania, in his 1910 *Catalogue of the Minerals of Tasmania*. This deposit was never seen by Petterd and was described by Hills (1921*a*) as "doubtful".

Dr Arthur Wade was requested to examine alleged oil seeps on Bruny Island in 1915. He was unable to verify the existence of the reported occurrences of bitumen seeping from the ground (Wade, 1915), even though claims had been made in a company prospectus that liquid bitumen had been known to exude from two places for more than 50 years.

In 1917, W. H. Twelvetrees produced a small booklet entitled *The Search for Petroleum in Tasmania* to be given to interested members of the public. Twelvetrees documented the finds of bitumen on the south and west coasts, and outlined the nature and origin of petroleum, and the relationship of oil fields to structural geology. Twelvetrees noted that in Tasmania "unequivocal indications of any native oil are so far not apparent", and recommended that prospecting schemes be based on signs and evidences at the surface, followed by "geologically correct drilling" (Twelvetrees, 1917).

In the early 1920s Loftus Hills, Director of the Geological Survey, engaged in a fairly energetic campaign to stop the never-ending flow of enthusiastic press articles relating to the search for petroleum in Tasmania. Hills was particularly irritated at what he saw as a misrepresentation of geological facts by enthusiastic and even unscrupulous entrepreneurs. This controversy is detailed in Bacon (1996).

Hills wrote to the Minister for Mines in December 1921 commenting on proposals put to the Government by J. T. Moate and the Adelaide Oil Exploration Company Ltd; in particular Hills was scathing of the request for the Geological Survey to carry out geological surveys

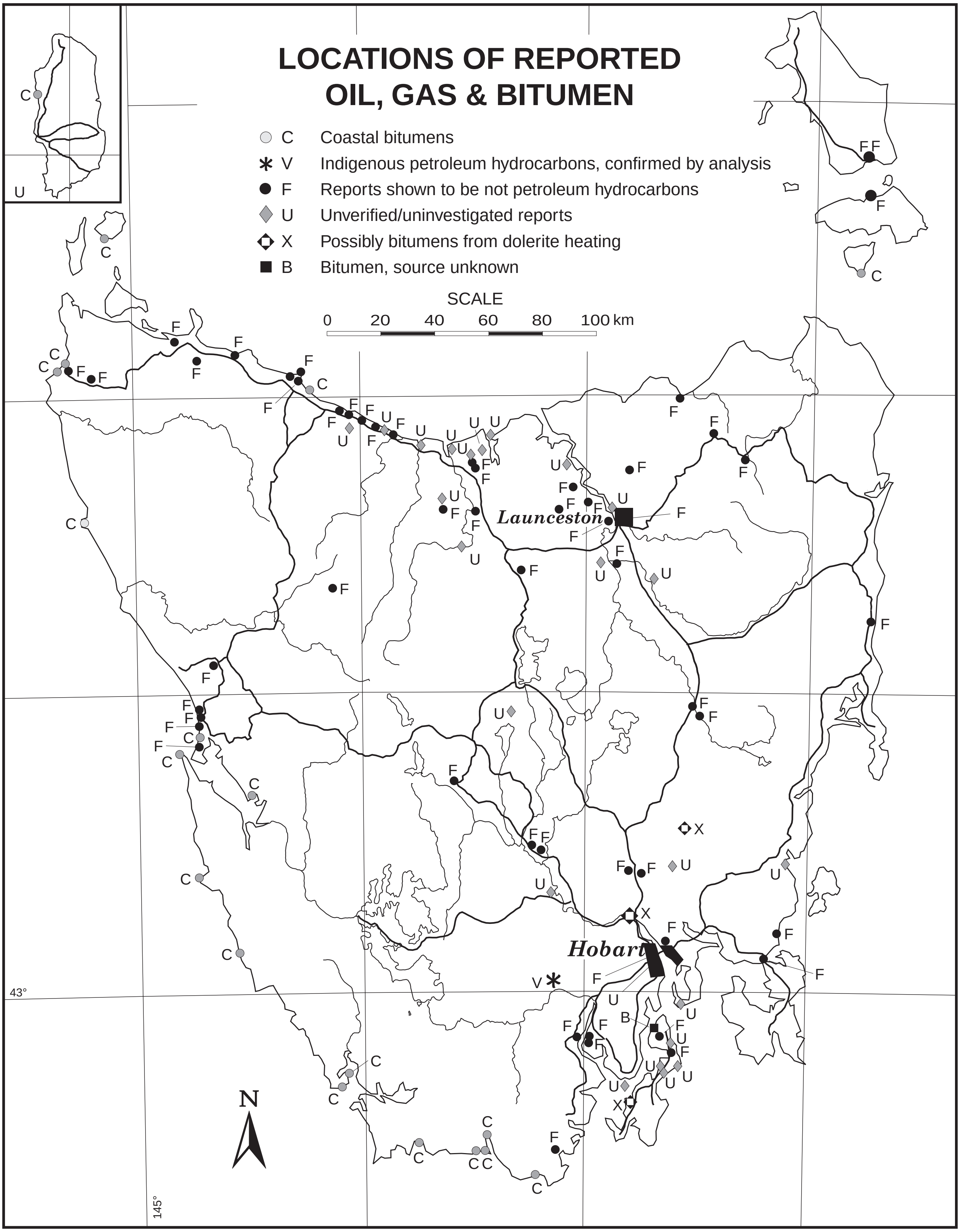
LOCATIONS OF REPORTED
OIL, GAS & BITUMEN
C Coastal bitumens
V Indigenous petroleum hydrocarbons, confirmed by analysis
F Reports shown to be not petroleum hydrocarbons
U Unverified/uninvestigated reports
X Possibly bitumens from dolerite heating
B Bitumen, source unknown
SCALE
0 20 40 60 80 100 km
Launceston
Hobart
N
43°
145°

Figure 2

searching for oil. Hills argued that this would repeat work already done, and stated;

> ". . . it must be remembered that we already possess very definite knowledge in regard to the salient geological features in Tasmania controlling the occurrence of oil. We possess this to such an extent that it can be definitely stated, and is now so stated by me, that 21,000 square miles of Tasmania has no possibility of containing liquid oil. Of the remaining 5000 square miles which is country of which we know very little, the greater part, we have evidence I believe, is most unlikely from the point of view of the occurrence of oil."

Hills went on to illustrate some of the "mistaken and unbalanced conclusions" reached by speculators looking for oil, including pelionite (a coal) being mistaken for the mineral albertite (dried up petroleum). In April of the following year Hills addressed the Royal Society of Tasmania on the topic 'Tasmania's Liquid Oil Possibilities — Not Worth Investigation'.

In January 1923, an enquiry was held 'In connection with alleged friction in the Mines Department'. Correspondence was produced to show that Hills had managed to have disagreements with almost everyone in the Department — the former Secretary Wallace, the current Secretary Pretyman, the Inspectors, the Minister, and most of the Survey staff. The Commissioner heard the staff reel off lists of grievances, and Pretyman had an enormous store of petty and trivial incidents involving Hills about which he complained at length. The main problem seems to have been that (in Pretyman's words) "He (Hills) does not seem to have the tact, and he seems to have a domineering spirit" (Bacon, 1996).

Hills was relieved of his duties as Director while the Commissioner considered the case, and would have been reinstated had the Survey staff (the two Reids, Bath, Edwards the draftsman, Nye and Manson) not written to the Minister stating that "his reinstatement would lead to constant friction in the Geological Survey and other branches of the Mines Department". So although Hills was not found to have done any wrong, the Commissioner resolved the issue by abolishing the position of Director, Geological Survey and recommending that the Launceston office be moved to Hobart (Bacon, 1996).

In July 1923 Hill's position was abolished, and he was out of a job. His successor, Alexander McIntosh Reid, wasted no time writing a report which he "designed to lend encouragement to the companies engaged in oil exploration in areas where the conditions are favourable". Reid conceded that ". . . the work of some of the companies has not been well advised" and overall the report was not greatly encouraging (Reid, 1923*a*).

Significantly, Reid did consider some of the sightings of oil to be genuine. These were:

- globules rising to surface when bedrock was struck at Johnson's well on Bruny Island (Reid, 1929);
- an oily scum on a backwater in Miles Creek, Bruny Island (Reid, 1929);
- a thick scum of oil on water in 10′ (3 m) deep shaft dug next to Ray Creek, Nook. The shaft was sited next to a fault cutting Parmeener Supergroup sediments, a seam of coal being exposed on one side of the fault and a four foot (1.2 m) thick seam of tasmanite on the other (Reid, 1923*a*);
- another seep noted downstream from the above (Reid, 1923*a*);
- oil seeping from Tertiary strata where tree stumps had been removed by fire on Rockcliffe's land, Mersey Valley (Reid, 1923*b*);
- on the property of P. Roche, Sassafras, only active after heavy rainfall (Reid, 1923*a*).

Reid suspected that the oil seen at Nook had been produced by local heating of sediments by dolerite (Reid, 1923*a*). Unfortunately none of these sightings were confirmed by analysis, and none have been reported again to the Department.

After Reid's encouragement, drilling in the in the Permo-Carboniferous beds in the Mersey Valley stopped, and attention was directed at the Tertiary strata.

Reid was the only Government Geologist to consider any of these reported sightings of oil to be genuine. In March 1935, the Secretary of the Geological Advisory Committee of the Commonwealth Oil Refineries Ltd wrote to the Secretary for Mines asking, rather pointedly, "if anyone other than Reid" had verified the existence of the seepages, in view of the negative results from all the drilling in the Mersey Valley[14]. Reid's 1929 report on Bruny Island was made "as a result of prospecting under the superintendence of Mr A. G. Black, undertaken for a syndicate formed in Hobart"[15], so it is possible that it was couched in positive terms.

Reid may also have been the only geologist interested in oil exploration. He did not produce any positive reports while Hills was Director — and as Hills was of the view that oil exploration in Tasmania was a waste of time, this is not surprising. On Hills' departure, Reid started writing his more positive, but still cautious, reports. Reid did note that some of the phenomena he saw were definitely not due to petroleum hydrocarbons — thus indicating that Reid did try to be objective, at least some of the time.

Yet another summary of the geology and structure of Tasmania and the possibilities of finding liquid oil was produced by Nye in 1924. Nye made no comment on the probability of finding oil, and confined himself to a brief description of work already completed. With the dismissal of Hills fresh in everyone's mind, Nye may well not have wanted to 'rock the boat' by proffering any of his own opinions, if indeed he had any. Nye had already had a taste of having to do without help, Hills having made him map the Midlands on a bicycle, without a promised car for transport. He had been admonished for losing a geological hammer, and for forgetting to pack appropriate sample jars, and was narked at not being given enough credit by Hills for his part of the coal bulletin, produced in 1922 — although the draftsman and typist were both thanked.

By 1929 Nye did have an opinion on this matter, writing that "As far as our present knowledge extends, the geological conditions are not favourable for the occurrences of oil"[16]. This view was in conflict with the hopeful and positive reports written by Reid.

The New River area was assessed in 1929 by H. S. Lyne and the district found to be "occupied by Lower Palaeozoic rocks and to be unfavourable for the occurrence of oil"[16]. This private inspection followed the finding of bitumen strandings on the coast.

Reid was also on friendly terms with J. T. Moate, Chairman of the Adelaide Oil Exploration Company, the entrepreneur with whom Loftus Hills had a very public and bitter disagreement due to Moate's claims relating to oil in Tasmania (documented in Bacon, 1994). Moate wrote to Reid[17] in January 1930;

> ". . . I understood . . . that you had certain information which you were willing to impart to us, and naturally it did not then occur to me that your government would interfere with your movements to the extent mentioned in your letter. Can anything be done by Mr Darling approaching your Minister for Mines . . . It is hardly conceivable that he should wish to withhold information regarding the discovery of oil within the Commonwealth . .".

Reid replied[18] that permission to him (Reid) to travel to South Australia and furnish a confidential report to the Adelaide Oil Exploration Company had been refused, so further representations would be futile. Enigmatically, Reid hints at the possibility of finding an oil field;

> ". . . In making my investigations I found quite early that the surface revealed little, and in order to decipher subsurface structure I started the investigation of the history of geological development. That supplied the key and gave me an insight into the hidden recesses. I feel quite sure that my evidence cannot be refuted".

Reid was sacked in 1930, following an enquiry during which witnesses alleged Reid (who was Director of Mines at the time) undertook commissions to do private work for companies whilst still being employed by the Government. Although Reid denied the charge, he did admit to giving advice, but had accepted only sufficient funds to cover expenses[19].

The unhappiness generated by the persistent squabbling, both within the Geological Survey and between members of the Survey and others (entrepreneurs, ministers, members of the public), resulted in a climate where the topic of oil exploration was not discussed for many years. Whilst there are very few, if any, encouraging signs which would be of interest to the petroleum industry in general, there are some opportunities for high-risk grass-roots exploration work to fill in the knowledge database, which is still incomplete.

A kerosene substitute was retorted from oil shale during the 1930s. An account of this activity is given in Bacon (1986).

A précis of previous attempts to explore for oil in Tasmania was compiled by S. Warren Carey in 1946 at the request of the *Oil Weekly* of Texas, USA. Carey wrote that there had been "no large scale co-ordinated search for oil in Tasmania, Government or private, because prospects have not been considered sufficiently attractive to warrant such a programme". Since then there have been no further summaries of oil exploration produced by the Department of Mines until now.

A piece of bitumen was collected by Dr D. Leaman at Barnes Bay in 1988, within tidal range. This site was revisited in 1999 and the bitumen was found as surficial coating on dolerite outcrop in a number of places. Analysis showed that the material was characteristic of a heavy oil with a signature not consistent with any known possible Tasmanian source rock.

An occurrence of bitumen and petroleum hydrocarbons was noted by Mineral Resources Tasmania's petrologist R. S. Bottrill at a location six kilometres northwest of Lonnavale in late 1995. The bitumen occurred in a recently used Forestry Tasmania quarry on Russell Road, at approximately 482 700 mE, 5 247 800 mN. The quarry is located in fine-grained Jurassic dolerite, close to a contact with fossiliferous Permian mudstone, which is well exposed in a small, older quarry about 300 m to the southeast. The contact is probably faulted and strikes northeast. Lonna Creek, on the northwest side of the quarry, follows the strike of the contact.

Laboratory analysis showed that the bitumen and a liquid sample (swabbed off freshly broken dolerite) were derived from a *Tasmanites*-bearing source rock (Revill, 1996). No tasmanite is known in southern Tasmania, but disseminated *Tasmanites* were found in the Woody Island Siltstone at Maydena (BHP, 1982*a*). While the bitumen and 'swab' samples are thought to have been derived from the same parent material, there are differences between the two in terms of maturity, with the bitumen being the more mature of the two. This may mean that either:

- there have been two phases of hydrocarbon generation; or
- the bitumen may represent a biodegraded fraction of one generating event; or
- dolerite intrusion may have caused generation of hydrocarbons of differing maturity with distance from the intrusion (Revill, 1996).

The hydrocarbons may have been generated by the Jurassic dolerite intruding into the Permian section. Feeder complexes and complex structural features in this particular area (D. E. Leaman, pers. comm.) could have provided sufficient heat to generate hydrocarbons from a *Tasmanites* source, and facilitated migration through the now zeolite-filled fractures in the dolerite.

The origins of some hydrocarbon occurrences have not been adequately defined, even with the use of modern analytical methods. For example, three samples analysed for Conga Oil all showed the same unusual biomarker characteristics. These samples included a black brittle tar on weathered sandstone from south Bruny Island, a tar from Bridgewater and tar-impregnated sandstone from Tunnack. All contained abundant polycyclic aromatic hydrocarbons, a low content of aliphatic hydrocarbons that included 1-alkenes, and a high asphaltene content. Steranes showed a strong predominance of C^{29} isomers indicative of terrestrial organic matter. The origin of these hydrocarbons is still unknown. However, they do not match any potential source rock in Tasmania and it seems most likely that they are a product of high temperature pyrolysis.

Some rock samples taken from various places around Tasmania do show traces of petroleum hydrocarbons when subject to field inspection and/or chemical analysis. There is nothing unique or unusual about this; in fact many rocks will contain traces of petroleum hydrocarbons, given suitable composition and an appropriate thermal history. However, traces of petroleum hydrocarbons in a rock do not constitute a seep.

Gas 'seeps'

Most of the reported gas seeps have been either explained as, or shown to be, marsh gas produced by rotting vegetation. In recent years, gas samples have been collected from seeps at:

- Kimberley (a thermal spring);
- Marion Bay (gas seeping through sand in the intertidal zone);
- Johnson's Well on Bruny Island (where a stick poked into the bottom of a water-filled hole produced bubbles);
- Douglas River (drill hole);
- the Saw Pit on Bruny Island (bubbles seen in a water-filled pit).

The gas collected from each of these localities has been shown to be of biogenic origin, and not related to any petroleum source. The laboratory results are shown in Table 1.

Isotopic data can be used to understand the process of oil and gas formation. The origin of petroleum (from lipid fractions of organisms) and coal (from higher plants) can be demonstrated by the use of ^{13}C data (Silverman, 1963, 1967 sighted in Fuex, 1977). Isotope data can also be used to assess the origin and migration of specific hydrocarbon occurrences (Fuex, 1977). The range of ^{13}C content is a useful measure in such studies.

Methane has the largest $\delta^{13}C$ range of any naturally occurring material (from –90‰ to about –13‰ PDB).

Table 1

Analyses of various gas samples, and their interpreted origins

	Smithton	Kimberley	Marion Bay	Douglas River		Johnson's Well)	Saw Pit
Chemical analyses				(1)	(2)		
methane	0.07%	19.8 ppm	63%	68.1%	81%	70.3%	54.3%
carbon dioxide	59.8%	1.2%	36%	0.1%	0.1%	7.8%	7.1%
oxygen	8.7%	10.9%		3.2%	0%	2.4%	1.1%
nitrogen	31.5%	87.9%		28.6%	19%	19.4%	37.5%
hydrogen sulphide			1%				
ethane			possible trace				
propane			possible trace				
Isotopic analyses							
methane $\delta^{13}C$ (‰)	-32.3 PDB	-77.4 PDB	-45.5 PDB	-66.3 PDB		-55.2	-56.1
methane $\delta^{13}D$ (‰)			-348 SMOW				
CO_2 $\delta^{13}C$ (‰)	-4.0 PDB	-18.2 PDB	-10.4 PDB				
CO_2 $\delta^{18}O$ (‰) (3)			+27 SMOW				
CO_2 $\delta^{18}O$ (‰) (3)	-4.9 PDB	-5.9 PDB					
Conclusion	CO_2 probable geothermal origin	bacterial origin	biogenic origin	biogenic origin		biogenic origin	biogenic origin
Reference	Baillie (1992)	Baillie (1992)	Baillie (1990)	Revill and Volkman (1993) Summons (1993)		Revill and Volkman (1994)	Revill and Volkman (1994)

(1) Raw data (2) Data re-normalised after removing air contamination
(3) To interconvert between the PDB (International Standard Peedee Belemite) and SMOW (Standard Mean Ocean Water) scales use the equation $\delta^{18}O$ SMOW = 1.03086*$\delta^{18}O$ PDB + 30.86

Different categories of methane have distinct ^{13}C ranges (Fuex, 1977). The ranges of $\delta^{13}C$ values of methane analyses from a variety of materials (from Schoell, 1983) are shown in Figure 3.

Bacteria are capable of producing methane which has been depleted in ^{13}C, a fact proved by laboratory experiments and from analyses of methane of bacterial origin (Fuex, 1977). The $\delta^{13}C$ range for bacterial methane is large, and the values are evenly spread over the range for this type of gas.

There is an overlap in $\delta^{13}C$ values between –50‰ and –60‰ between methane of thermogenic origin and biogenic origin. Some very highly mature gases of thermogenic origin, such as the Ellenberger gas in the Delaware–Val Verole Basin of West Texas, may show similar chemical and isotopic analyses to gases of biogenic origin (Fuex, 1977).

In addition to the overlap between end members of different gas types, mixtures of bacterial and thermogenic gases are sometimes found. An interpretation of the origin of a gas can only be made after the isotopic, chemical and geological evidence has all been considered (Fuex, 1977).

Table 2

Averaged, air-corrected trip gas and cuttings gas analyses from Shittim-1.
Data from Davies (1996) and Burrett and Tanner (1997)

Depth (m)	1528	1568	1630–1745.8
Samples	4	10	40
Nitrogen (%)	82.85	94.06	94.5
Hydrogen (%)	0.84	0.56	2.79
Helium (%)	nd	0.05	0.44
Carbon dioxide (%)	2.02	0.084	0.39
Methane (%)	14.27	5.01	1.88
C2–C6 (%)		0.004	0.097
C2 (%)	0.006		
Methane $\delta^{13}C$ (‰)	-50.1		

Also included in Table 1 are the analysis results from a sample taken of gas bubbling into puddles in a paddock near Smithton. This gas was found to be carbon dioxide, with trace amounts of methane. The heavy isotopic signature of the methane (-32.3‰, Table 1) suggests a thermogenic origin (fig. 3).

Stratigraphic holes Shittim-1, Jericho-1 and Lonnavale-1 were drilled in southern Tasmania between 1994 and 1998 as part of an oil and gas exploration program by Condor Oil Investments Pty Ltd and Great South Land Minerals Ltd. Analyses of gas from cuttings recovered from these holes show minor proportions of methane and C2–C6 hydrocarbons. Large corrections for air contamination are necessary, and the highly variable amounts and proportions of gases in 'air-corrected' results suggest that the data are of semi-quantitative value only. Table 2 gives a synopsis of results from Shittim-1. The sampled stratigraphic interval consists of Jurassic dolerite, baked basal tillite of the Parmeener Supergroup, and Proterozoic phyllite basement. Helium was present at deeper levels in this hole.

A helium concentration of 0.09% occurs in Boggy Creek-1 in the Port Campbell Embayment in Victoria, whilst in South Australia concentrations of 0.07% in Carolain-1 and 0.029% in Kalangadoo-1 have been recorded. These are interpreted to be of volcanic origin.

Terrestrially-derived helium is generally a by-product of the disintegration of radioactive elements. While the concentration of such elements may be low in plutonic and volcanic rocks, they are the most likely source of helium in petroleum accumulations (Hunt, 1979).

INLAND BITUMENS

A number of reports have been made of apparent tar or bitumen finds inland, well away from any tidal influence. One of these samples was identified as bat guano, collected from the floor of a cave, and others have been explained as burnt remains of refined petroleum products.

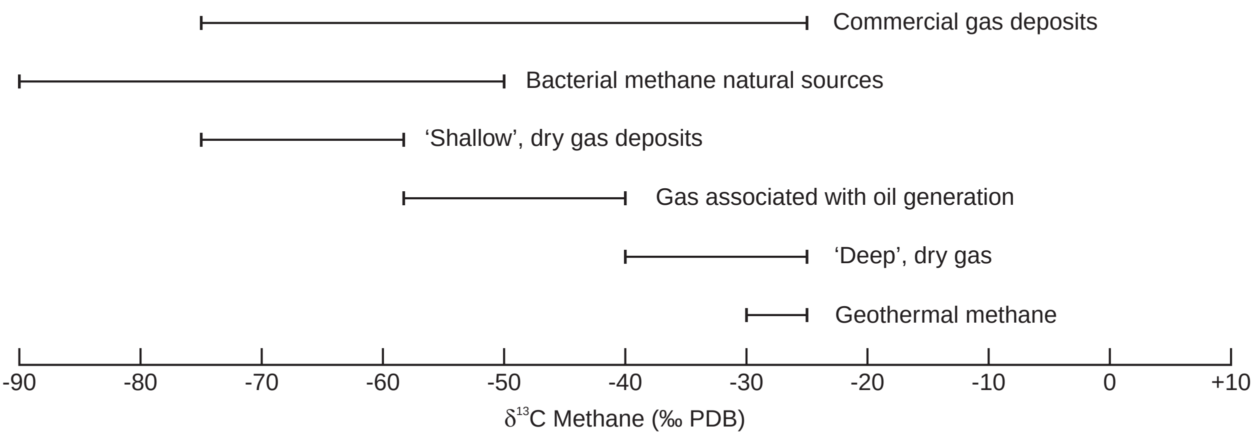

Figure 3

Carbon isotope distribution, methane gas of biogenic and thermogenic origins (from Fuex, 1977)

Local heating of coal and shale by dolerite has, in some cases, produced samples of bitumen, sometimes grading to protographite. Bushfires can also cause tar and bitumen-like material to be produced by surface heating of organic-rich shale and burning of coal seams (see Appendix 1).

An occurrence of bitumen and oil is known from Lonnavale, where the material is lodged in fractures in dolerite.

Pyrobitumens have been noted in a number of Tasmanian rocks — primarily limestone, where the rock has been heated and the contained organic matter has been thermally altered. Pyrobitumens have been recorded from limestone collected from Benders quarry at Ida Bay, and from the Smelters quarry at Queenstown (Volkman, 1988*a*), and can be seen in Gordon Limestone in the core of a hole drilled at Grieves Siding, near Zeehan.

These occurrences show that petroleum has been generated from these rocks at some stage, although only thermally altered traces are apparent today. The Gordon Group comprises warm-water limestone, shale and sand deposited on a continental shelf, with lagoonal mud facies, abundant algal mats and pellet beds, all common features in rocks which could be expected to have generated some petroleum at maturity temperatures.

COASTAL BITUMEN STRANDINGS

The occurrence of lumps of bitumen at various places around the southeast Australian coastline has been reported by a number of observers, one of the first being a Mr Honchim who noted that "loose pieces of a pitch like substance" had been found on the shores of Kangaroo Island off the coast of South Australia as early as 1844 (Twelvetrees, 1915). Reported findings of stranded bitumens from Tasmania are listed in Appendix 1.

These bitumens have all been found near high water mark, between "normal and storm tide levels", and have varied in weight between an "ounce or two and a hundredweight" (Twelvetrees, 1917).

Hills (1914) noted that pieces varied in size from 3 feet long by 2 feet wide (900 × 600 mm) down to small fragments a few inches in diameter. One fragment found on King Island was 7 feet long, 1 foot wide and 1 foot thick (2.1 × 0.3 × 0.3 m) and had not been on the granite boulders where it was found some nine weeks earlier (Pritchard, 1927).

Hills (1914) observed that some blocks were quite plastic, while other fragments were hard and brittle. The fact that the material changed on exposure to the elements was noted, as the asphaltum, when fresh, was "slightly plastic" and the "plasticity diminishes with exposure, excepting under the burning rays of the sun" (Twelvetrees, 1915).

The Government Analyst, Ward, noted that the samples tested in 1917 were slightly denser than sea water, with specific gravity values ranging from 1.0313 to 1.0459, compared with sea water having a specific gravity of 1.030. Twelvetrees (1917) suggested that whilst these fragments would not float in stationary sea water, they would certainly do so in moving water. The possibility exists that the stranded lumps may have lost some of the more volatile fraction on being exposed to the air. After collecting the 1915 samples Twelvetrees wrote "In the course of drying the substance it no doubt loses some of its buoyancy". Fresh exudations were thought to float and be carried along by ocean currents. Hills (1914) noted "it will just float on sea water".

The strandings of bitumen were not found every year. Twelvetrees only found three pieces of the material in 1915 although "the beaches were thoroughly and repeatedly searched". Taylor (1966) interviewed Melaleuca resident Mr Deny King, who was familiar with the bitumen strandings and who told Taylor that they occurred after a high tide. Taylor found none on his 1966 visit, noting that this was probably due to the fact that the last extremely high tide was in May 1964.

The asphaltum (bitumen) pieces were found resting on a wide variety of substrates — granite, limestone, conglomerate and quartzite. Twelvetrees (1915) commented that the pieces "were not actually derived from these beds respectively, but had a common origin", and that "the parent beds are not at an excessive distance (offshore). By this it is meant that they are not separated from Tasmania by thousands of miles of ocean. On the other hand the comparative rarity of specimens indicates that the beds of origin are not close in to shore, where every tide or storm would bring in fresh pieces". Hills (1914) referred to a map produced by Ward, which showed the distribution of a trend of ocean currents in the southern ocean which "will explain the known distribution of asphaltum if we assume them to be from a point in the southern ocean".

Taylor (1966) records that the local Port Davey resident Deny King had found pieces of a South American *Nothofagus* washed up, along with large pieces of pumice thought to have come from a volcanic eruption in the South Sandwich Islands in 1962, and postulated a South American origin for the bitumens.

Modern analytical chemistry has shown that the bitumens can be classified into several groups (Volkman *et al.*, 1992; Currie *et al.*, 1992). Most of the Tasmanian occurrences are of an asphaltic bitumen that breaks with distinctive conchoidal fracture. These particular bitumens have a distinctive biomarker signature that is unrelated to any oils derived from the Bass, Gippsland or Otway basins, or from the tasmanite. They are not derived from a carbonate source. The high proportions of C_{27} steranes and presence of C_{30} steranes, including dinosterane, suggested that the bitumens were derived from a marine source rock of Cretaceous age or younger containing mainly marine organic matter.

While the source of most of the waxy botryococcane-containing bitumens found on southern Australian beaches is clearly from oil seepages in southeast Asia (Currie *et al.*, 1992), the source of the asphaltic coastal bitumens has not been established. It is important to note that they are not restricted to Tasmania, and thus may have a distant source. They have been found on the shores of Western Australia, South Australia, Victoria as well as Tasmania. Edwards *et al.* (1998) have argued that they might be derived from an as-yet unidentified southern margin petroleum system, or represent historical artifacts of the early whaling and seal harvesting industry, but proof for either proposition is still lacking.

EXPLORATION HISTORY

The finding of bitumen as beach strandings, or the sighting of some material thought to be oil, has been enough to encourage many individuals to establish either syndicates or companies to raise capital to exploit the supposed oil 'find'.

To date, thirty-eight shallow holes have been drilled in onshore Tasmania for the purpose of exploring for oil or gas. Of these, gas was noted at one drill hole, and 'oily water' was reported from another. No oil or petroleum was reported from the other 36 holes. Details of the various drill holes are given in Appendix 2, with locations shown in Figure 4.

The beach strandings of bitumen on the south coast led to the formation of the Asphaltum Glance and Oil Syndicate in 1915. One prospecting permit of 640 acres (260 ha) was taken out at Recherche Bay, with a further four of 320 acres (130 ha) each being taken out near New River. The men who formed the syndicate, Messrs Herbert Smith, Adams and Harry Glover, found a piece of asphaltum, estimated to weigh 'a hundredweight' (50 kg), on the New River beach. The syndicate reported seeing oil floating on the sea in the vicinity of the bitumen finds at New River and Rocky Boat Harbour (Twelvetrees, 1915).

Several patches of calm water were pointed out to Twelvetrees by the prospectors, who viewed these patches as indicating the presence of oil and water, but Twelvetrees thought the patches more likely represented masses of seaweed, or were an artefact of mixing fresh water and sea water at the mouth of New River. No petroleum odour was apparent, despite the prevalence of the 'oil' patches. Around this time, a large piece of bitumen was brought to Hobart by the Davey River Oil and Mineral Exploration Company, after being found near the mouth of Deep Creek, Port Davey.

The Bruni Island Petroleum Company NL was floated in 1915 for the purpose of raising funds to explore for oil on North Bruny Island. Six Licences to Search of 320 acres (130 ha) each were taken out, and several shallow holes were drilled. The funds raised by the float supported the development of some expensive and elaborate infrastructure — as seen in Plates 9 and 10. The company was very hopeful of finding oil, stating in the prospectus "The discoveries of bitumen which have been made within certain localities absolutely prohibit the possibility of its having been deposited there by any outside agency, such as the ocean. This assures us of the fact that petroleum is underlying the island of Tasmania, and we confidently predict that the day is not far distant when Tasmania will take its place amongst the oil producing countries of the world"[20]. The company set up a 30 horsepower Jameson portable boiler and a 25 horsepower oil well supply engine[21].

The Minister for Mines asked Wade to report on the possibility of finding oil or bitumen on Bruny Island. Wade (1915) could not verify any petroleum seeps on the island and considered conditions for finding any such material to be unfavourable.

However, the Bruni Island Petroleum Company NL pressed ahead, drilling Andrew's Bore to a depth of 430′ (131 m) [the log is given in Twelvetrees (1917) and Reid (1929)]. No oil was found, and the operation ceased after one hole had been drilled and £5000 had been spent[22].

In January 1920, the Commonwealth Government stimulated the search for liquid oil by announcing a reward of £10,000 for the discovery of a payable oil deposit anywhere in Australia[23]. This had the effect of encouraging explorers and entrepreneurs to turn their attention to oil exploration.

A flurry of activity resulted in a plethora of small companies springing onto the scene, all jostling for acreage, especially in the Mersey Valley. A number of bores searching for oil were put down in this area in the early 1920s, firstly in the Permo-Carboniferous strata but later in the Tertiary sediments. When this exploration proved to be unsuccessful, attention turned to oil-bearing substances such as oil shale and a coal, pelionite.

The Adelaide Oil Exploration Company Ltd and the Mersey Valley Oil Company drilled a number of holes in the Mersey Valley region in the search for liquid oil during the 1920s. These two companies, along with many others, also spent much time and effort searching for oil shale, and then for 'rich in oil' material (see Appendices 2 and 4 and Figure 5).

Gas was reported at 1100′ (335 m) in Bore 8 drilled by the Adelaide Oil Exploration Company (Iles Bore) near Sassafras. Reid (1924) considered the report of gas to be genuine; drilling apparently ceased due to an 'inrush of sand' when the bore intersected a bed of sand containing natural gas. Gas was also reported from two holes drilled near Conara (one drilled by the Department of Mines and another by a landowner; both were drilled primarily to search for water). The three holes from which gas has been reported were all drilled into Tertiary sediments. One explanation for the observed phenomena is that the bores have intersected bands of decomposing vegetable matter (peat, lignite) in which gas (methane) has become trapped.

Gas was also reported from Douglas River DDH 10, drilled by the Department of Mines as a stratigraphic hole during a gravity survey of the East Coast Coalfields. The hole was drilled through Upper and Lower Parmeener Supergroup sediments, and did intersect an oil shale horizon (the tasmanite found in

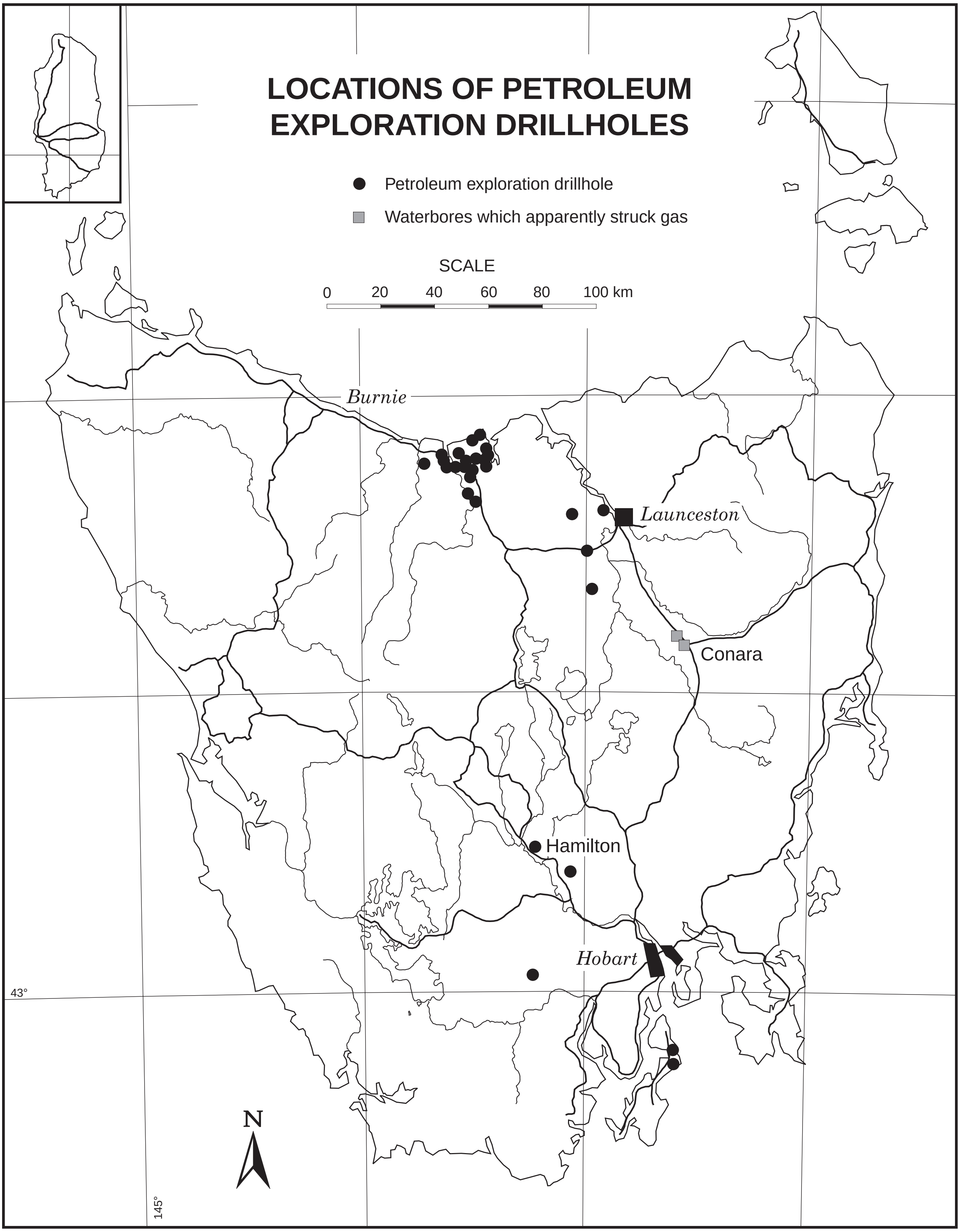
LOCATIONS OF PETROLEUM EXPLORATION DRILLHOLES
Petroleum exploration drillhole
Waterbores which apparently struck gas
SCALE
0 20 40 60 80 100 km
Burnie
Launceston
Conara
Hamilton
Hobart
43°
145°
N

Figure 4

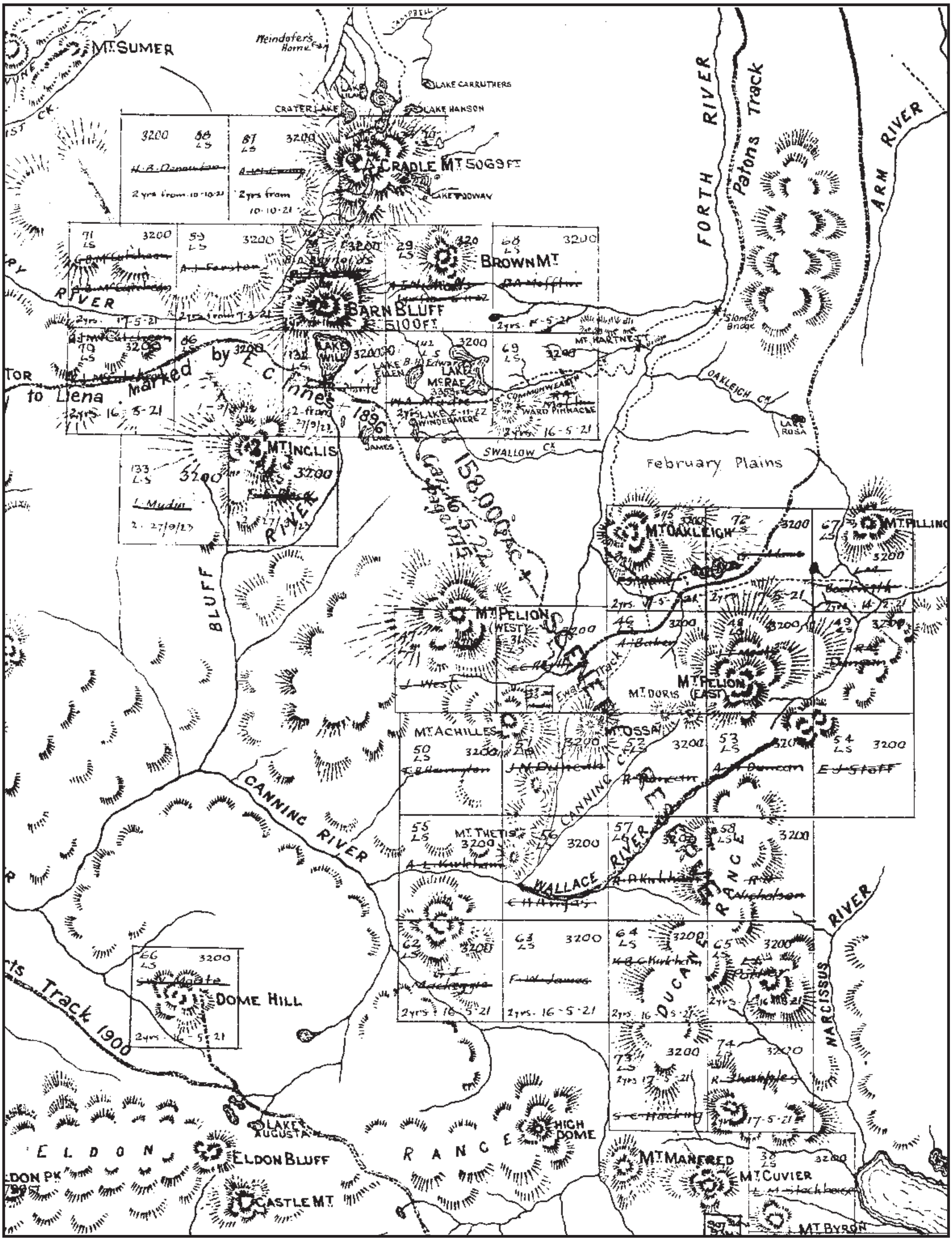

Figure 5

Map showing coverages of Licences to Search, Cradle Mt–Mt Pelion areas northern Tasmania, primarily around Latrobe). Gas was noted by the presence of bubbles in water filling the hole on completion of drilling, but a gas sample taken for analysis was shown to be methane of biogenic (bacterial) origin, and not from any petroleum source (see Table 1).

Alfred George Black (who had had run-ins with Loftus Hills) and Frederick Boddy each took out Licences to Search over parts of North Bruny Island in 1929. These two, together with five others, registered the Tasmanian Oil Exploration Company in April 1929. The company drilled several shallow holes "all without success" (Carey, 1946), including one hole near Johnson's well.

An anecdotal report of 'oily water' being struck at a depth of about 90 feet (27 m) in Johnson's well during the 1929/30 drilling was made in 1987 by an individual who had visited the site as a child; he remembered bringing containers from the family orchard to collect the oily water (Morrison, 1988). Curiously, a report of oily water being struck in Johnson's well is not recorded in the Department of Mines Annual Reports for 1929 or 1930 (or for any other year), or in the correspondence files for this time. Reid visited Bruny Island in 1929 but made no mention of the bore at Johnson's well, or even of any plans to drill such a hole. The log attached to Reid's (1929) report is that of Andrew's bore (drilled in 1915). Another anecdotal source claims that the hole was 'salted', and that after collecting money ostensibly to drill deeper, the entrepreneur, Black, disappeared with the funds, after telling locals he was off to Hobart to buy spare parts for the rig (Morrison, 1988). Locals 'still remember' the debts accrued by the project[24].

In 1936 the Austral Oil Drilling Syndicate began investigation of large areas in the vicinity of Lady Barron on Flinders Island, after the finding of an oil-bearing corky substance (coorongite), derived from the alga *Elaeophyton coorongiana*. The syndicate was impressed by the high oil yield which could be obtained by distillation of the material (73–85 gallons/ton) but disregarded Nye's advice that the algal deposit had nothing to do with an occurrence of natural petroleum (Carey, 1945).

The syndicate were no doubt encouraged by the occurrence of oily films on 'paludal waters' near Lady Barron, and two smoky fires in the region, one in 1913 which burnt 'for years' and another around 1936 (Cane, 1966).

A shallow hole was drilled at Danbury Park, a property owned by George Luck on the west bank of the River Tamar, in 1939 (see Plate 11). The site was chosen by a 'patent oil finding device', under the guidance of Max Steinbuchel, who agreed 'no oil, no pay'. The drilling was funded by Producers Oilwell Supplies Ltd. An argument erupted between the (then) Minister for Mines, Major Davies, and Producers Oilwell Supplies Ltd when the Minister stated in Parliament that the company did not hold a permit to explore for oil. The General Manager, Mr Richmond, had obtained a permit to search over a quarter of an acre (0.1 ha) for minerals (but not oil), in his own name. The saga was played out in the press, complete with demands for the Minister to apologise, something he refused to do[25–45].

Producers Oilwell Supplies Ltd held a meeting in the Cygnet Town Hall in December 1939 (*Huon and Derwent Times*, 7 December 1939) outlining the company's plans to test an area near Cradoc for oil. The meeting was told that material from the property of the Armstrong Brothers had been sent for analysis and 'the report was favourable to the possibility of the presence of oil'. Nye (1931) was dispatched to view this reported occurrence of oil, and examined a 'brownish sand' at the top of a shaft 3–4′ (0.9–1.2 m) deep, thought to be an indication of oil. The sand tested nil for liquid petroleum, and nil for a yield of crude oil after distillation. Gas bubbles in water in the bottom of the shaft were deemed to be marsh gas. Dr Leaman checked the same area in 1965 after receiving reports of oil seeps from locals and found only iron oxide scums on farm dams.

In 1944 the Government gave a grant of £300 to Mr H. E. Evenden and his party for the purpose of prospecting for the source of the bitumen which had been found from time to time on nearby foreshores (Keid, 1944). The prospecting activities were observed by Keid, who reported that there had been no discovery of bitumen *in situ*, and that the geological evidence was "definitely against the occurrence of bitumen at Port Davey" (Keid, 1944). The prospecting party found one 4 ounce (120 g) piece of bitumen during their investigations.

Samuel Adams registered the Bass Strait Oil Company NL in May 1962, and took out Licences to Search over parts of northern Tasmania. Adams had previously lived on King Island, and in 1927 he and his mother had been very taken with the beach strandings of bitumen[46]. Mrs Adams applied to the Department for a Reward Lease, which was not granted, but mining lease 10103/M of 588 acres was taken out and held until 1929. The initial discovery was examined by Dr Pritchard, an 'oil geologist' (see Pritchard, 1927) and Mr Moate of the Adelaide Oil Exploration Company[47].

In 1955 Mrs Adams approached the Department indicating she had found signs of oil inland. Whilst initially requesting exploration rights for oil for the whole of King Island, Mr S. Adams and Mrs A. J. Adams–Smith (Ulverstone) and Mr J. Adams (Melbourne) decided to apply for exploration licences over areas of interest, although further requests were made to the Minister[48] for such rights, which could not be granted under the existing provisions of the *Mining Act* 1929[49, 50].

In 1968, Adams claimed that if he and his mother had been able to convince the Mines Department of oil indications on King Island, Tasmania could have been a major figure in the oil business. The need to actually have a commercial oil field seems to have escaped Adams, who continued "Geologists from Canberra were quite excited by the find but the Tasmanian Mines Department put the kybosh on it"[51]. The Commonwealth did write to the State following a visit by Mr Adams to Canberra in 1960[52], asking for the matter to be investigated. Arrangements were made for

Mr Stinear (Bureau of Mineral Resources) and Mr T. Hughes (Department of Mines) to visit King Island and investigate the occurrence[53, 54]. The previous reports on the area were forwarded to Canberra and from then on the subject was not mentioned again in correspondence between the two agencies. The Department of Mines was convinced that the sightings were of asphaltum washed up by the sea.

Mr C. G. Sulzberger imported a drilling rig from Gippsland in 1966. The rig, which arrived in pieces, stood 100′ (30 m) high when assembled and was said to need nine men to operate it (*The Examiner*, 22 September 1966). At the time of importation the rig was the largest to operate in Tasmania. Mr Sulzberger and his company, Nudec Petroleum Exploration Pty Ltd, drilled a number of holes in the Westbury–Longford and Port Sorell–Sassafras areas with the aim of finding oil and gas. The sites of the drill holes were chosen by Mr Sulzberger with the aid of a divining rod, which allegedly flicked upwards to indicate the presence of gold and downwards to indicate water or metals. Possible petroleum sources were allegedly marked by a rapid 'wriggling' of the divining rod. Several samples of lignite were submitted to the Department for analysis. The drilling rig aroused much local interest, and several photos of the drilling operation appeared in the press (see Plates 12, 13 and 14). No hydrocarbons were discovered by this exploration program.

In 1974 the Amoco Australian Petroleum Company examined the hydrocarbon prospectivity of areas to the north and south of Macquarie Harbour on the west coast (the 'Macquarie Harbour graben'). The company relinquished the ground in 1975, concluding the area was non-prospective for hydrocarbons (Womer, 1983). The rock sequence was deemed to be "much too thin to have thermally generated hydrocarbon".

An area near Cranbrook, on the east coast, was examined by Meekatharra Minerals Ltd in 1981. Interpretation of seismic data collected indicated that the gravity lows found by the company's initial work could be explained by variations of less than 300 m of Tertiary sediment thickness. The Company concluded that "these thicknesses are insufficient to provide maturity of any basal Tertiary sequences" (Shaw, 1985).

In 1981, Victor Petroleum and Resources Ltd, in partnership with the Northwest Bay Co. Pty Ltd, held exploration licences covering a large part of the Midlands for coal and oil. A preliminary report on the petroleum potential of onshore Tasmania was made (Summons, 1981*a*) and twelve rock samples were sent for assessment of their content. Some of these samples showed that the host rock had been, at one time, through the oil window, with a TAI of 2–4. One example of Woody Island Siltstone contained 1.2% carbon.

Since 1984 exploration licences covering much of central and southern Tasmania have been held by Conga Oil Pty Ltd and the related, successor companies Condor Oil Investments Pty Ltd and Great South Land Minerals Limited. In the 1980s a large amount of infill gravity and reconnaissance magnetic data were gathered in southern Tasmania to elucidate first-order structure in the Tasmania Basin and basement geology. Geochemical studies of bitumens, sediments, water samples and extracts from potential source rocks were undertaken (Bendall *et al.*, 1991). Work was initially concentrated on the possibility of oil generation from the Gordon Group limestone but more recent exploration has been premised on sources within the Tasmania Basin, particularly the tasmanite. Since 1994 these companies have carried out nearly 4 km of drilling at seven separate sites in the Tasmania Basin, including a 1750 m hole to basement (Shittim-1) on North Bruny Island. Methane and C2–C6 hydrocarbons have been detected in cuttings gas and trip gas in some of these holes (see page 16).

The concept of the tasmanite being prospective as both a source and a reservoir for oil, by analogy with the Spraberry Formation in Texas, was developed by exploration companies in the 1980s. The Spraberry Formation is a 300 m thick package of black shale, siltstone, limestone and dolomite, with oil production from siltstone reservoirs at an average depth of 2200 metres. These siltstones have a primary porosity of 8% and a permeability of 0.5 millidarcies (Wilkinson, 1953), so fracture stimulation and pumping are required to enable oil to be produced from the formation.

A total of 203 exploration permits have been held in Tasmania to search for oil (see Appendix 4), not counting the 'permits to enter' held over private property in the Mersey Valley in the 1920s, and permits held solely to search for oil shale. Some 63% of the oil exploration permits were issued between 1920 and 1925, no doubt in response to the Commonwealth offer of a reward of £10,000 for the discovery of a payable oil deposit anywhere in Australia.

CONCLUSIONS

A dolerite quarry near Lonnavale is the only known place in Tasmania where hand sample-sized pieces of naturally occurring *in situ* bitumen may be viewed. Of the many reports of oil and gas seeps made to the Department of Mines, most have been proved to have been caused by phenomena other than petroleum hydrocarbons. The six seeps considered genuine by A. M. Reid have not since been reported by anyone, and we have no evidence as to whether they may be regarded as authentic seeps or not.

Many examples of coastal bitumen have been documented, and some of the material has been profitably used by collectors. These bitumens are probably derived from Indonesian oil sources, and have been washed up onto the Australian coastline by currents and tides.

A number of rock types in Tasmania contain trace quantities of petroleum hydrocarbons. As rocks of appropriate chemical composition have undergone a suitable thermal history, the generation of small quantities of petroleum hydrocarbons is to be expected. Some occurrences of bitumen, sometimes grading to protographite, can be found in metasediments in many areas of Tasmania. Such occurrences undoubtedly result from the metamorphism of organic-rich sediments by some igneous or tectonic heat source. To date, none of the analysed occurrences of such phenomena constitute a petroleum seep as would be recognised by the petroleum industry.

Nonetheless, some rocks which may be considered potential source rocks do exist in the Ordovician Gordon Group, and they definitely occur in the Carboniferous–Permian oil shales containing marine algae and the terrestrial sediments such as the Preolenna Coal Measures. It is encouraging that some of these latter sediments have entered, or are still within the 'oil window', although to date there is no tangible evidence that significant quantities of oil have been produced.

A fortuitous combination of source rock, reservoir and trap leads to the development of a play concept — and some hope that commercial accumulations of petroleum hydrocarbons can be found. Plays can be readily found with the information available for offshore Tasmania, but the same studies onshore are still at a preliminary stage.

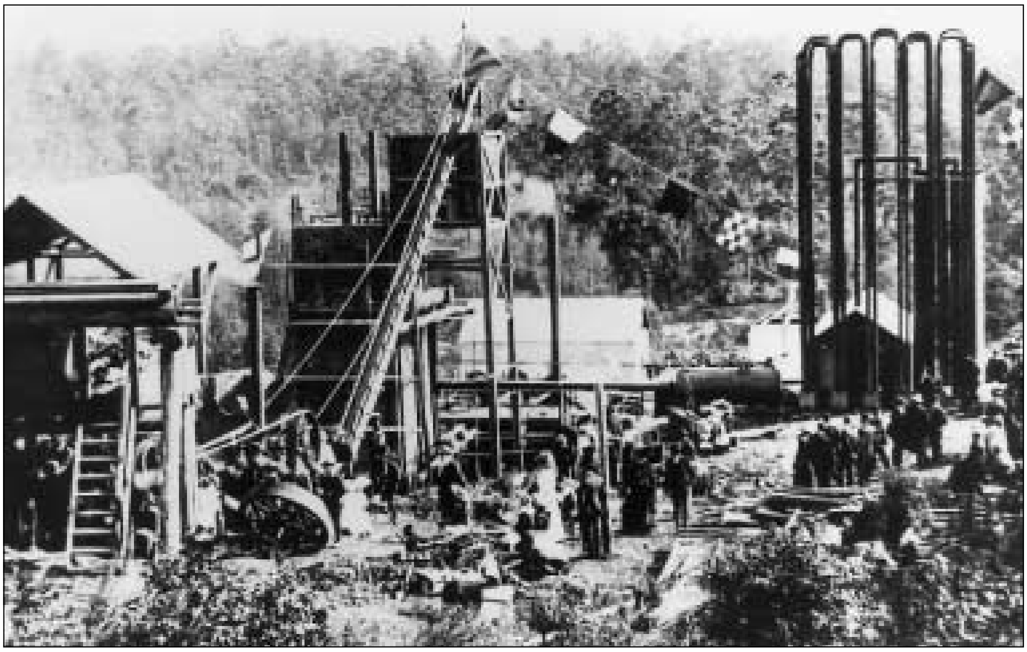

Plate 1

Opening day at the shale works on the eastern side of the Mersey River, 1912

(Latrobe Museum Historical Collection)

Plate 2

Southern Cross Motor Fuels Ltd oil shale mine near Latrobe, 1923

Plate 3

Australian Shale Oil Company plant, showing retort, condenser and storage tank (ca. 1926–1931)

(Latrobe Museum Historical Collection)

Plate 4

Australian Shale Oil Company condensing plant (ca. 1926–1931)

(Latrobe Museum Historical Collection)

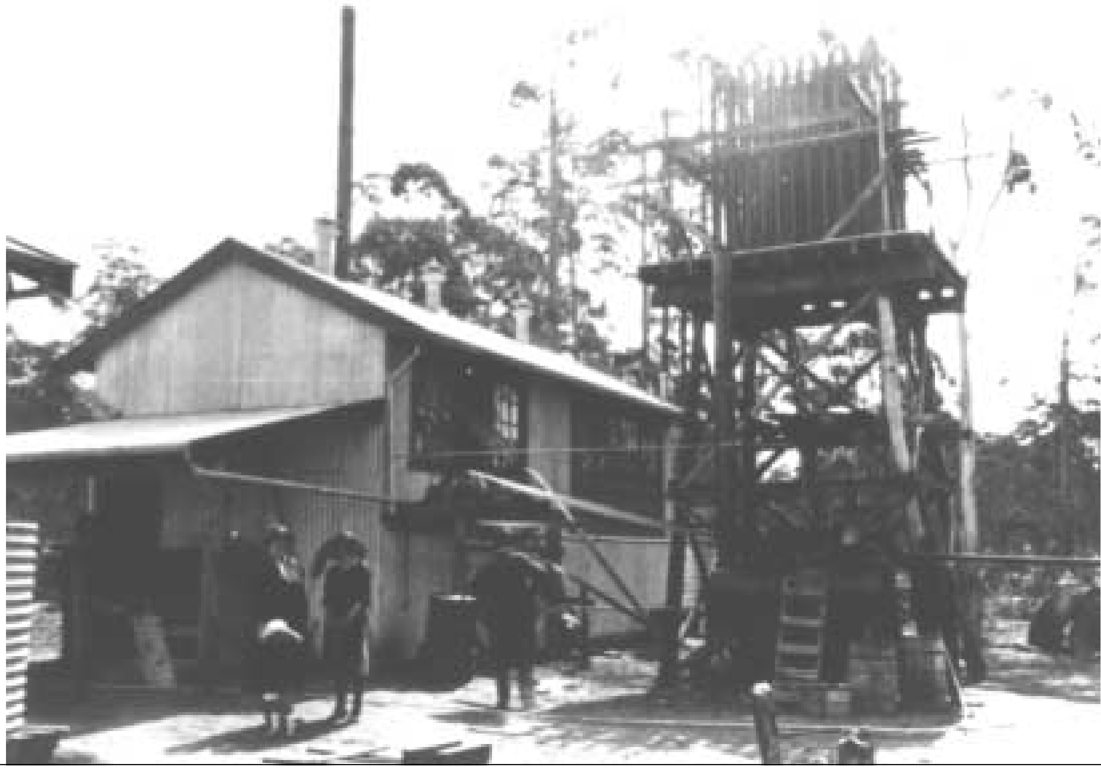

Plate 5

Condensing plant near Mersey River, date unknown

(Latrobe Museum Historical Collection)

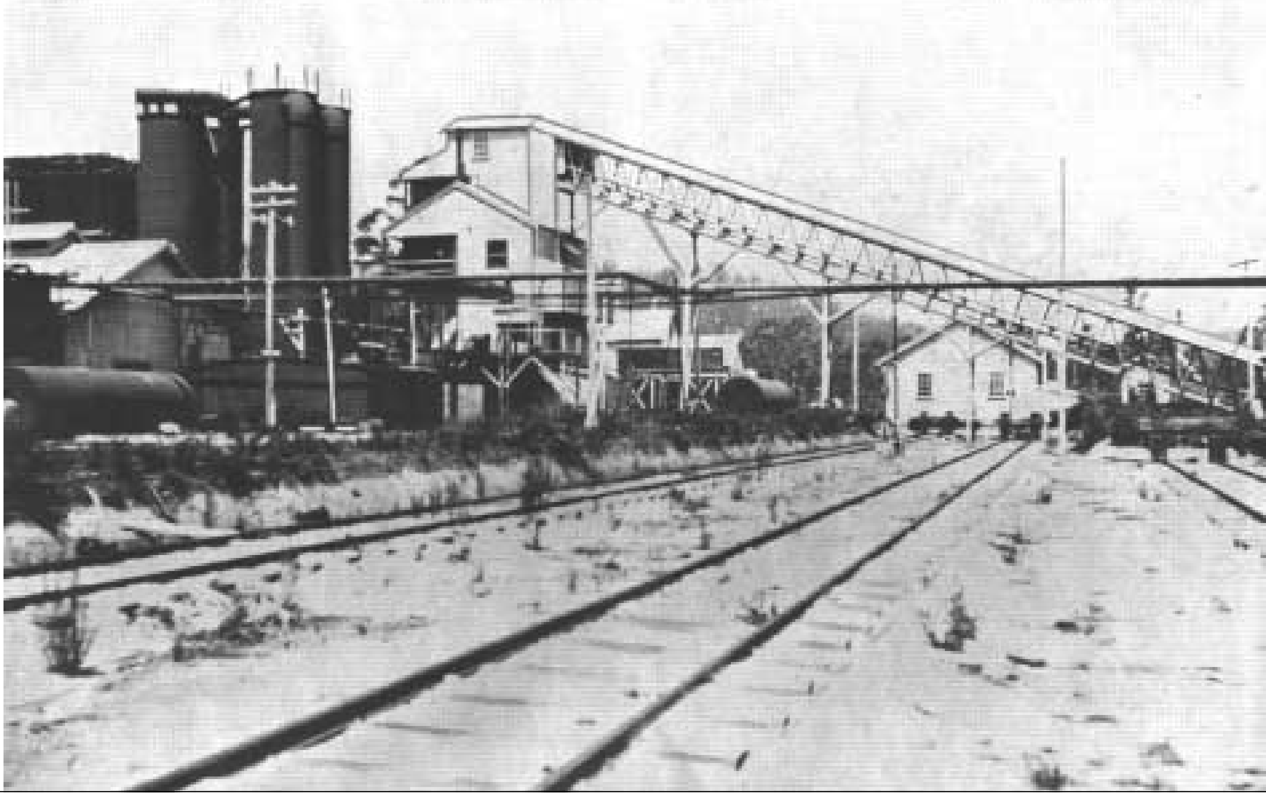

Plate 6

Australian Shale Oil Company works near Latrobe, 1928

Plate 7

Vacuum Oil Company vehicle, late 1930's

(Queen Victoria Museum and Art Gallery QVM:1991:P:127)

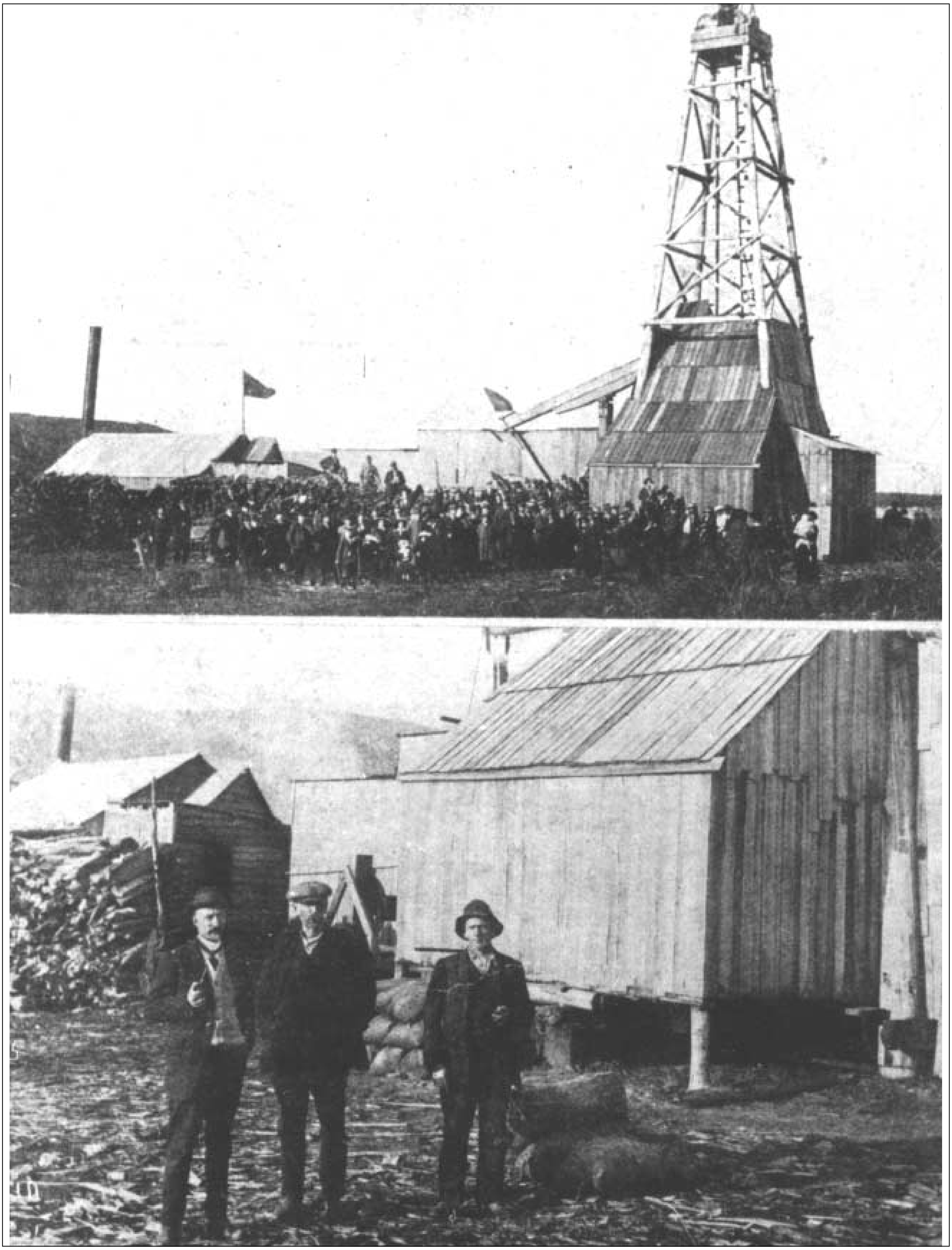

Plate 8

Drilling at Andrews Bore, Bruny Island, 1915
(Tasmanian Mail, 29 June 1916)
(Top) Visitors from Hobart visiting the site works
(Bottom) The company's staff G. R. Andrew (Superintendent), A. McDonald (Driller),
C. Koslowski (Assistant Driller)

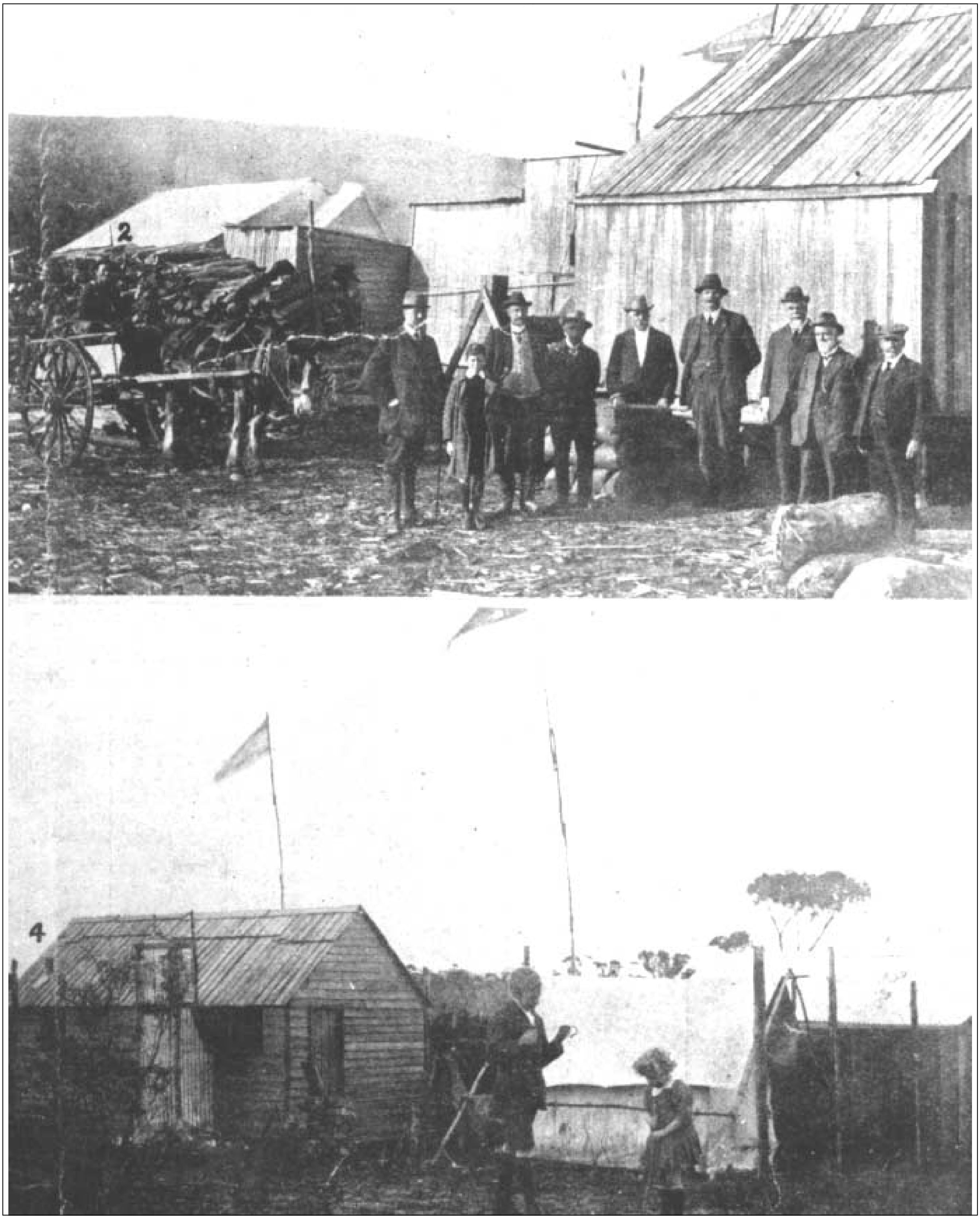

Plate 9

Drilling at Andrews Bore, Bruny Island, 1915
(Tasmanian Mail, 29 June 1916)

(Top) Some of the Directors visiting the site works
(Bottom) The camp at Bruny Island

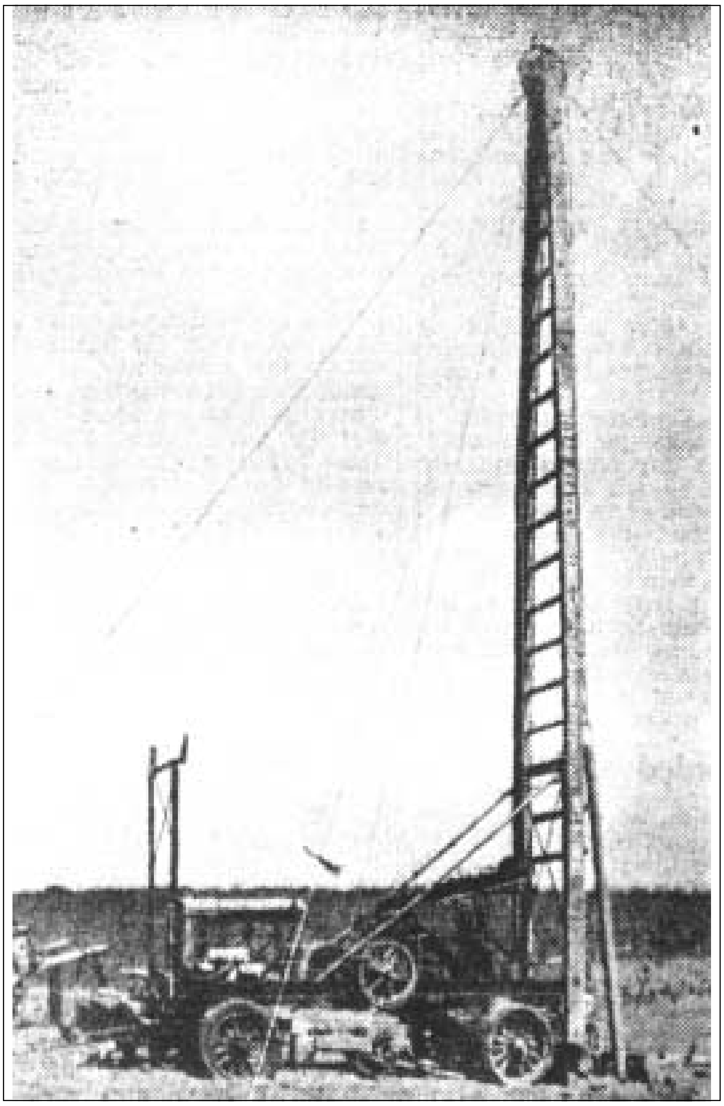

Plate 10

Tasmanian Oil Bore No. 1, drilled at Danbury Park near Launceston in 1939 by Producers Oilwell Supplies Ltd

(The Mercury)

Plate 11

Drilling by Mr Sulzberger at Port Sorell, 1966. Mr Lee and a drilling bit (The Advocate)

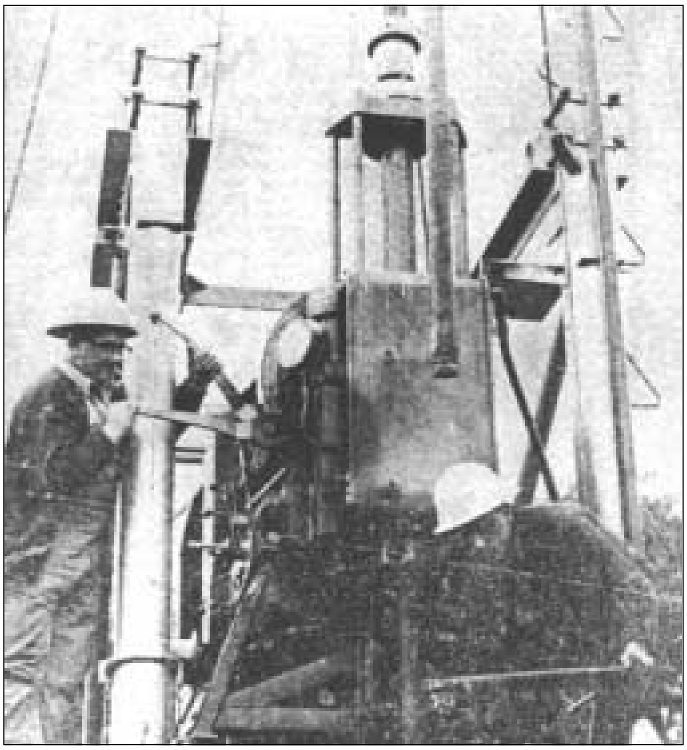

Plate 12

Drilling by Mr Sulzberger at Port Sorell, 1966. Mr Lee and the drilling rig (The Examiner)

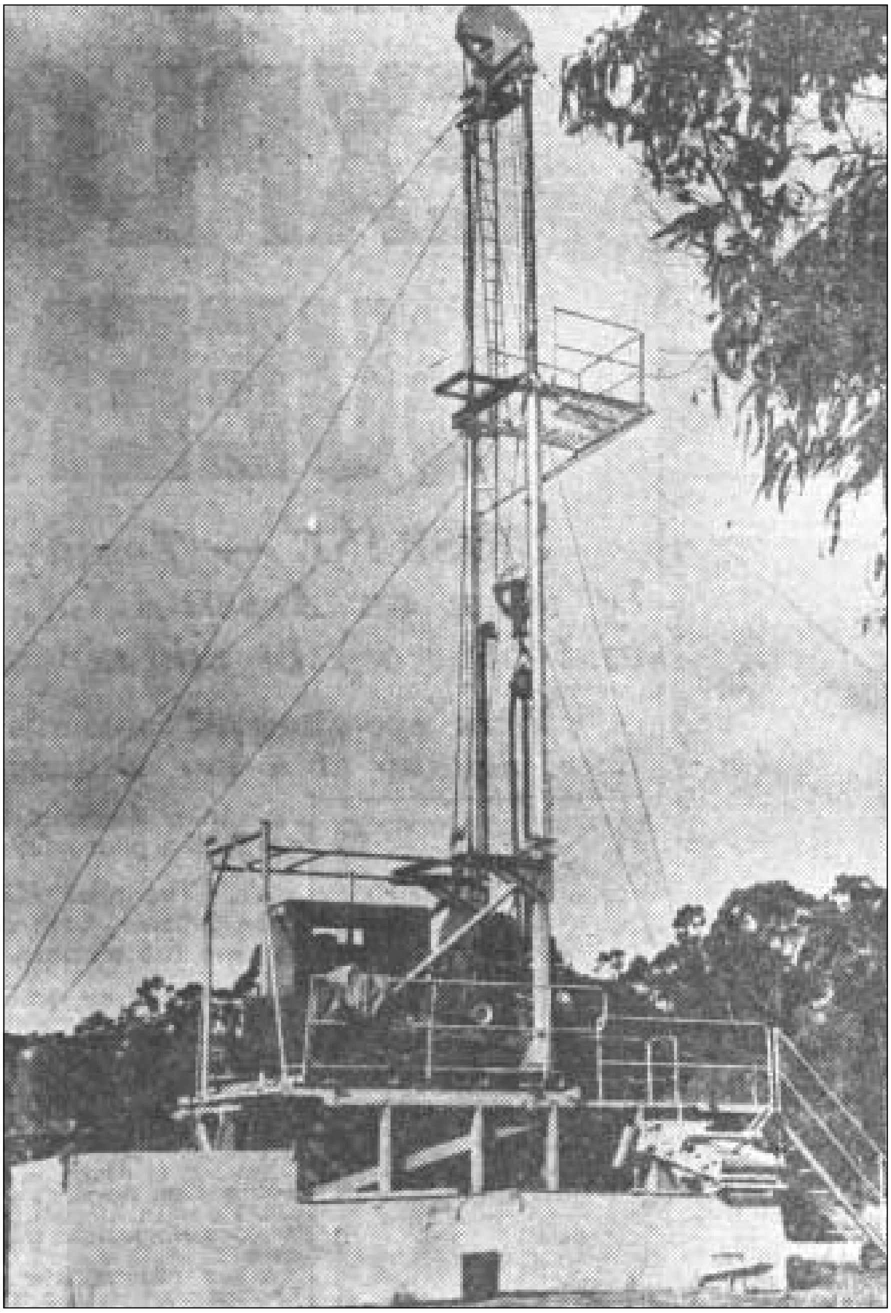

Plate 13

The drilling rig, imported by C. G. Sulzberger in 1963, on location at Parkers Ford, near Port Sorell

(The Advocate)

Plate 14 (below)

Drill rig used to deepen hole Shittim 1 on Bruny Island in 1996

Geological Setting

About half of Tasmania is covered by the erosional remnant of a shallow epicratonic basin of Late Carboniferous to Jurassic age known as the Tasmania Basin (fig. 6). This basin is underlain by deformed Devonian and older basement rocks, which also comprise most of the remaining surface area of Tasmania. Both the basement and the Tasmania Basin may be locally prospective for hydrocarbons (see Burrett and Martin, 1989; Leaman, 1992; Seymour and Calver, 1995 for reviews of Tasmanian geology).

Basement

A diverse and structurally complex array of Proterozoic and lower Palaeozoic rocks comprises basement to the Tasmania Basin. Of the basement rocks, only the Wurawina Supergroup — a Late Cambrian to Early Devonian shelf carbonate and clastic succession — is considered to have petroleum potential given current information. The basement rocks have been affected by a mid-Devonian tectono-metamorphic event correlated with the Tabberabberan Orogeny.

Wurawina Supergroup

The Wurawina Supergroup consists of Late Cambrian to Early Ordovician, shallow marine to fluvial siliciclastic rocks (the Denison Group) overlain by about 1.5 km of predominantly micritic, shallow-marine, warm-water Ordovician limestone (Gordon Group), then up to 5 km of shallow marine, Silurian to Early Devonian siliciclastic rocks (the Eldon Group).

A regional conodont alteration index (CAI) study (Burrett, 1992) of the Gordon Group carbonates shows that these rocks are mature for hydrocarbon generation in southern Tasmania (CAI typically between 1.5 and 4). By contrast, the rocks are overmature in western and northern Tasmania (CAI mainly 5).

Maturation is likely to have been brought about by high heat flow during the Tabberabberan Orogeny (Burrett, 1992), during which gentle to moderate folding affected the Wurawina Supergroup in southern Tasmania. In western Tasmania, the Gordon Group limestone appears to have been subjected to deeper burial (an overburden of 5 km of Eldon Group sediments is preserved in the deepest synclinoria: Calver, *in* Banks and Baillie, 1989, p. 230) and Devonian deformation was more intense.

The generalised distribution of the major basement rock types concealed beneath the Tasmania Basin has been inferred from gravity and magnetic data (Leaman, 1990, 1991, 1996*b*; Gunn *et al.*, 1996). The distribution of the Wurawina Supergroup in southern Tasmania, including the inferred subsurface distribution and generalised CAI contours, is shown in Figure 6.

Tasmania Basin

The Tasmania Basin is a shallow epicratonic basin (Veevers, 1984) which contains a succession of predominantly flat-lying sedimentary rocks of Late Carboniferous to Late Triassic age, known as the Parmeener Supergroup. This succession has been intruded by thick sheets and sills of Jurassic dolerite that currently occupy most of the outcrop area of the basin. The total known maximum thickness of the succession (excluding the dolerite) is 1.7 kilometres. The Tasmania Basin covers most of central and eastern Tasmania (fig. 6). The present basin limits are erosional, not depositional, and the original basin was probably considerably larger. The succession was deposited on an uneven basement with a relief of about one kilometre. Basement highs consist largely of Proterozoic quartzitic rocks in the west, and Devonian granitic rocks in the east. The main depocentre appears to have lain along a meridional zone extending roughly through Cygnet, Hobart and the Midlands (Banks and Clarke, 1987). The thin and incomplete succession in far northeast Tasmania suggests proximity to a basin margin in this area.

The provincialism of the cold-climate Gondwanan biotas hinders precise correlation with international biozonations. However, correlation within Tasmania is well established, with a detailed local biostratigraphic framework based on marine macroinvertebrates in the Lower Parmeener Supergroup (Clarke and Banks, 1975; Clarke and Farmer, 1976; Clarke, 1989) and on palynomorphs (e.g. Truswell, 1978; Truswell *in* Calver *et al.*, 1984; Forsyth, 1989*b*). The locally-defined faunal zones (Clarke and Farmer, 1976) are indicated on Figure 7.

Lower Parmeener Supergroup

The Lower Parmeener Supergroup, of Upper Carboniferous to Upper Permian age, consists largely of glacigene and shallow-water glaciomarine rocks resting on a landscape unconformity with a relief of about 1000 metres. In many areas, the succession begins with a unit of tillite, diamictite and minor rhythmitic claystone that reaches a maximum thickness of over 500 m near Wynyard (Wynyard Tillite) and over 580 m at Cygnet (Truro Tillite) (Clarke and Banks, 1975; Hand, 1993).

The basal glacigene rocks are succeeded by a unit of carbonaceous, pyritic mudstone up to 250 m thick, known as the Woody Island Siltstone in southern Tasmania and the Quamby Mudstone in the north. Just above the base of this unit, 'tasmanite' up to about two metres thick is locally present in northern Tasmania. 'Tasmanite' is the rock name for an oil shale consisting of a high proportion of the probable green alga *Tasmanites punctatus* (Church, 1864; Newton, 1875; Twelvetrees, 1912). The Woody Island Siltstone and correlates, including the tasmanite, are the main

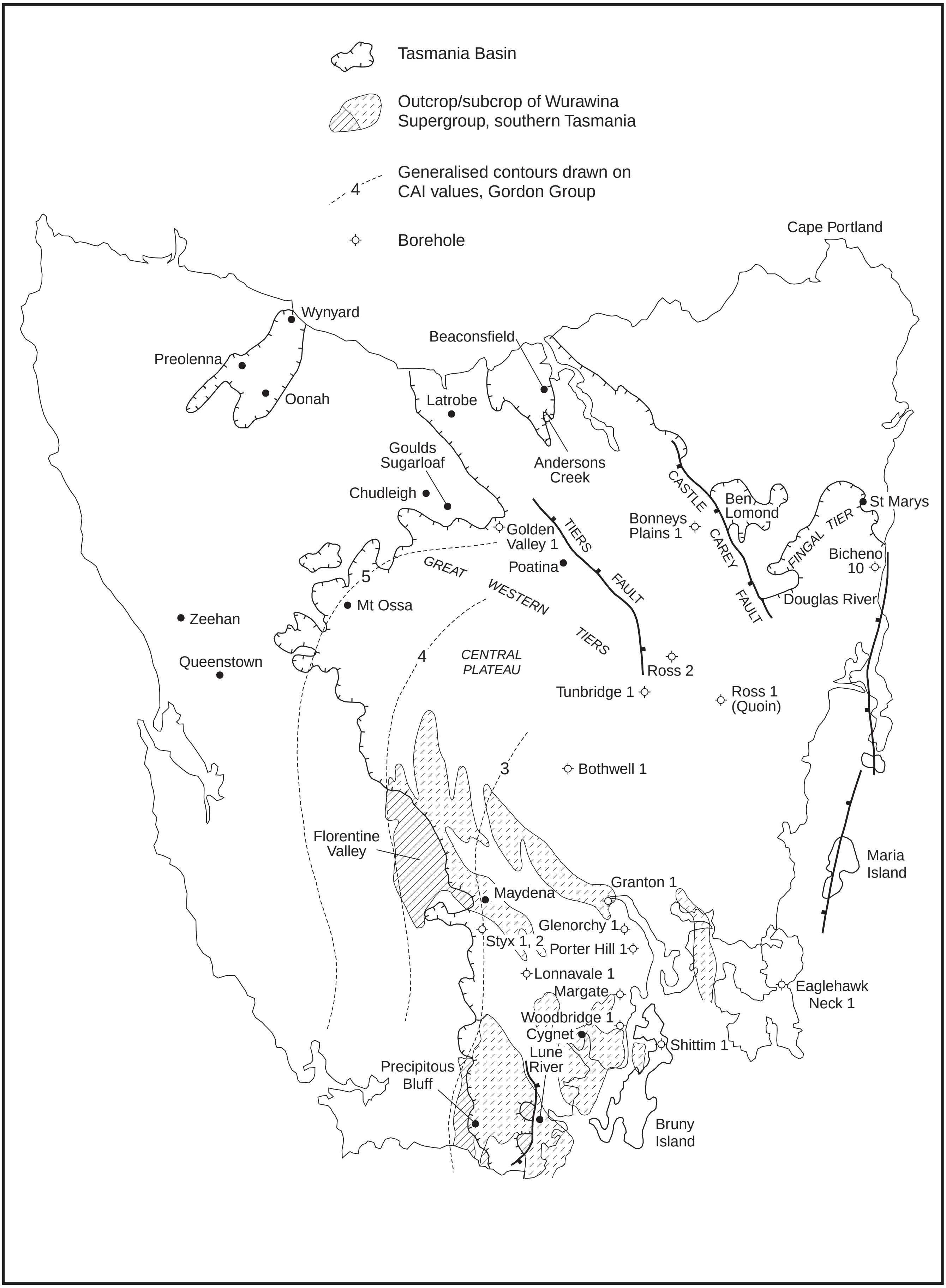

Figure 6

Tasmania Basin and major drillholes. Also shown is outcrop and inferred subsurface extent of Ordovician–Devonian basement rocks in southern Tasmania that may be mature for oil and gas generation. Subsurface distributions based on Leaman (1996b). Generalised CAI contours from Burrett (1992).

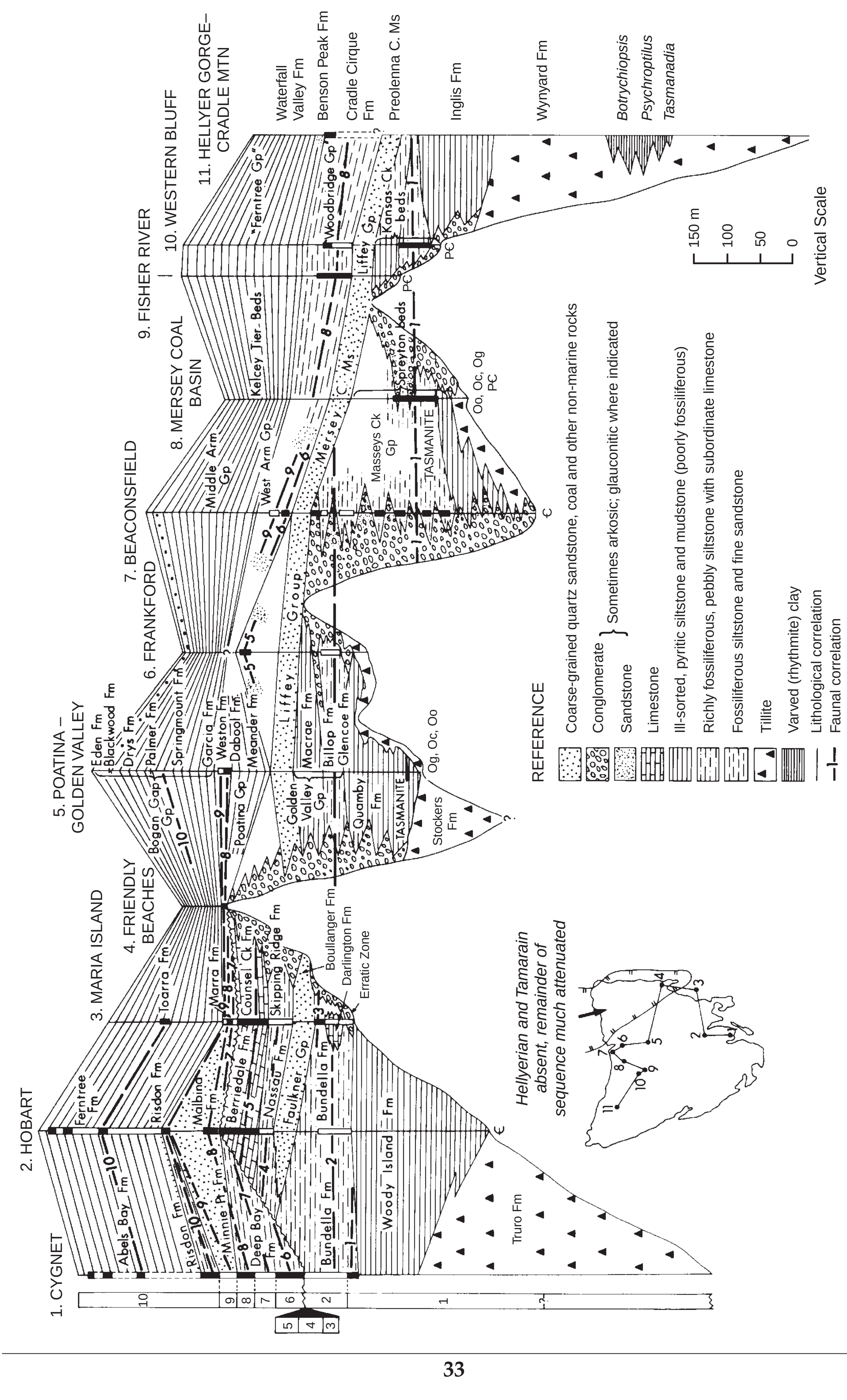

Figure 7. *Correlation diagram of stratigraphic columns through the Lower Parmeener Supergroup (from Clarke and Forsyth, 1989).*

potential source rocks within the Tasmania Basin and are described in more detail below.

The Woody Island Siltstone and correlates pass up into richly fossiliferous siltstone, sandstone and minor limestone (the Bundella Formation and correlates, including the Golden Valley Group in the north). Ice-rafted dropstones are common in these rocks. This sequence is nearly everywhere succeeded by a thin (20–40 m) unit of fluvial to paralic origin (the Lower Freshwater Sequence, also known locally as the Faulkner Group, the Liffey Group or the Mersey Coal Measures). Well-sorted, cross-bedded quartzarenite is characteristic, but siltstone and carbonaceous mudstone is dominant in the southeast near what is inferred to have been the seaward margin of the coastal plain. A thin marine intercalation is present in southeast and central Tasmania. Lateral equivalents of the Lower Freshwater Sequence are wholly marine in the far southeast (Farmer, 1985). Thin coal seams, aggregating just over one metre, are present in the north, northwest and northeast, around the landward margin of the basin (Banks and Clarke, 1987) (fig. 8).

In southeast and eastern Tasmania the Lower Freshwater Sequence is succeeded by marine calcareous siltstone (Nassau Formation and correlates), then bioclastic (bryozoal-crinoidal) limestone (Berriedale Limestone and correlates), which together comprise the Cascades Group, roughly 100 m in maximum thickness. Rocks of this age (mid to late Bernacchian) are absent from most of northern and western Tasmania, which were probably emergent at this time (Clarke and Banks, 1975). Lonestones are present and cold-water conditions persisted throughout deposition of the limestone (Rao, 1981).

Preliminary unpublished work by D. E. Leaman on thickness variations between biostratigraphic markers in the Cascades Group indicates some rifting or growth faulting, and the presence of minor tuffs indicates contemporaneous volcanism. Fault boundaries are not yet identified with confidence due to lack of work, limited exposure and complex dolerite intrusions.

Uplift in southern Tasmania resulted in local erosion down to the level of the Bundella Formation, and a more widespread disconformity at the top of the Berriedale Limestone, before renewed marine sedimentation of the lower Lymingtonian Stage (Farmer, 1985). These rocks (Malbina Formation, Deep Bay Formation and correlates) are dominantly fossiliferous siltstone and poorly-sorted sandstone in which ice-rafted lonestones are common. Thicknesses reach a maximum of 180 m along the meridional axis of the basin but thin rapidly to the west and northeast, the latter area being marked by condensed shallow-water glauconitic sandstone in places only a few metres thick.

The upper Lymingtonian is represented by the uppermost Malbina Formation and the Ferntree Formation and its correlates, including the Abels Bay Formation. These sequences are characterised by a predominance of bioturbated, unfossiliferous siltstone of probable brackish-estuarine environment, and minor fossiliferous intervals representing brief fully-marine incursions in the southeast. Invertebrate affinities suggest a Kazanian age (Clarke, 1987). There are two or more thin (a few metres) coarse-grained units probably representing brief regressions (Risdon Sandstone, Blackwood Conglomerate). This succession is thickest (180 m) in the southeast, and thins to the northeast and northwest. Basement highs in far eastern Tasmania (e.g. Friendly Beaches, Maria Island) were finally buried beneath the depositional surface at this time. At the top of this succession in many areas, there is a transition over several metres into the Upper Parmeener Supergroup, although there is commonly an erosional disconformity at the base of the Upper Parmeener Supergroup, for example in the northeast (Turner and Calver, 1987).

Units viewed as potential reservoirs in the Lower Parmeener Supergroup include the Lower Freshwater Sequence, various marine sandstone units, and the Berriedale Limestone (Maynard, 1996; Rao, 1997; and see below).

Upper Parmeener Supergroup

The Upper Parmeener Supergroup, a non-marine succession of Late Permian to Late Triassic age, has been divided into four lithological units (Leaman, 1971; Forsyth, 1989*b*).

Unit 1 corresponds to the Late Permian Cygnet Coal Measures (*sensu* Farmer, 1985) and correlates. The unit consists of well-sorted, cross-bedded sandstone — feldspathic in southern Tasmania, but tending to be more quartz-rich and micaceous in the north — and carbonaceous siltstone and mudstone. Thin coal seams are present in the far southeast (Cygnet–Bruny Island) and in the northwest (Mt Ossa). The unit is thickest in the west (108 m) and in most other areas is around 50 m thick, but wedges out to the northeast, at least partly because of erosion prior to the deposition of Unit 2.

Unit 2 is 200–300 m thick but is thinner in the northeast. This unit consists predominantly of well-sorted quartzarenite, with a widespread lutite-dominated interval, 20–60 m thick, at the top of Unit 2; and 35 m of lutite in the middle of the unit at Hobart. Conglomeratic horizons are common in the northwest. The sequence was deposited from low-sinuosity rivers flowing east or southeast. The unit is widely distributed and may have originally extended across western Tasmania, but wedges out against high basement in the northeast. A microflora near the middle of the unit is assigned a Greisbachian to mid-Smithian age. Other microfloras and macrofloras near the top of Unit 2 are mid-Smithian to pre-Anisian (Forsyth, 1989*b*).

Unit 3 begins with an impersistent quartz granule conglomerate, which is pebbly in places and around five metres thick, overlain by interbedded quartz sandstone, lithic sandstone and lutite. Then follows an interval, about 80 m thick in the southern Midlands, of interbedded lithic sandstone and lutite. Lithic grains are

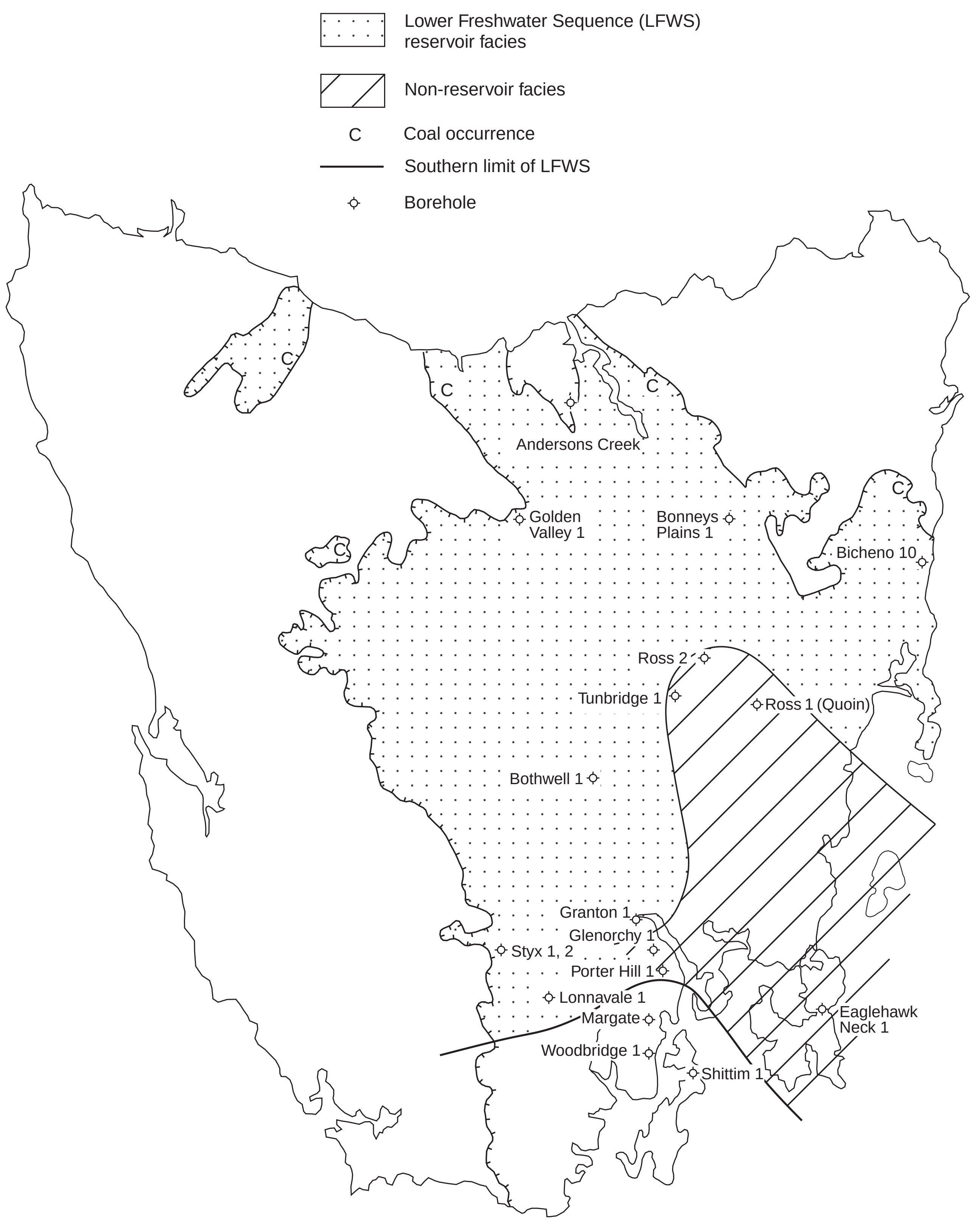

Figure 8

Palaeogeography of the Lower Freshwater Sequence, and inferred, highly generalised distribution of reservoir and non-reservoir facies.

mostly of fine-grained felsic volcanic type. Unit 3 concludes with an interval, 100 m thick in the Midlands but thinner elsewhere, of quartz sandstone interbedded with lutite and minor lithic and feldspathic sandstone. Thin coal seams are locally present. In far eastern Tasmania, this uppermost interval overlaps all older units of the Upper Parmeener Supergroup to rest directly on eroded Lower Parmeener Supergroup, and basalt flows are locally present. Microflora indicate a Middle Triassic (Anisian to Ladinian) age for Unit 3.

Unit 4 is predominantly lithic sandstone with minor lutite and coal, and the thickest preserved sections are in the northeast (maximum ca. 350 m). Unit 4 contains all of Tasmania's economic coal reserves, also mostly located in the northeast (Bacon, 1991), where eight or more seams or groups of seams are present. The base of Unit 4 is transitional on Unit 3 and is diachronous, being slightly older in the northeast than elsewhere. The lithic sandstone is largely of intermediate to felsic volcanic provenance, and there are rare, thin (<1 m) felsic tuffs high in Unit 4 (Bacon and Everard, 1981). There are also rare conglomerates with common rhyolitic clasts. A calc-alkaline volcanic source, probably to the east of Tasmania, is indicated. Unit 4 is characterised, almost throughout, by Carnian microfloras. The youngest preserved part of Unit 4 is a lutite-dominated interval about 100 m thick near Douglas River, with Norian microfloras.

Jurassic dolerite

A large volume of tholeiitic dolerite was intruded into the Tasmanian crust in the Middle Jurassic, mainly as sheets in the flat-lying sediments of the Tasmania Basin. These sheets are typically 400–500 m thick, and dolerite is currently exposed over most of the area of the Tasmania Basin. Styles of intrusion have been described by Leaman (1975, 1976, 1997*a*).

Basalt flows near Lune River, in far southern Tasmania, associated with Jurassic(?) plant-bearing sediments, are the only known extrusive occurrences of this phase of magmatism (Hergt *et al.*, 1989).

Dolerite sills, unroofed by erosion, are underlain by rocks as young as Norian. A younger cover of unknown thickness, now entirely removed by erosion, can be inferred. Attempts to constrain the thickness of the cover by inferring burial depths are inconclusive (Hergt *et al.*, 1989), but there is circumstantial evidence for at least 800 m of post-Norian cover at the time of dolerite intrusion (Everard, *in* Turner and Calver, 1987).

In general, contact metamorphism is limited to the immediate vicinity of intrusions; thus a magma of low heat capacity and low in volatiles is indicated. Metamorphism is more severe over the roof of intrusions.

Intrusion of the dolerite was probably related to tensional stresses that heralded the rifting of Australia and Antarctica in the mid-Cretaceous (Veevers and Ettreim, 1988). An average of widespread whole-rock and feldspar K-Ar ages is 174.5 ± 8.0 Ma (Schmidt and McDougall, 1977). Multiple intrusions have been recognised in places (e.g. Leaman, 1975), but the magma appears to have been compositionally uniform.

Inferred Jurassic–Cretaceous sediment cover

A regional apatite fission track (AFT) study shows that most of the rocks currently exposed at the surface in Tasmania, including Jurassic dolerite, have mid-Cretaceous or younger AFT ages (O'Sullivan and Kohn, 1997). This implies that these rocks were at a temperature of 95°C or more up until the mid-Cretaceous, and a superincumbent succession, 2.5–4 km thick and now entirely removed by erosion, has been inferred (O'Sullivan and Kohn, 1997). Maturation criteria in the Parmeener Supergroup and other considerations discussed below suggest that this succession was somewhat thinner (<2 km). Sutherland (1977) suggested burial depths of about two kilometres for the Jurassic dolerite, based on zeolite mineralogy. By analogy with sediments preserved in Tasmania's offshore basins (the Bass and Sorell Basins), the superincumbent succession may have comprised volcaniclastic rocks of Late Jurassic to mid-Cretaceous age (correlates of the Otway Group and Strzelecki Group). The AFT data provide useful constraints on the timing and degree of maturation of the subsurface Tasmania Basin (see below).

The Otway, Bass and Gippsland Basins to the north of Tasmania experienced high geothermal gradients (ca. 65°C/km) immediately before mid-Cretaceous cooling. Cooling was accomplished through a rapid decline in geothermal gradient (to present day levels, ca. 35°C/km) combined with uplift and erosion (Duddy *et al.*, 1997). Onshore Tasmania may have experienced a similar decline in geothermal gradient.

Cretaceous igneous rocks

Small intrusions of Cretaceous alkaline igneous rocks occur in the southeast (Cygnet–Oyster Cove area) and in the far northeast (Cape Portland). The Cygnet rocks occur as a series of sheet-like bodies a few tens of metres thick and as numerous, widely dispersed smaller sills, dykes and pipes (Farmer, 1981; 1985). The rocks are principally intruded into the lower stratigraphic units of the Lower Parmeener Supergroup with radiometric dates indicating mid-Cretaceous emplacement (100.5 ± 3 Ma). A combined regional magnetics/gravity interpretation suggests a large syenite laccolith, 750 m thick, lies close to the surface at Cygnet (Leaman, 1990). This appears to have domed the Lower Parmeener Supergroup around Cygnet. Regional heating associated with the syenite intrusions is thought to have caused carbonisation of organic matter (as seen in palynological preparations) from the Parmeener Supergroup throughout the Cygnet–Oyster Cove–Woodbridge district (Farmer, 1985).

Tertiary sediments

There are widespread, patchy developments of Tertiary terrestrial sediments and basaltic volcanic rocks in

Tasmania. The thickest successions occur in grabens and have been unsuccessfully explored for petroleum in the past. The sediments are immature with respect to petroleum generation. The thickest known onshore Tertiary succession is preserved in the Longford Sub-basin, which contains up to 800 m of mainly Eocene sediments (Matthews, 1983).

Structure

The Parmeener Supergroup is essentially sub-horizontal. However the intrusion of the Jurassic dolerite and widespread Cretaceous to Early Tertiary normal faulting have resulted in complex structures, particularly in the southern part of the basin. Dips rarely exceed 10° in areas free of Tertiary extensional faulting but in faulted areas dips may exceed 25°.

There is localised evidence of gentle compressional deformation. An outlier near Zeehan displays gentle northwest-trending folds of unknown age (Goscombe, 1991) and there are broad, gentle domes at Hunterson (Fairbridge, 1949), Cygnet (Leaman and Naqvi, 1967; Farmer, 1985) and Forcett. Outcrop-scale folding, concentric in style, occurs at National Park and other localities (Banks, 1962); such folds tend to be associated with major dolerite intrusions or faults. Analysis of fault striations and geometry near Hobart indicates a phase of compression from the NNW, resulting in strike-slip faulting, both before and after dolerite intrusion (Berry and Banks, 1985).

The dolerite intrusions are complex in form, tending to occur as stepped sheets, around 400 m thick, broadly trough-shaped or cone-shaped in section (Leaman, 1975; Turner and Calver, 1987). Virtually every part of the basin has been intruded by at least one such sheet. Feeder pipes occur with an average lateral spacing of 4–13 km (Leaman, 1975; Leaman and Richardson, 1981; Hergt *et al.*, 1989; Leaman, 1990). Only a single sheet intruding the Upper Parmeener Supergroup appears to be present over much of the northern part of the basin (for example, around the northern margins of the Central Plateau, at Ben Lomond and Fingal Tier; e.g. Leaman and Richardson, 1981), with the top of the sheet and superincumbent succession eroded away. In the southern and central parts of the basin, two and even three large sheets are present in many places, and the Lower Parmeener Supergroup is extensively intruded (Leaman, 1975, Farmer, 1981). There may have been four or five main periods of intrusion in the Hobart district, resulting in transgressive and laterally overlapping sheets (Leaman, 1975).

Steep, normal faults of Jurassic to Early Tertiary age are widespread in the Tasmania Basin. Trends are variable, but north to northwest trends are dominant. Fault analysis in the Hobart area indicates an earlier (Mesozoic) phase of strike-slip faulting related to NNW-SSE compression, and a later, early to middle Tertiary phase of normal faulting related to WSW-ENE extension (Berry and Banks, 1985; see also Leaman, 1995). Among the more significant faults affecting the Tasmania Basin are the Tiers Fault, which is partly Jurassic and has a throw of 700–1000 m near Poatina (Matthews *et al.*, 1996); the Castle Carey Fault, with a throw of about 600 m south of Ben Lomond, and the Lune River Fault (fig. 6). The Cascades Fault near Hobart is also partly Jurassic, with a displacement in excess of 1300 m in places.

Potential Source Rocks

Unmetamorphosed sedimentary facies which may constitute potential source rocks in onshore Tasmania exist in strata ranging in age from Ordovician to Tertiary. Most attention has focused on two units potentially capable of supplying hydrocarbons to hypothetical traps within or beneath the Tasmania Basin; the Ordovician carbonate rocks of the Gordon Group, and the Lower Permian dark mudstone of the Woody Island Formation and its correlates, including the tasmanite (e.g. Summons, 1981a; Woods, 1995; Burrett, 1996).

All available source rock pyrolysis data are listed in Appendix 5. These include 63 analyses from the Australian Geological Survey Organisation's ORGCHEM2 database and 41 additional analyses undertaken for this review. Before specific potential source rocks are discussed, some general considerations pertaining to assessment of source potential are discussed.

Assessment of source potential using Maceral analysis and Rock-Eval

The hydrogen content of sedimentary organic matter is the most important factor affecting its potential to generate hydrocarbons (Boreham and Powell, 1994). Optical measurements in reflected-light petrography can be used as an indirect measure of hydrogen content and rely on a classification of the organic component of rocks into the three main organic building blocks (termed macerals), which are liptinite, vitrinite and inertinite. These macerals have strong affinities with structural components of plants and algae (e.g. vitrinite is thought to be derived from the lignitic woody tissue of plants) and as such the macerals show a cursory relationship to chemical composition. Thus liptinitic components are generally hydrogen-rich and are composed of Type I and Type II organic matter (see below), while vitrinite commonly has a lower hydrogen content and is associated with Type III. Inertinite can have hydrogen contents approaching those of vitrinite but it is usually more depleted in hydrogen and is considered to have little to no hydrocarbon generative potential (Tissot and Welte, 1984).

A more direct method used to assess the oil and gas potential relies on a quantitative analysis of the adsorbed organics (bitumen) and those hydrocarbons released on artificial pyrolysis of the organic matter using the Rock-Eval method. A classification of source rock parameters based on this approach is shown in Table 3. Here, the S1 parameter represents the amount

Table 3

Classification of Source Rock Parameters

*Guidelines for interpreting source rock potential**

Quantity	TOC (%)	Rock Eval S2 (mg HC/g rock)	EOM Wt %	HC (ppm)
Poor	<0.5	<2.5	<0.05	<200
Fair	0.5–1	2.5–5	0.05–0.1	200–500
Good	1–2	5–10	0.1–0.2	500–1200
Very good	>2	>10	>0.2	>1200

*Guidelines for interpreting type of petroleum generated from immature sediments (R_0 <0.6%)**

Type	Hydrogen Index (mg HC/g TOC)	Rock Eval S2/S3	Extract Yield (mg HC/gTOC)§	Atomic H/C
Gas	50–200	1–5	<20	0.6–0.9
Gas and oil	200–300	5–10	20–50	0.9–1.1
Oil	>300	>10	50–200	>1.1

Guidelines for interpreting degree of thermal maturation

Maturation Level	Production Index (PI)	T_{max} for Type I	T_{max} for Type II	T_{max} for Type III
Immature	<0.15	<445	<435	<440
Mature	0.15–0.4	445–455	435–460	440–470
Overmature	>0.4	>455	>460	>470

* Modified after Peters (1986) and Espitalié and Bordenave (1993).
§ mature samples

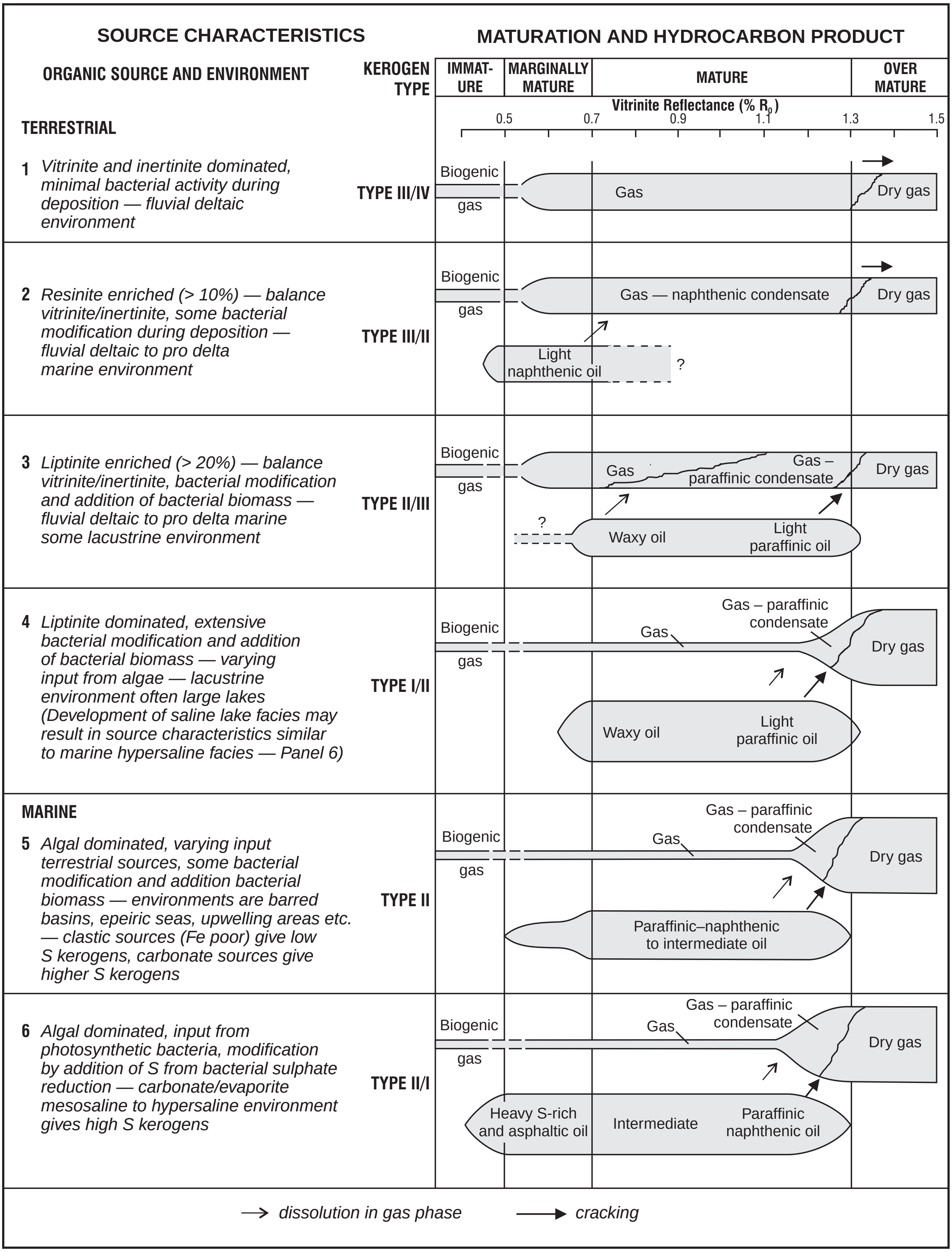

Figure 9

Source characteristics – maturation and hydrocarbon product (from Powell, 1985; reproduced with permission).

of free bitumen that is thermally desorbed from the rock at low temperatures, and is similar to the bitumen yields that can be obtained on extraction from the rock with organic solvents. S2 and S3 are the yields of hydrocarbons and carbon dioxide respectively, released on pyrolysis of the bulk of organic matter. The Hydrogen Index (S2 yield normalised to the organic carbon content; HI = 100*S2/TOC) and Oxygen Index (S3 yield normalised to the organic carbon content: OI = 100*S3/TOC) are directly related to the atomic hydrogen and oxygen content, respectively. Table 3 shows that different rock types can have the same source rock potential (S2), but with different organic carbon contents. For example, carbonate source rocks generally contain marine algal organic matter which is predisposed to moderate hydrogen contents (Type II) and therefore requires a lower initial organic carbon content to generate the same quantities of petroleum compared with a siliciclastic sediment containing hydrogen-poor, Type III organic matter.

Largely in response to an increase in thermal stress, organic matter in buried sediments evolves through the immature, mature ('oil window'), and overmature stages of petroleum generation (Tissot and Welte, 1984). The values in Table 3 show that maturity levels for the 'oil window' depend on the type of organic matter, and encompass a vitrinite reflectance range of Ro 0.5–1.3% and pyrolysis T_{max} temperatures (temperature at maximum rate of hydrocarbon generation during S2 evolution) of 430–470°C. The pyrolysis Production Index (PI = S1/(S1 + S2)) is another measure of maturity, with values ranging from 0.15 to 0.4 normally associated with oil generation. Higher values usually reflect allochthonous bitumen associated with staining from migrating hydrocarbons within the section.

Snowdon and Powell (1982) and Powell (1985) developed a detailed relationship between kerogen type, maturity and hydrocarbon type (fig. 9). Their work shows that the onset of peak generation for paraffinic oils from Type I and Type II kerogens requires Ro 0.7%, but that in siliciclastic sequences, Type II and resinite-rich (a specific liptinite maceral) Type III kerogens will produce naphthenic oils at Ro 0.5%. Likewise in carbonates, algal-derived Types II and I kerogen will generate asphaltic oils at Ro 0.5%.

At maturity, an effective source rock must have sufficient hydrocarbon saturation to overcome the absorption threshold of the remaining carbon in the rock matrix, thus permitting expulsion and migration to a reservoir. For this reason many coals are ineffective source rocks, despite their high TOC.

Assessment of source potential and maturity using biomarkers

Crude oils are composed primarily of hydrocarbons with small amounts of polar functionalised compounds such as porphyrins, and compounds containing sulphur, oxygen or nitrogen (collectively referred to as the NSO fraction or 'resins plus asphaltenes'). Some of these hydrocarbons have distinctive chemical structures that can be related, through reasonable transformation pathways over geological time, to compounds produced by living organisms such as microalgae, bacteria and terrestrial plants. Brief information about these biomarkers is provided below. For more information the reader is referred to Peters and Moldowan (1993).

Hydrocarbons are commonly divided into two classes termed aliphatic and aromatic. Aliphatic hydrocarbons contain either no double bonds (alkanes or saturates), or one or more double bonds (alkenes). Alkanes and alkenes may be straight-chain (e.g. *n*-heptadecane, *n*-C_{17}), branched (e.g. the isoprenoid alkanes pristane and phytane) or polycyclic (e.g. biomarkers such as the steranes and hopanes) (fig. 10). Aromatic hydrocarbons contain from 1 to 5 carbocyclic fused rings with alternating double and single bonds (i.e. conjugated double bonds); common examples in oils include naphthalene (2 ring) and phenanthrene (3 ring) and their alkylated analogues (fig. 10).

The distribution of biomarkers such as steranes, diasteranes, hopanes, methyl hopanes etc. is usually determined by capillary gas chromatography-mass spectrometry (GC-MS) using selected ion monitoring of mass spectral ions characteristic of each class of compound. Ions monitored included isoprenoid alkanes (*m/z* 113 and 183), steranes (*m/z* 217 and 218), 4-methylsteranes (*m/z* 231), hopanes (*m/z* 191), 25-norhopanes (*m/z* 177) and 2-methylhopanes (*m/z* 205). It is important to note that biomarkers represent a very small proportion by weight of an oil and thus they cannot always be used to identify the origin(s) of the total hydrocarbons if they are derived from multiple sources.

Alkanes

Straight-chain alkanes are not biomarkers *sensu stricto* as their structures contain no distinguishing features (other than chain-length) and they can be derived from multiple sources. With few exceptions, oils contain distributions of *n*-alkanes showing little odd or even chain length predominance. The most abundant chain length is a function both of the type of organic matter (lacustrine oils tend to have a high proportion of waxy long-chain C_{25}–C_{35} *n*-alkanes) and of thermal maturity (higher proportions of shorter chain-length alkanes occur with higher maturity). For example, the relatively immature Triassic shale (sample 402075) still exhibits an odd over even predominance in the longer chain lengths, while the more mature Woody Island Siltstone (sample 402099) exhibits a predominance of shorter chain *n*-alkanes (fig. 11). Samples contaminated by diesel have a smooth distribution of shorter-chain *n*-alkanes in the C_{12}–C_{22} range, maximising at *n*-C_{16} –*n*-C_{18}. Unsaturated hydrocarbons (alkenes) are rarely found in petroleum, but can be abundant in high temperature pyrolysis products.

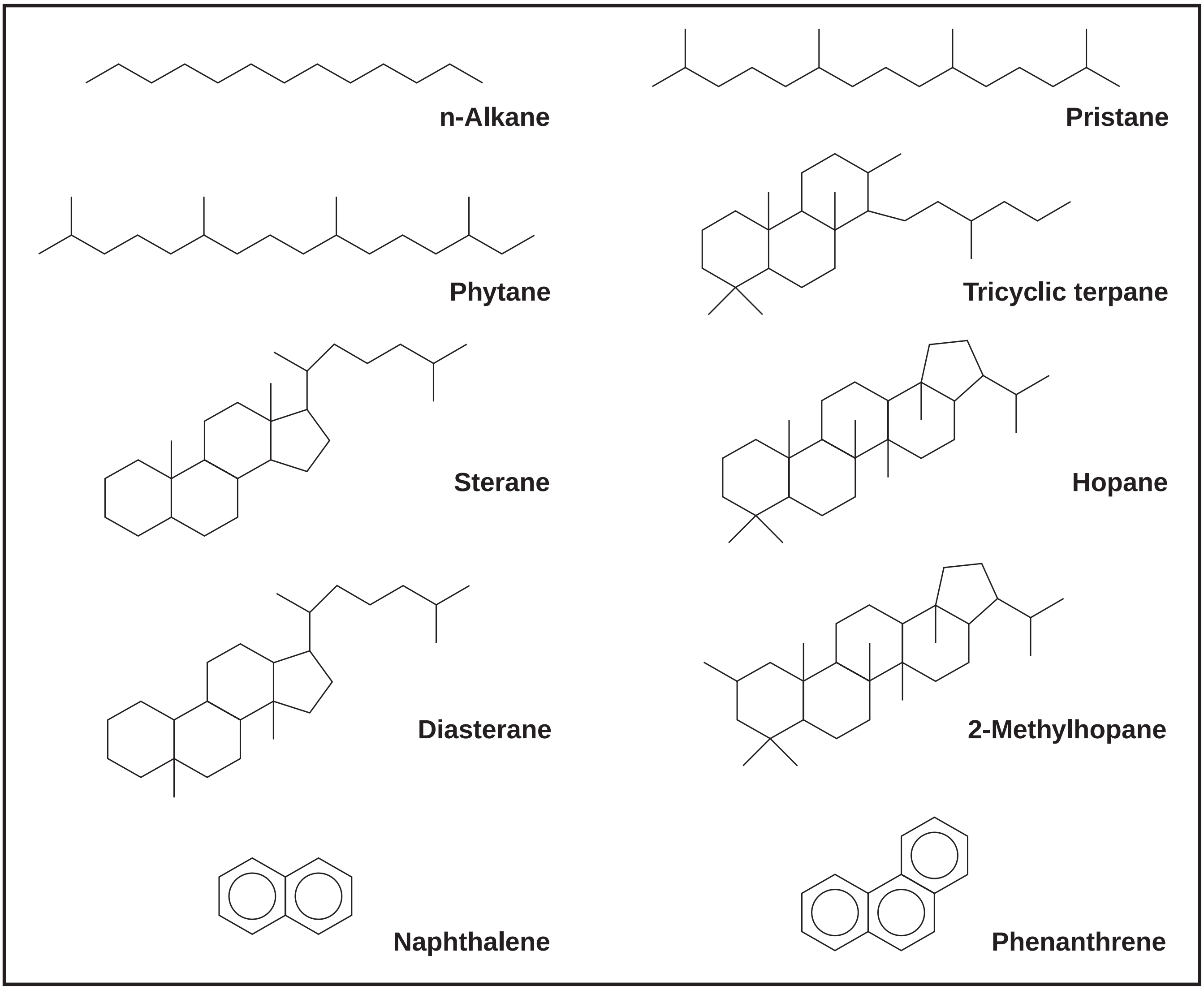

Figure 10

Structures of some common hydrocarbon biomarkers found in oils.

Isoprenoid alkanes

The isoprenoid alkanes pristane (C_{19}) and phytane (C_{20}) are common constituents of most oils but their relative abundances vary greatly. A pristane/phytane ratio of about 1 is typical of oil derived from marine organic matter deposited under reducing conditions (Didyk *et al.*, 1978). Pristane is usually much more abundant than phytane in oil and coal derived from terrestrial organic matter (Volkman, 1988*b*).

Tricyclic alkanes

The most widely occurring tricyclic alkanes in crude oils are the extended chielanthanes which have a long isoprenoid chain attached to the C ring of the tricyclic system (Moldowan *et al.*, 1983). This gives rise to a carbon number distribution from C_{19} to C_{35} (or higher) which is readily determined from the same *m/z* 191 mass fragmentogram used to fingerprint hopanes. In crude oils, the 13β,14α-isomers predominate with 22R and 22S doublets occurring for higher homologs. Extended tricyclic alkanes dominate the biomarker distributions in the tasmanite (Revill *et al.*, 1994), and in the Tasmanian context are most likely to indicate that the hydrocarbons originate from *Tasmanites*-associated source rocks. The oil shale also contains distinctive aromatic hydrocarbons related in structure to the tricyclic alkanes (Revill *et al.*, 1993).

Steranes and diasteranes

Steranes are widely used to fingerprint petroleum. These compounds are produced by a sequence of oxidation-reduction reactions in sediments from the sterols derived from living organisms. These processes tend to leave the side-chain intact and so different proportions of C_{27}, C_{28} and C_{29} constituents can be used to characterise the oil. Steranes occur in a number of isomeric forms having different stereochemistries at positions 5, 14, 17, 20 and 24; all but the latter are separable on non-polar capillary columns so that sterane distributions are quite complex. The ratio of 5α(H),14α(H),17α(H) to 5α(H),14β(H),17β(H)-steranes (abbreviated to ααα/αββ) is often used as an index of thermal maturity, but most crude oils have similar proportions of these isomers which limits the use of this

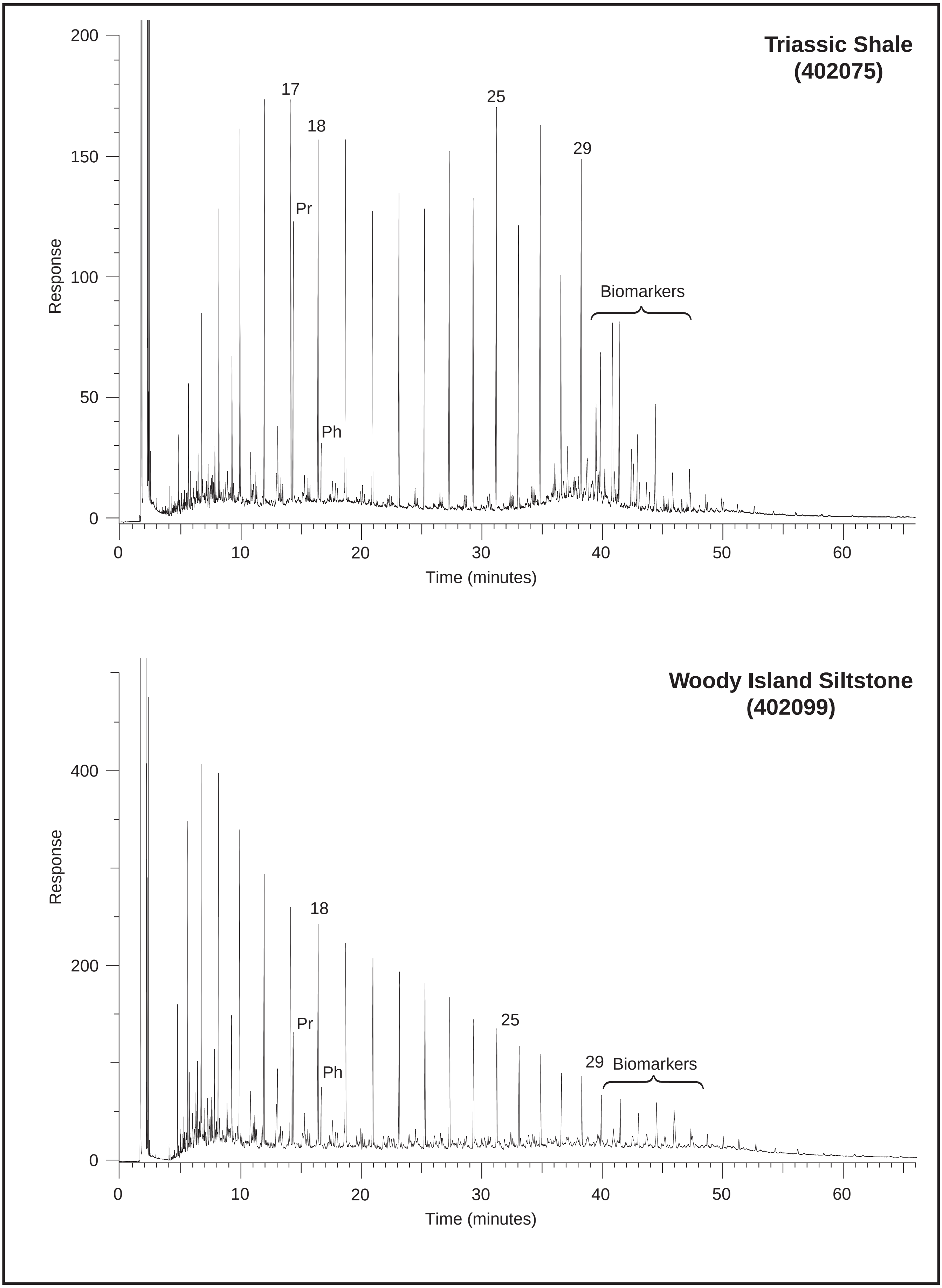

Figure 11

Gas chromatographs showing the n-alkane distributions in a relatively immature Triassic shale and the more mature Woody Island Siltstone (numbers refer to number of carbons; Pr and Ph refer to pristane and phytane).

ratio in environmental studies. A ratio of 20S and 20R isomers of about 1.0 is considered typical of mature crude oils. A high abundance of C_{21} and C_{22} steranes relative to C_{27}–C_{29} steranes is typical of oil generated at high thermal maturities.

High C_{29} sterane abundances are usually associated with source rocks containing primarily higher plant organic matter (Huang and Meinschein, 1979; Volkman, 1988*b*). A predominance of C_{27} steranes and only slightly lower abundances of C_{28} steranes and C_{29} steranes is typical of oil derived from marine algal source rocks. The distribution of 4-methyl steranes, as shown by mass chromatograms of the *m/z* 231 ion, can provide clear evidence for the importance of algal-derived organic matter. The presence of the four major isomers of dinosterane as well as 24-ethyl-4α-methyl C_{30} steranes is usually associated with marine depositional environments. Rearranged steranes (diasteranes) are found in most oils and are usually fingerprinted using the *m/z* 259 mass fragmentogram, although they are also readily discernable in *m/z* 217 mass fragmentograms.

A high diasterane abundance is often taken as evidence that the oil was derived from clastic source rocks containing clay which catalyses the steroid backbone re-arrangement (Ensminger *et al.*, 1978). It has recently been shown that the diasterane/sterane ratio is determined by the ratio of clay to TOC, rather than to clay content *per se* (van Kaam-Peters *et al.*, 1998). This provides an explanation for the high diasterane content found in some carbonate rocks (e.g. Ordovician limestone from Queenstown and Ida Bay).

Hopanes and methyl hopanes

Hopanes are found in almost all ancient sediments and crude oils. They are derived from oxygenated analogues such as the bacteriohopanetetrols found in most bacteria and cyanobacteria. Their distribution is usually recorded using a *m/z* 191 mass fragmentogram. In mature samples, the 17α,21β-isomers greatly predominate over the 17β,21α isomers (moretanes). An unusually high proportion of the C_{29} 30-norhopane is often associated with oil derived from carbonate source rocks. These oils also show a slightly enhanced abundance of the C_{35} extended hopanes compared with the C_{34} pseudo-homologue. The ratio of the two C_{27} hopanes Ts (18α(H)-22,29,30-trisnorneohopane) and Tm (17α(H)-22,29,30-trisnorhopane) can be a sensitive indicator of thermal maturity when comparing oil or sediment samples from the same source. Some oils also contain significant amounts of the C_{29} analogue of Ts (i.e. 18α(H)-30-norneohopane) which elutes just after the C_{29} α,β-hopane.

Carbonate-derived oil often contains significant amounts of 2-methyl hopanes although these are not restricted to this source facies. These can be fingerprinted from their major fragment ion at *m/z* 205. Methyl hopanes are not common in Australian crude oils since most of these are derived from terrestrial organic matter found in clastic source rocks. 30-nor-Hopanes are commonly found in carbonate-derived oils and span the carbon number range C_{28}–C_{34}.

Potential pre-Carboniferous source rocks

Nine samples of black shale from the Neoproterozoic Togari Group from northwestern Tasmania show no pyrolysis yield except for one oil-stained core sample from the Black River Dolomite, which shows a high production index but very low total hydrocarbon yield (sample 7050, Appendix 5). The average content of total organic carbon in Togari Group samples analysed by Calver (1995) is 0.25%.

The Ordovician Gordon Group consists predominantly of dark grey, micritic limestone deposited in a warm, shallow sea. Although such platform carbonates can be rich, oil-prone source rocks (e.g. Palacas, 1984), sparse analytical data show poor source rock characteristics, with nine Rock-Eval analyses all showing negligible yields of hydrocarbons, and the eight TOCs determined (Appendix 5; see O'Leary *in* Leaman, 1988) average only 0.14 ± 0.07%. Low yields of extractable organic matter also suggest that the kerogen is of poor quality (O'Leary *in* Leaman, 1988).

The Ordovician carbonate rocks have conodont alteration indices (CAI) of mostly 1.5 to 3 in the Florentine Valley, Ida Bay and other inliers in southern Tasmania (Table 4; fig. 6; Burrett, 1992). Methylphenanthrene indices of four Gordon Group samples from Ida Bay, Surprise Bay and Florentine Valley indicate oil window maximum burial temperatures (O'Leary *in* Leaman, 1988) consistent with the CAI data.

Some organic geochemical data are available from extracts from two samples collected at Queenstown and one from Ida Bay (Volkman, 1988*a*; Bendall *et al.*, 1991). One of the samples from Queenstown appeared to contain flecks of asphaltic material. The rocks contained low amounts of extractable hydrocarbons (2.9 mg/g at Ida Bay and 0.8 and 1.2 mg/g at Queenstown), but the distributions were typical of those found in mature petroleum. The *n*-alkanes showed a bimodal distribution with maxima at *n*-C_{17} or *n*-C_{18} and a secondary maxima at about *n*-C_{25}. Pristane/phytane (Pr/Ph) ratios are 1.4–1.9. The hopanes were typical of those found in carbonate rocks and showed a high proportion of the C_{29} hopane and slightly enhanced abundances of the C_{35} hopanes relative to the C_{34} hopanes (fig. 12). 2-Methyl hopanes typical of this rock type were also found, but demethylated hopanes indicative of biodegraded crude oil were not detected. The steranes were also typical, showing similar proportions of C_{27}, C_{28} and C_{29} with significant amounts of shorter-chain steranes indicative of thermal cracking reactions. Diasteranes (re-arranged steranes) were surprisingly abundant and perhaps reflect the presence of clay within the limestone (fig. 12). These

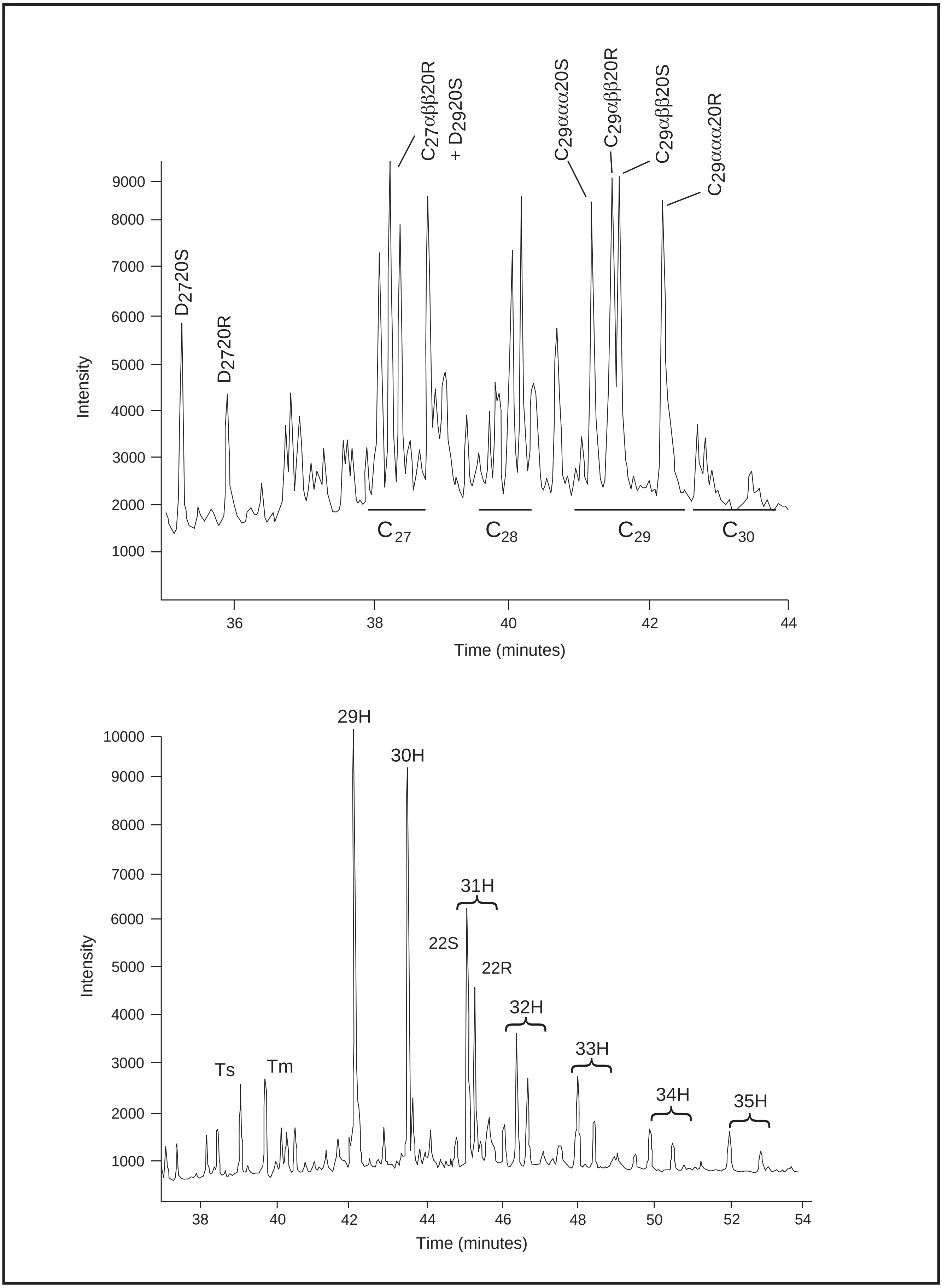

Figure 12

Mass chromatograms showing steranes (top) and hopanes from a sample of Ordovician carbonate. (Numbers refer to carbon number; D = diasteranes; α and β refer to stereochemistry at carbons 5, 14 & 17; S and R refer to stereochemistry at carbon 20 in steranes and carbon 22 in hopanes; H = hopanes) data suggest that the biomarkers were indigenous to the rocks analysed. The biomarker maturity parameters implied a moderately thermally mature distribution, suggesting that the rock was in the early oil window with equivalent Ro values of 0.6–0.7 (Volkman, 1988*a*)This is very likely to be an underestimate, particularly for the Queenstown samples.

Extracts from a shale within Gordon Group at Ida Bay, and from the Florentine Valley Mudstone (a Lower Ordovician unit that underlies Gordon Group in the Florentine Valley), show similar biomarker distributions to the Ida Bay and Queenstown limestone samples, and biomarker indices suggest moderately mature organic matter (Volkman and O'Leary, 1990*b*).

Attention was focused on Gordon Group limestone as the main source of onshore hydrocarbons during one phase of recent exploration. The Tasmania Basin section was thought to be generally immature and there were perceived chemical similarities between extracts from Gordon Group carbonate rocks (and other known Ordovician oils) and trace surface hydrocarbons in southeast Tasmania (Leaman, 1987). However trace hydrocarbons on North Bruny Island and in the D'Entrecasteaux Channel are now considered of uncertain provenance because of the very low concentrations found and interferences in the biomarker analyses from naturally-occurring hydrocarbons (Morrison, 1988; Volkman, 1989). Viable organic-rich source rocks have yet to be geochemically identified in the Gordon Group in southern Tasmania.

It is encouraging to note that the Devonian has been shown to be a viable source elsewhere on mainland Australia (Edwards *et al*., 1997; Boreham and de Boer, 1998). A true assessment of the source potential of the Tasmanian Devonian rocks cannot be made on the limited data available (Appendix 5, Bell Shale).

In summary, available analytical data are extremely sparse and further (Rock-Eval and TOC) data need to be obtained to reliably assess the source potential of the pre-Carboniferous units.

Woody Island Formation and correlates

The tasmanite near the base of this formation is an exceptionally rich, although thin and impersistent, potential source rock; this unit is dealt with separately below. Rock-Eval data show that the remainder of the formation is a lean potential source rock that is both oil and gas-prone.

The Woody Island Formation, and its northern correlate the Quamby Mudstone, consist of monotonous, dark grey, thick-bedded to massive pyritic siltstone or mudstone which generally lacks fossils. Dropstones are absent or rare, and relatively small (Forsyth, 1989*a*, Farmer, 1985). Glendonites — calcite pseudomorphs after ikaite, an authigenic precipitate that forms at low temperatures in the interstitial waters of organic-rich sediments (Jansen *et al*., 1987) — are characteristic of the unit. Rare agglutinated foraminifera are present (Gee, 1977; Forsyth, 1989*a*). Beds of tasmanite are locally present near the base of the unit in the northern part of the basin (see later section).

The formation crops out around the erosional northern and western margins of the Tasmania Basin, and as small inliers at Cygnet, Woodbridge, Margate, and Glenorchy. Over most of the basin the formation is present in the subsurface, and has been intersected in a number of fully cored drillholes (fig. 13).

A high-latitude, quiescent, somewhat restricted, dysaerobic marine environment of deposition is indicated (Banks and Clarke, 1987; Domack *et al*., 1993). The environment has been interpreted as deep ('several hundred metres', Domack *et al*., 1993), or relatively shallow (<100 m), as suggested by the presence of shelly fossils in the tasmanite at Latrobe and elsewhere (see Domack, 1995; Revill *et al*., 1995). Considerable intercalated fossiliferous siltstone and pebbly sandstone in the Beaconsfield district, in the far north of the basin (Andersons Creek drillholes), and near Latrobe suggest a northward facies transition into probably shallower environments (Burns, 1964, p. 90; Clarke *in* Jennings, 1979). To the east, the formation onlaps basement. A nearshore sandy to pebbly facies was intersected in the Bonneys Plains drillhole, and in Eaglehawk Neck-1, a thin Woody Island Formation equivalent is overlain by pebbly sandstone of probable shallow-water origin (Gulline and Clarke, 1984).

The unit reaches a maximum known thickness of at least 254 m in drillhole Granton-1 (Clarke and Farmer, 1982), but rapid lateral thickness variations are known, in part because of onlap onto basement highs. For example, the Woody Island Formation is 200 m thick in the Styx Valley, but wedges out entirely only 10 km to the north where Bundella Formation rests directly on basement (Calver and Forsyth, 1997). The lower two-thirds of the formation at Golden Valley wedges out westwards against a small basement high (Clarke, 1968). The formation is absent from the large basement high of eastern Tasmania, except for a small sub-basin at Douglas River, which is known only from a single drillhole (Bicheno-10: Calver *et al*., 1984). The Douglas River sub-basin may not have been connected to the main part of the basin in Woody Island time (fig. 13). Details of the thickness variation over the large subcrop area within the basin are known only from a few drillholes, and the isopach map (fig. 13) is therefore highly interpretive over most of the basin.

Source rock geochemistry — Woody Island Formation and correlates

Systematic TOC and Rock-Eval determinations from a number of localities, including forty Rock-Eval analyses undertaken for this study, allow the source potential of the Woody Island Formation and correlates to be appraised with fair confidence.

TOC determinations were carried out at 500 mm intervals of the Woody Island Formation correlate in

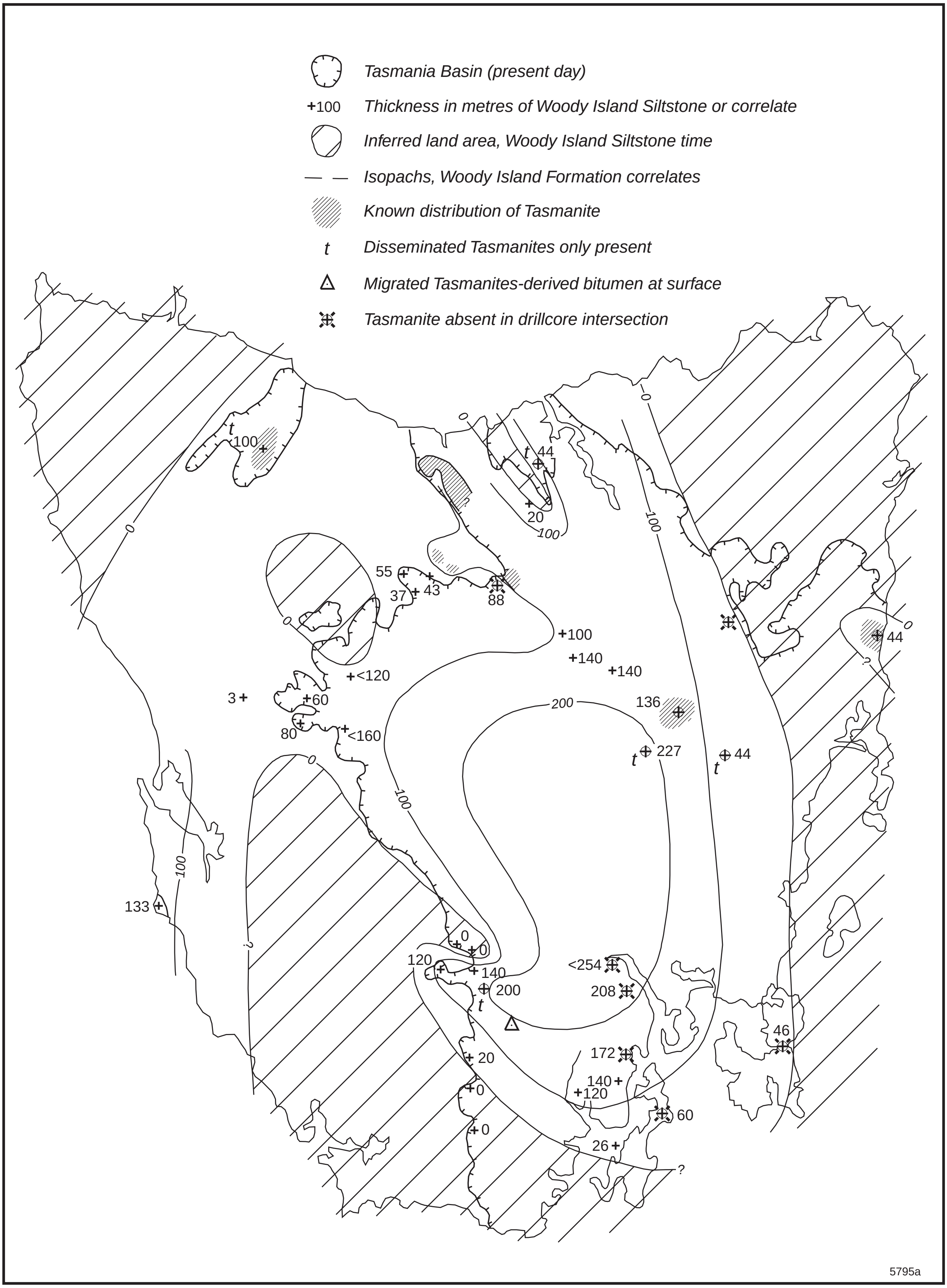

Figure 13

Isopachs and palaeogeography of the Quamby Mudstone, Woody Island Formation and correlates, and distribution of the Tasmanite Oil Shale.

Bicheno-10 and Ross-1 (Quoin) drillholes by Domack *et al*. (1993) as part of a chemostratigraphic-palaeoenvironmental study. In Bicheno-10, the 287–305 m interval averages 1.2% TOC with a maximum of 1.7% TOC and the 305–332 m interval averages 1.7% with a maximum of 2.4% (excluding the tasmanite beds). In Ross-1, the formation (70–128 m depth) averages 1.1% TOC. As the formation in Ross-1 is probably mature (i.e. may have already expelled some hydrocarbons) these figures in isolation may be taken to indicate fair to good petroleum source rock potential (e.g. Peters and Cassa, 1994).

The Rock-Eval analyses show the present day organic matter to be of relatively poor quality (Type III to Type II/III), with low hydrocarbon yields. A total of 53 Rock-Eval analyses are available from widespread localities (Appendix 5). Samples from Bicheno-10, Golden Valley-1 and other northern localities (Oonah, Andersons Creek-1, Relapse Creek, Hellyer Gorge) are immature to marginally mature, based on T_{max} and other data (see below). The remaining samples, from Tunbridge Tier-1, Ross-1, Ross-2, Eaglehawk Neck-1 and the Styx Valley, are mature. The immature to marginally mature samples have Hydrogen Indices mainly less than 200. A few samples have higher HI; that with the highest (D3, HI = 433) is from 0.2 m above the tasmanite seam in Bicheno-10 and probably includes a component of Type I tasmanite kerogen. Total hydrocarbon yields (S1 + S2) average 2.0 kg/t for the immature to marginally mature samples.

For these organically lean samples, the S2 parameter is likely to be influenced by the 'mineral matrix effect', a common artefact in the Rock Eval method. The 'mineral matrix effect' artificially reduces the S2 peak and consequently suppresses the estimate for HI. Indeed, there is a fairly good linear relationship between S2 and TOC for the immature to marginally mature Woody Island Formation samples from the northern localities (fig. 14), indicating that the organic matter type remains reasonably constant. The slope of the best-fit line defines a true HI of 200 to 250, indicating both gas and oil potential for the Woody Island Formation. As shown on Figure 14 the line does not pass through zero and a 'TOC offset', where the line crosses the TOC axis, occurs at 0.35% and defines the extent of the mineral matrix effect. This effect is related to lithology, whereby a clay-rich lithology usually has a higher mineral matrix effect compared with a carbonate-rich sediment.

The mature samples (which are late oil window to gas window) have lower hydrogen indices and higher production indices consistent with maturation, and distinctly lower total hydrocarbon yields (averaging 0.8 kg/t), consistent with expulsion of some hydrocarbons from the samples.

Systematic Fischer pyrolysis analyses on one-metre-long drillhole samples from the whole 200 m Woody Island Formation section in Styx-1 and Styx-2 range up to 7 L/t, averaging 2 L/t (i.e. 1.6 kg/t), and a 'gas + loss' component averaging 12 L/t (Anon., 1981).

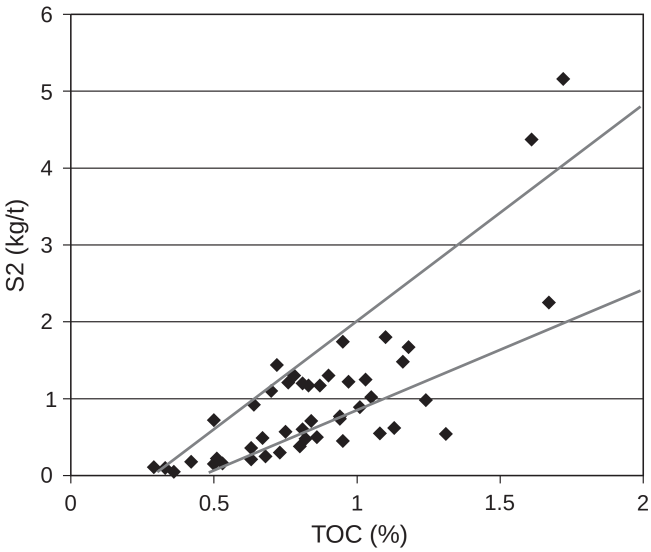

Figure 14

Rock-Eval S2 versus TOC, Woody Island Formation and correlates. The slope of the line of best fit defines a 'true' Hydrogen Index corrected for matrix effects.

The 'gas + loss' includes light hydrocarbons and CO_2 but excludes water. A single analytical repeat suggests that the oil yields may be highly inaccurate (Anon., 1981), presumably due to matrix effects. Yields were no higher in that part of the core where disseminated *Tasmanites* were noted. Oil yields in Fischer analysis are roughly equivalent to Rock-Eval S2 yields (Peters, 1986). Rock-Eval analyses of eight outcrop samples collected near these drillholes show somewhat lower hydrocarbon yields (S2 averages 0.57 kg/t; S1 + S2 averages 1.01 kg/t; Appendix 5).

The pyrolysis assays indicate relatively low hydrocarbon generative potential. An S1 + S2 yield of at least 2.5 kg/t is thought to characterise viable source rocks (e.g. Katz, 1995).

Rocks with low hydrocarbon generative potential are poor source rocks for oil (even if voluminous) because expulsion is inefficient; oil must fill part of the source rock porosity before migrating out. When the hydrocarbon generative potential is less than 5 kg/t, expulsion efficiencies are likely to be less than 50%. However gas and gas condensate expulsion efficiencies are generally high, regardless of the initial hydrocarbon generative potential (Mackenzie and Quigley, 1988).

Maceral analyses of six samples of Woody Island Formation and correlates by Harris (1981) showed highly variable compositions, ranging from 95% to 10% sapropelic kerogen (amorphogen). Sapropelic kerogen yields the most hydrocarbons.

The pristane-phytane ratio of a Quamby Mudstone sample from Oonah is 3.1, higher than the tasmanite (range 0.45–1.6, n = 5 at Oonah, Latrobe and Bicheno-10) and consistent with deposition under more oxygenated conditions, which may partly explain the poorer kerogen quality (Revill *et al*., 1994).

A petroliferous odour may be noted on breaking outcrop of Woody Island Siltstone or correlates at Styx River, Poatina and Mersey River (Anon., 1981; Summons, 1981*a*; Wiltshire, 1980). An extract from such a sample from Poatina was analysed by Volkman and Holdsworth (1989*b*). Only 120 ppm hydrocarbons were extracted, but this excludes volatile components. *n*-Alkanes and low molecular weight aromatics are abundant. Another sample of Woody Island siltstone from Poatina has an extract yield of about 600 ppm and appears to more mature than a sample from the Bicheno borehole. A mudstone from the Woody Island Siltstone at Ross appears to have been subjected to particularly high heating.

Woody Island siltstone samples have been analysed for biomarkers by Volkman and Holdsworth (1989*b*), O'Leary and Volkman (unpublished data, 1991) and Revill and Volkman (unpublished data, 1998). The hydrocarbons in the samples from Poatina and Bicheno show a strong predominance of quite short chain-length alkanes, suggestive that the organic matter has been subjected to a high degree of heating. The *n*-alkane distribution shows no odd-even predominance and is typical of that found in a mature crude oil (for example see fig. 11). Pristane is approximately twice as abundant as phytane in the Poatina samples. The steranes show a high proportion of the αββ isomers indicative of high thermal maturity. Diasteranes are much more abundant than steranes (fig. 15), which is typical of sediments containing clay. Hopanes are dominated by the thermally mature αβ isomers but moretanes are very minor components. Some samples show moderate amounts of tricyclic alkanes (fig. 15), but these are still much less abundant than the hopanes. Methyl-phenanthrene indices suggest that the hydrocarbons were generated at a thermal maturity equivalent to a vitrinite reflectance of 0.75.

In conclusion, the geochemical data indicate that the Woody Island Formation and correlates comprise a voluminous but lean potential source rock that is both oil and gas prone. A source potential index (SPI = 'cumulative hydrocarbon potential'; Demaison and Huizinga, 1991) of a fully mature 200 m thick section of roughly one tonne of hydrocarbons (= 50,000 cubic feet of gas or 7 barrels of oil) per square metre of surface area is indicated, excluding the tasmanite.

Tasmanite Oil Shale (tasmanite)

The Tasmanite Oil Shale consists of silty shale with a high content (ca. 10–70%) of compacted cysts of the probable green alga *Tasmanites punctatus*. The tasmanite occurs as two or more close-spaced beds or seams, with an aggregate thickness of up to 1.5 m, at a stratigraphic level 5–20 m above the base of the Quamby Mudstone at a number of widespread localities in the north of the basin. The tasmanite is laterally impersistent, for reasons not wholly understood. Dispersed *Tasmanites* cysts in shale, at presumably the same horizon, are distributed over a wider area (Domack *et al*., 1993) (fig. 13). The areal extent of the tasmanite is important to an appraisal of the source potential in the basin, and so its known distribution and palaeogeography are briefly reviewed below.

Fuel production by retorting of the tasmanite took place at a small scale in the Mersey valley early this century (see Bacon, 1986 for a review of tasmanite exploration and utilisation).

Distribution

The three main known developments of tasmanite appear to be restricted in palaeogeographic setting to nearshore locations, in embayments in the northern margin of the basin (Banks and Clark, 1987).

A large outlier of Lower Parmeener Supergroup rocks occurs in the Wynyard–Oonah area in northwestern Tasmania. This is thought to be the erosional remnant of a northeast-trending trough, originally connected to the main part of the basin further south (Gee, 1977; Hand, 1993; Domack *et al*., 1993). Lenticular tasmanite beds up to 0.6 m thick are present on the eastern side of the trough at Oonah, but it is absent 10 km to the northwest at Preolenna (Gee, 1977) and only dispersed cysts are seen at nearby Farquhars Road at the western edge of the trough (Domack *et al*., 1993). At least the western boundary of the trough was probably land during tasmanite deposition, because there the Quamby Mudstone equivalent onlaps basement.

The thickest and most extensive known tasmanite occurrence is in the Latrobe–Railton area in central-north Tasmania, where typically two seams are present with an aggregate thickness of 1.2–1.7 m (Nixon, 1975). Twelvetrees (1912) recognised the nearshore palaeogeographic setting of the tasmanite in this area. A comparison of drilling records (Clementson, 1981) with available mapping (Sheffield geological map; Jennings *et al*., 1959) suggests that Ordovician and Precambrian rocks at Dulverton Hill and near The Great Bend were small basement highs (islands) against which the lower Quamby Mudstone (including the tasmanite) wedges out in a westerly direction. Similarly, drillcore data indicate that the lower part of the Quamby Mudstone wedges out against higher basement to the north, in the Spreyton area (Burns, 1964, fig. 18). To the east, the possible subsurface extent of the tasmanite is limited by high basement in the Frankford area where the Quamby Mudstone is relatively thin (20–40 m) and locally absent, for example where the Lower Freshwater Sequence directly overlies Precambrian basement of the Proterozoic Badger Head inlier (Gulline, 1981). Tasmanite may continue in the subsurface as far as Golden Valley, 30 km to the southeast of the Railton–Latrobe area. At Golden Valley, a 1.4 m thick tasmanite seam wedges out against a high basement only 1 km to the west (Clarke, 1968). Tasmanite is known at Gibsons Sugarloaf and Chudleigh, but apparently not from the north face of the Great Western Tiers to the south and west of those localities (Jennings,

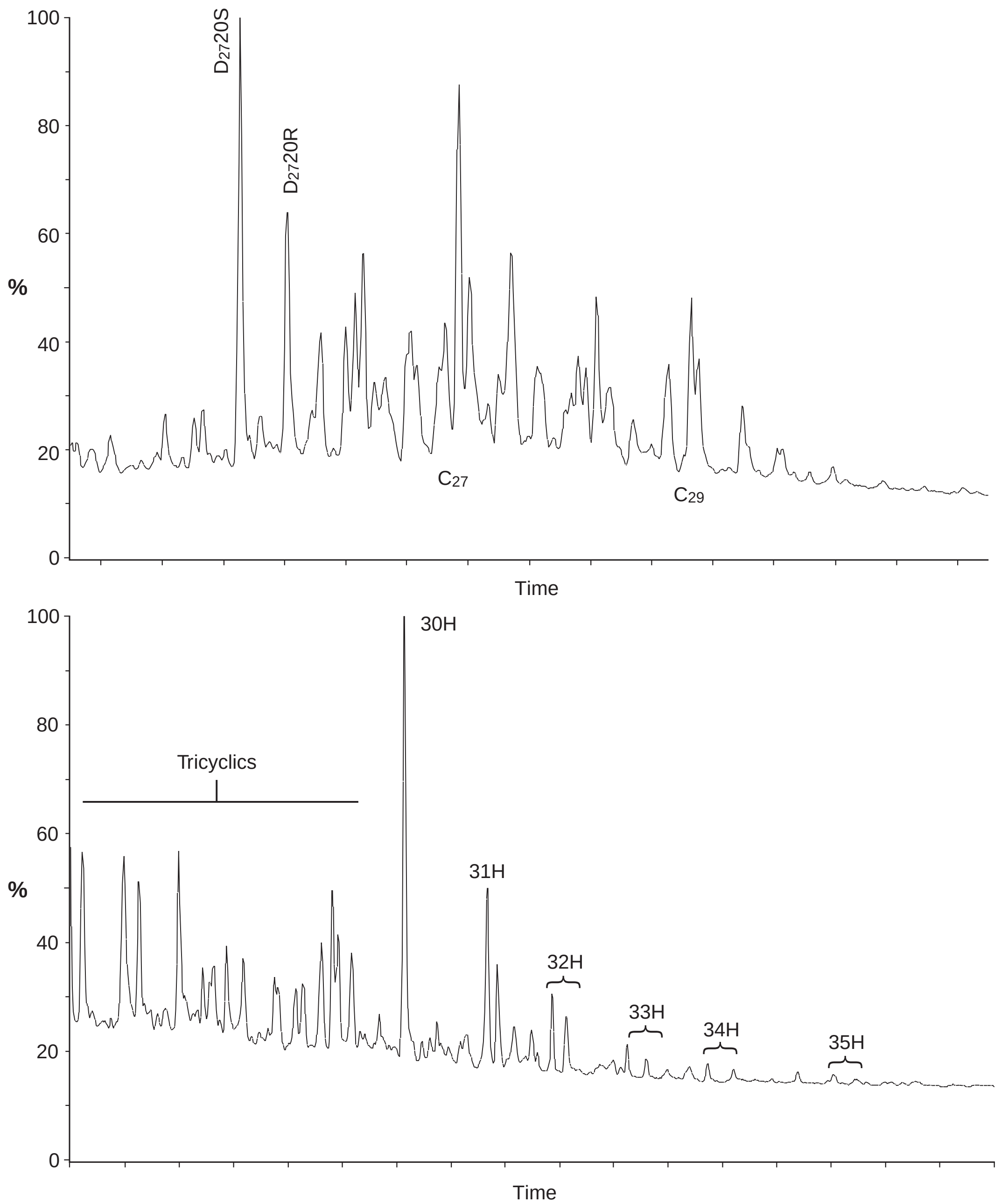

Figure 15

Mass chromatograms showing steranes (top) and hopanes from a sample of Woody Island siltstone.

1963), perhaps because of higher basement as the Quamby Mudstone is relatively thin there (fig. 13). The tasmanite outliers at Gibsons Sugarloaf, Chudleigh and Beulah may have once been continuous with the Railton–Golden Valley occurrences. The fragmentary palaeogeographic evidence suggests a complex embayment for these originally possibly laterally continuous occurrences, the embayment being open to the southeast towards the main part of the basin.

The third discrete tasmanite occurrence is that of the Douglas River sub-basin, known only from drillhole Bicheno-10. As in the Latrobe–Railton area, there are two seams, with an aggregate thickness of 1.3 metres. This occurrence is delimited by high basement (land areas) to the west, north and south (Calver *et al*., 1984), and it is not known whether this sub-basin was connected to the main part of the basin in Woody Island Formation time.

No other comparable developments of tasmanite are known. A possible exception may be in drillhole Ross-2 (RG146), in the central-north of the basin, where a tasmanite sample with TOC of 17% is noted by Domack *et al*. (1993), but the thickness is not recorded and no tasmanite is present in the core remaining in the Mineral Resources Tasmania core library.

Disseminated *Tasmanites* are present in shale at similar stratigraphic positions at widespread localities (e.g. the Ross-1 (Quoin), Tunbridge Tier, Andersons Creek and Styx drillholes) (fig. 13).

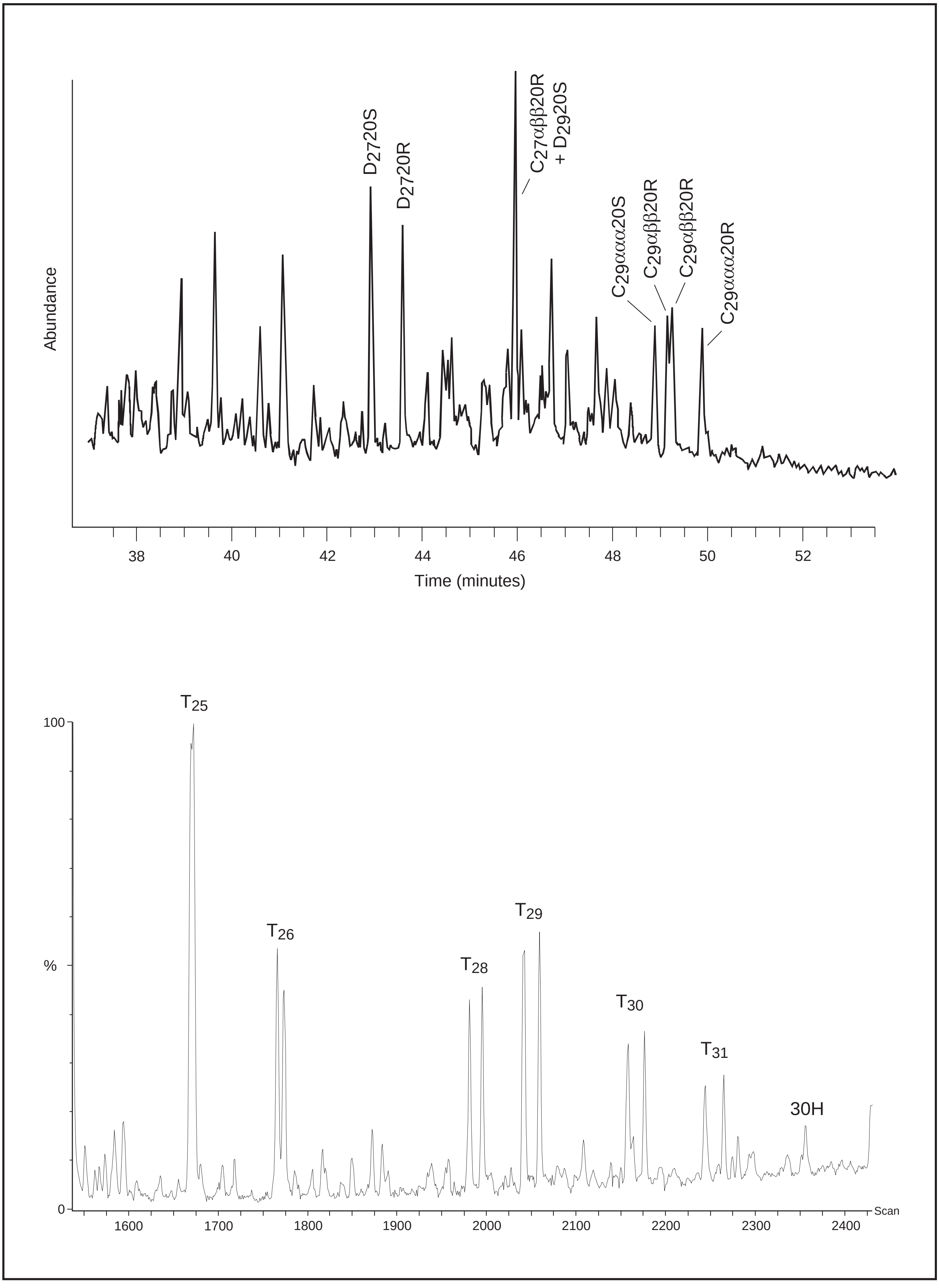

Figure 16

Mass chromatograms showing steranes (top) and the hopane region from a sample of tasmanite (Douglas River).

Low hydrocarbon yields were found throughout the Styx drillhole section, including the horizons where *Tasmanites* occurs (Anon., 1981). This observation, together with the consistently low TOC in drillhole Ross-1 (Domack *et al*., 1993), indicates that the lack of true tasmanite development at these locations is not due simply to sediment dilution of the *Tasmanites* flux in basinward settings, as suggested by Banks and Clarke (1987).

A bitumen recovered from joints in Jurassic dolerite near Lonnavale in southern Tasmania contains biomarkers suggesting a source rich in *Tasmanites* (Revill, 1996; Whythe and Watson, 1996). This occurrence is significant, not only in demonstrating the presence of migrated hydrocarbons, but in suggesting the presence of a significant tasmanite development in the subsurface in southern Tasmania. No tasmanite is known in outcrop or drillholes in surrounding areas (Styx Valley, Cygnet, Margate-1, Granton-1, Glenorchy-1), although disseminated *Tasmanites* is known from the Styx Valley (fig. 13) (Anon., 1981).

The tasmanite is thought to result from high-latitude seasonal (springtime) algal blooms, either within or marginal to melting sea ice (Simoneit *et al*., 1993; Revill *et al*., 1994; Domack, 1995). This may be the key to its apparently limited nearshore palaeogeographic distribution.

Source rock geochemistry

Ten Rock-Eval pyrolysis analyses described as tasmanite or tasmanite concentrate are available (Appendix 5). Of these, three have relatively low TOC (<3%) and might better be described as *Tasmanites*-bearing shale.

The high Hydrogen Index (HI) of the tasmanite (typically 700–1000 mg hydrocarbons/g TOC) demonstrates that it contains predominantly hydrogen-rich, oil-prone Type I kerogen, over 70% of which is convertible to hydrocarbons. At Latrobe, the atomic H/C ratio of the kerogen is 1.6, O/C is 0.02, and the kerogen contains 4 % organic sulphur (Church, 1864; Telfer *et al*., 1979). The tasmanite also contains small amounts of vitrinite and inertinite (Telfer, 1979).

All samples, except those from Tunbridge Tier-1 and Ross-2, have very low production indices (0.05 or less) and high HI, demonstrating that little if any hydrocarbons have yet been generated — that is, the samples are thermally immature.

The Tunbridge Tier-1 and Ross-2 samples are *Tasmanites*-bearing shales with low TOC, low hydrogen indices (8–33 mg/g), high T_{max} and high production indices, indicating these samples are mature. The low TOC of these two samples also means they are likely to contain a greater proportion of Type III organic matter (which predominates in the Woody Island Formation and correlates) and this probably partly explains their low hydrogen indices. Methylphenanthrene indices (Bendall, 1991) and T_{max} from the enclosing Woody Island Formation also indicate that both these sections are mature (early gas window: see below).

Revill *et al*. (1994) have described in detail the organic geochemistry of the tasmanite at Oonah, Latrobe and Douglas River (Bicheno-10 drillhole). Tricyclic alkanes are abundant in extracts; these are the characteristic biomarker of the tasmanite (Simoneit *et al*., 1986; Denwer, 1986). The most abundant aliphatic hydrocarbon in the immature oil shale from Latrobe is a C_{19} tricyclic alkane, whereas in the more mature samples from Oonah and Douglas River low molecular weight *n*-alkanes dominate the extractable hydrocarbon distribution because they are more mature. The aromatic fraction at Douglas River and Oonah is dominated by a trimethylphenanthrene, interpreted to be derived from the tricyclic alkanes in these slightly more mature samples. Various biomarker data (steranes; fig. 16) indicate that the Oonah and Latrobe samples are immature, but that the Douglas River sample is in the early oil window (equivalent Ro of 0.55 to 0.6%: Revill and Volkman, 1993). The Production Index for the Douglas River sample is only 0.04, which indicates that the kerogen has barely begun to generate hydrocarbons. There is a very narrow distribution of activation energies in the tasmanite kerogen, which means that the bulk of petroleum production will occur over a relatively narrow temperature range. The Douglas River sample has not reached this part of the oil window, with only a small proportion of total potential hydrocarbons yet generated. Kinetic modeling indicates that an additional 10–15°C temperature rise would lead to substantially increased hydrocarbon production.

Over 90% of the tasmanite kerogen has an activation energy of ca. 225 kJ/mol (Revill *et al*., 1994), which is in the middle range for Type I kerogen (Tissot *et al*., 1987; Hunt, 1996). Tasmanite kerogen would thus liberate hydrocarbons faster (or at lower temperatures) than typical Type III kerogen, but slower than most Type II kerogens (Hunt, 1996).

The tasmanite kerogen and its derived *n*-alkane pyrolysates are characterised by enrichment in ^{13}C with $\delta^{13}C$ values of -12 to -15‰, suggesting that the source alga occupied an environmental niche similar to that of modern sea-ice diatoms and that bloom conditions, coupled with physical isolation from atmospheric CO_2, resulted in the distinctive 'isotopically heavy' $\delta^{13}C$ (Simoneit *et al*., 1993; Revill *et al*., 1994). The tricyclic compounds (-8‰) are isotopically heavier than the kerogen and may have been derived from a non-*Tasmanites* source (Revill *et al*., 1994).

The overall weighted average oil yield by Fischer pyrolysis at Latrobe is 146 L/t over an average total thickness of 1.44 m (Clementson, 1981). This is equivalent to a total hydrocarbon yield of roughly 0.3 tonnes (or 2.5 bbl) per square metre of surface area.

Other possible source rocks, Parmeener Supergroup

On the sparse evidence available, the Macrae Mudstone and the coals of the Lower Freshwater Sequence appear to be good, but volumetrically minor potential source rocks. The remaining parts of the Lower Parmeener Supergroup, including the basal tillite, are unlikely to be source rocks.

A single sample from 0.5 m below the top of the Macrae Mudstone (= base of the Lower Freshwater Sequence) (Clarke, 1968) in drillhole Golden Valley-1 shows good source rock parameters. The Macrae Mudstone is a dark shale, 49 m thick, immediately underlying the Lower Freshwater Sequence, and is lithologically similar to the Quamby Mudstone (Clarke, 1968). It contains (like the Quamby Mudstone) an immature to marginally mature Type III kerogen. The sample is 4.25% TOC and has a generative potential (S1 + S2) of 4.11 kg hydrocarbons/t (Appendix 5). Unfortunately basinward lateral equivalents to the southeast are fossiliferous, sandier, and bioturbated (Clarke and Farmer, 1982; Forsyth, 1989*a*), and are therefore unlikely to be good source rocks.

Based on Rock-Eval results of three samples from Preolenna and maceral analyses (fig. 17), coals from the Lower Freshwater Sequence are good potential source rocks with Type II–III kerogen, both oil and gas-prone.

Biomarker analyses of three Permian coal samples, from an outcrop at Relapse Creek near Preolenna, were carried out by Volkman and O'Leary (unpublished data, 1990). Of particular interest is that the major peaks in the aliphatic hydrocarbon chromatogram are due to the hopanes, rather than *n*-alkanes. This is suggestive of a marginally mature distribution of hydrocarbons. The major peak in the m/z 191 mass fragmentogram is the C_{30} hopane, with the C_{29} hopane present in reasonable abundance. The third most abundant peak is due to the C_{27} hopane Tm which is considerably greater than Ts, again indicating only marginal maturity. Moretanes were about one-fifth the abundance of the corresponding hopanes. An unusual feature is the presence of the full suite of 2-methyl hopanes. These compounds are not usually associated with coal and yet here their abundance relative to the hopanes is almost half that seen on the carbonate samples. Tricyclic alkanes were only trace constituents. As expected for a sample containing abundant plant material the C_{29} steranes are considerably more abundant than the C_{27} steranes. Diasteranes are particularly abundant in these extracts. The aromatic fraction consisted of a complex mixture dominated by tri- and tetramethyl naphthalenes, methylphenanthrenes and dimethylphenanthrenes. Aromatic maturity parameters gave values of equivalent Ro of 0.63.

In places the coal includes thin seams of torbanite oil shale derived from the freshwater alga *Reinschia*. The coal is relatively thin (typically about one metre in cumulative thickness) and appears to be restricted to the northern, submature parts of the basin (fig. 8). Low Production Indices (PI <0.1) and T_{max} values (<445°C) for the Preolenna Coal Measures suggest that these samples (numbered 2002–2004) are marginally mature. The torbanite does not dissolve in solvent, but produces abundant alkanes when pyrolysed.

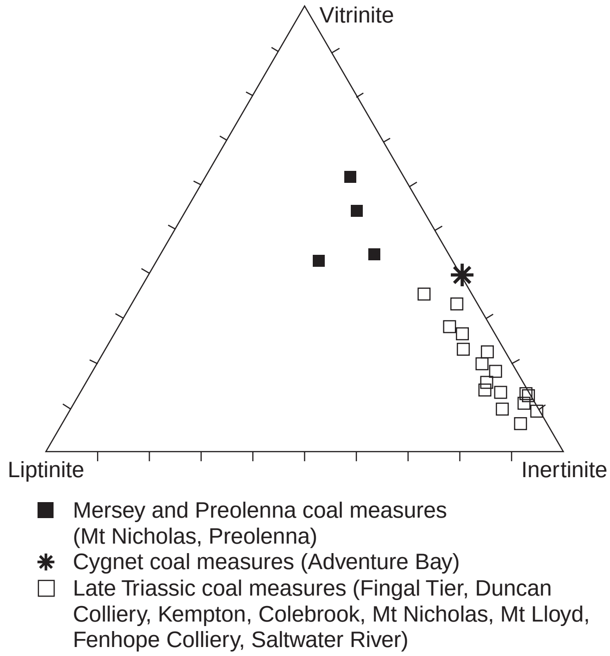

Figure 17

Maceral analyses of Tasmanian coals.

Thirty-five metres of the basal tillite in drillhole Ross-1 was analysed for TOC at 500 mm intervals by Domack *et al*. (1993). Most of the section had very low TOC (ca. 0.2%), rising to ca. 1% in the topmost few metres. Two samples of Wynyard Tillite are only 0.1% in TOC and yielded negligible hydrocarbons under Rock-Eval pyrolysis (Appendix 5). A shale unit within Truro Tillite in drillhole Shittim-1 had 0.57% TOC and no Rock-Eval hydrocarbon yield (Burrett, 1997*a*), but has probably been baked by nearby dolerite.

Abundant benthic macrofossils and pervasive bioturbation in the remaining parts of the Lower Parmeener Supergroup indicate poor conditions for the preservation of organic matter (Peters and Cassa, 1994).

The Late Triassic coal measures (Unit 4) are unlikely to be a viable hydrocarbon source. This uppermost part of the Parmeener Supergroup has been removed by erosion from much of the basin. In the northeast coalfields and at Hamilton, in central Tasmania, vitrinite reflectance data indicate that the succession is submature to marginally mature except where close to dolerite. Coal consists predominantly of inertinite (fig. 17), a poorly gas-prone hydrocarbon source. The low ratio of hydrocarbons to TOC (i.e. high internal adsorption) suggests that the coal is not a significant oil producer or effective source rock. The enclosing lithic sandstones are poor reservoir lithologies, with porosity occluded by compaction of lithic grains (Turner and Calver, 1987).

Thermal History and Timing of Hydrocarbon Generation

Pre-Carboniferous hydrocarbon generation

The attractiveness of the lower Palaeozoic (Ordovician source) play concept depends in large part on whether the timing of oil generation preceded or post-dated the deposition of the Tasmania Basin succession. If peak burial temperatures in the lower Palaeozoic rocks occurred during the mid-Devonian orogeny, then the various sub-unconformity and within-basin traps (see below) associated with the Permo-Carboniferous Tasmania Basin succession will not have been charged from lower Palaeozoic sources. Only more deep-seated traps, preserved below the level of Late Carboniferous erosion, would be prospective, assuming an appropriate thermal history and a viable source, unless subsequent events have allowed tertiary migration (i.e. movement of a previously formed accumulation).

Peak burial temperatures in the lower Palaeozoic rocks of western Tasmania did undoubtedly occur during the mid-Devonian orogeny, as indicated by high conodont alteration indices (CAI) of around 5 in the Gordon Group (Table 4), indicating burial temperatures much higher than any seen in Tasmania Basin rocks (Burrett, 1992). Relatively deep burial (>5 km) of the Gordon Group carbonate rocks occurred in western Tasmania, as indicated by the preservation of thick (5 km) Siluro-Devonian Eldon Group successions in the deepest synclinoria.

The question of timing in southern Tasmania is less clear-cut. CAI of 1.5 to 3 suggest oil-window burial temperatures perhaps similar to, or only slightly greater than, those of the Tasmania Basin (Burrett, 1992). Biomarker maturation indices from seven lower Palaeozoic samples in southern Tasmania provide corroborative evidence for broadly similar maximum burial temperatures (equivalent to vitrinite reflectances of 0.7 to 1.5; O'Leary *in* Leaman, 1987; Volkman and O'Leary, 1990*b*). Consistent with this, the postulated source rocks in the Gordon Group were probably less deeply buried, as suggested by the relatively thin (1.3 km) overlying Eldon Group correlate in the Florentine Synclinorium. Thus, if the Jurassic–Cretaceous thermal maximum (see below) felt by the Gordon Group in southern Tasmania locally exceeded that of the mid-Devonian, then an additional charge of hydrocarbons might have filled sub-unconformity traps and traps within the Tasmania Basin, as well as the deeper traps such as anticlines in the Eldon Group correlates.

Lopatin-style maturity modelling by Carne (1992) suggests that the Gordon Group in southern Tasmania did not enter the oil window until post-Permian time. However his model may under-estimate Devonian burial depths that can be minimally constrained by Siluro-Devonian sediment thicknesses, and may also underestimate the Devonian thermal gradient (40°C/km vs 75°C/km; Burrett, 1992; Woods, 1995). Maturity modelling by Woods (1995), in contrast, suggests that (except for a minimum burial scenario that probably under-estimates the Devonian burial depth) the Gordon Group in southern Tasmania for the most part entered the oil window, and locally exceeded gas window burial temperatures, in the Devonian.

Tasmania Basin thermal history

Potential Permian source rocks (Woody Island Formation and correlates) were buried to about 1.7 km by the end of Parmeener Supergoup sedimentation in the Late Triassic. Burial history after this time is poorly constrained. At least one dolerite sheet, with a thickness of about 0.5 km, was intruded at a high level in the basin sequence in the Middle Jurassic. A thickness of perhaps 800 m or more of late Triassic–mid Jurassic sediments made up the roof rocks to the highest-level dolerite sheets (Everard *in* Turner and Calver, 1987, p. 144), but has since been removed by erosion. Plausible source-rock burial depths of ca. 3 km, together with likely elevated heat flow during the Jurassic magmatism, suggest that the source rocks may have begun to enter the oil window during the Jurassic in the central parts of the basin (Woods, 1995). Information on post-Jurassic burial history comes from apatite fission track data (O'Sullivan and Kohn, 1997).

Apatite fission track data

The regional apatite fission track study of O'Sullivan and Kohn (1997) shows that most Tasmania Basin rocks currently exposed at the surface (including Jurassic dolerite) were at relatively high temperatures (>95°C) until the Late Cretaceous to Palaeocene (ca. 100–50 Ma). The rocks then underwent rapid cooling to temperatures below 60°C. Inland Tasmania is thought to have cooled in the mid-Cretaceous, while areas along the present eastern and western coasts cooled in the late Palaeocene to early Eocene (50–60 Ma). O'Sullivan and Kohn (1997) proposed that the cooling resulted from rapid erosion of a thick (at least 2.5–4 km) superincumbent succession that was probably of Jurassic to Early Cretaceous age, by analogy with offshore basins that still preserve thick successions of this age.

It should be noted that the five AFT samples derived from high in the Tasmania Basin stratigraphy all have distinctly older (Cretaceous–Jurassic) AFT ages. These include sample FT68, listed as Parmeener Supergroup but which is Jurassic dolerite at the drillhole depth quoted (this hole contains 453 m of dolerite overlying Upper Triassic coal measures). An AFT age of 194 Ma demonstrates that this sample has not re-entered the apatite partial annealing zone since the time of Jurassic

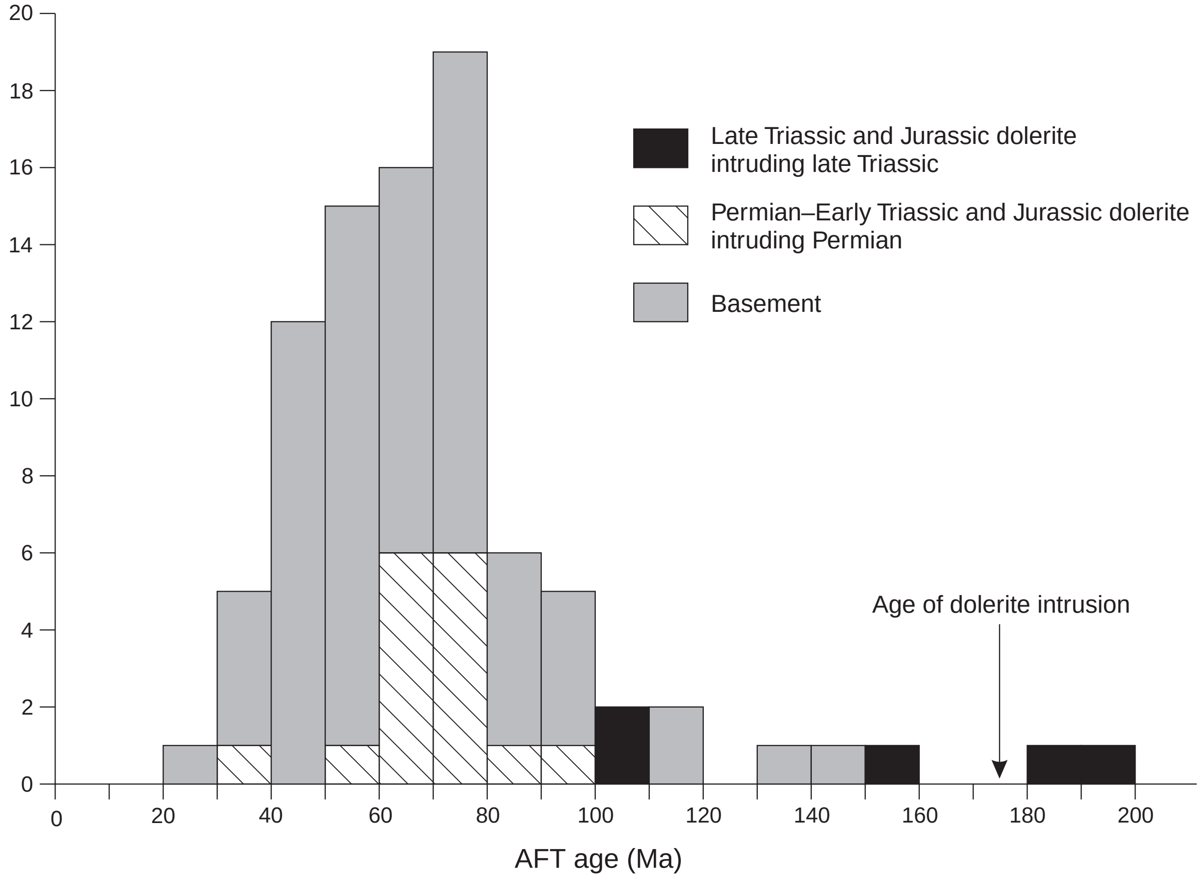

Figure 18

Frequency histogram of Apatite Fission Track ages, subdivided according to broad stratigraphic level. Data from O'Sullivan and Kohn (1997).

magmatism. The four Upper Triassic coal measures (Unit 4) samples all have Jurassic to mid-Cretaceous ages. In contrast, all Early Triassic and older Parmeener Supergroup samples, and most basement rocks, have Late Cretaceous to Palaeogene ages (fig. 18). This includes the remaining Jurassic dolerite samples which are all from stratigraphically low situations (intrusions into the Lower Parmeener Supergroup).

This suggests that the 95° isotherm only reached middle to upper Triassic levels in the Tasmania Basin stratigraphy in the Cretaceous/Palaeocene. Consequently the AFT results can be accommodated by an overburden of only 1.8 km on the high-level dolerite sills such as at Poatina and Fingal Tier (fig. 19).

It is probable that the mid-Cretaceous to early Eocene AFT ages are at least partly due to high heat flow associated with continental rifting. High Cretaceous heat flows are believed to have affected the offshore Sorell, Otway and Bass Basins (Duddy, 1992; Duddy *et al*., 1997). In onshore Tasmania, there are widespread, but volumetrically minor mid-Cretaceous intrusive rocks (Seymour and Calver, 1995). Contact metamorphism associated with the intrusive rocks around Cygnet is thought to have resulted in the widespread carbonisation of palynomorphs in the Parmeener Supergroup in the Cygnet–Oyster Cove area (Farmer, 1985). The Gordon Group at Ida Bay was remagnetised by a Late Cretaceous regional heating event that persisted for a period in the order of 10 million years (Sharples and Klootwijk, 1981).

Maturation indices

In assessing petroleum prospectivity it is necessary to determine whether the maximum thermal stress was sufficient to liberate hydrocarbons, and to map regional variations in maturation. Vitrinite reflectance data provide the bulk of quantitative thermal maturation information on the Tasmania Basin. The data (Table 5), mostly from the Late Triassic coal measures, are roughly bimodal, with a narrow lower mode (0.5–0.6%) and a broad upper one (1.3–4%). As the upper mode is clearly related to local contact-metamorphic effects of the dolerite, only the lower mode — mostly comprising samples known to be distant from dolerite intrusions — can be used to determine whether (and where) potential source rocks underwent regional heating to oil-window temperatures, without the aid of local heating by dolerite. These data are tabulated, together with biomarker ratios — mainly methylphenanthrene index (MPI), palynomorph colour (TAI) and selected Rock-Eval T_{max} data converted to Ro equivalents (Table 5). None of these indices in isolation is an entirely reliable guide to maturation (see review by Tissot *et al*., 1987). Rock-Eval T_{max} of Type III (but not Type I) kerogen is used as a maturation indicator (Tissot *et al*., 1987).

Table 4

Thermal maturity — Conodont colour (from Burrett, 1992)

Locality	Grid Reference	CAI*	Age and Unit
Andrew River	CP940131	5	Middle Ordovician, Gordon Group
Bubs Hill	CP985361	5	Middle–Lower Ordovician, Gordon Group
Claude Creek	DQ293068	5	Middle Ordovician, Gordon Group
Duck Creek	CP381749	5	Middle–Lower Ordovician, Gordon Group
Eugenana	DQ422349	5	Middle Ordovician, Gordon Group
Everlasting Hills	DP200154	4	Middle Ordovician, Gordon Group
Florentine Valley	DN560820	3+	Middle–Lower Ordovician, Gordon Group
Flowery Gully	DQ848312	5	Middle Ordovician, Gordon Group
Franklin River	CN990910	5	Middle Ordovician, Gordon Group
Gunns Plains	DQ190297	5	Middle–Lower Ordovician, Gordon Group
Huskisson Syncline	CP658743	5	Middle–Lower Ordovician, Gordon Group
Isle Du Golfe	DM615755	4	Middle–Lower Ordovician, Gordon Group
Judds Cavern	DN662107	4	Middle Ordovician, Gordon Group
Lake Sydney	DN682069	6	Lower Ordovician–Early Silurian, Eldon?/Gordon Groups
Liena	DP359996	5	Middle–Lower Ordovician, Gordon Group
Loongana	DQ120150	5	Middle–Lower Ordovician, Gordon Group
Lower Gordon River	CN911865	5	Lower Silurian–Early Devonian Eldon Group
Lower Gordon River	CN990740	5	Middle–Lower Ordovician, Gordon Group
Lune River/Ida Bay	DM891921	3+	Middle–Lower Ordovician, Gordon Group
Melrose/Paloona	DQ401339	5	Middle Ordovician, Gordon Group
Moina	DQ223067	5	Middle Ordovician, Gordon Group
Mole Creek area	DP505990	5	Middle–Lower Ordovician, Gordon Group
Olga River	CN000701	5	Middle–Lower Ordovician, Gordon Group
Picton River	DN739140	3+	Middle–Lower Ordovician, Gordon Group
Point Cecil	DM673738	3+	Middle–Lower Ordovician, Gordon Group
Point Hibbs	CN575804	1–5	Middle Ordovician–Middle Devonian
Precipitous Bluff	DM677880	5	Middle–Lower Ordovician, Gordon Group
Queenstown	CP800400	5	Middle–Lower Ordovician, Gordon Group
Railton	DQ516225	5	Middle Ordovician, Gordon Group
Salisbury River	DM680969	5	Middle–Lower Ordovician, Gordon Group
Sophia River	CP900744	5	Middle–Lower Ordovician, Gordon Group
Surprise Bay	DM716736	3+	Middle–Lower Ordovician, Gordon Group
Vale of Belvoir	DQ076010	5	Middle–Lower Ordovician, Gordon Group
Vanishing Falls	DM704954	1.5–2+	Middle–Lower Ordovician, Gordon Group
Wilson River	CP646763	5	Middle–Lower Ordovician, Gordon Group
Zeehan	CP617614	5	Middle–Lower Ordovician, Gordon Group

* Conodont Alteration Index (CAI) values of between 1 and 3 show that the rock has, at one time, been within the oil window.

\+ Within oil window.

There is consistent evidence from a number of criteria that the Lower Permian potential source rocks in the north of the basin are immature to marginally mature. Biomarker data are more or less consistent with vitrinite reflectance data of 0.5–0.6% at Oonah and Douglas River, and slightly less at Latrobe. The high hydrogen indices and low production indices of tasmanite at these localities also show that very little hydrocarbon generation has taken place.

In north–central Tasmania (the Golden Valley and Poatina areas), vitrinite reflectance data from the Liffey Sandstone (ca. 100 m above the top of the Quamby Mudstone) are also 0.5–0.6%. Rock-Eval data from the Quamby Mudstone in drillhole Golden Valley-1 are consistent, suggesting the section is submature to early mature (production indices average 0.2; T_{max} averages 442°: fig. 20). MPI data suggest that the Quamby Mudstone is early mature (equivalent to vitrinite reflectance of 0.7% at Golden Valley and 0.75% at Poatina).

The three drillholes in eastern–central Tasmania appear to have Quamby Mudstone sections that have been through the oil window. In both the Tunbridge and Ross-2 (RG146) boreholes, the Quamby Mudstone has an MPI indicating an equivalent vitrinite reflectance of 1.35% (wet gas window) (Bendall, 1991). The average T_{max} value of 452° from Tunbridge Tier-1 (excluding an aberrant value of 395°) suggests at least late oil window maturities. Consistent with this, these two holes, and the nearby Ross-1 (Quoin) hole, have TAI of 3 in the

Table 5

Maturation data of samples from the Tasmania Basin likely to be not significantly affected by proximity to dolerite intrusion.

Locality	*Age*	*Unit*	*Reference*	*Method*	*Ro or Re*
NORTHWEST					
Mt Pelion	Upper Permian		Banks (unpublished)	Vitrinite	0.76
Relapse Creek	Lower Permian	Lower Freshwater Seq.		T_{max} (av. 444)	0.7
Relapse Creek	Lower Permian	Lower Freshwater Seq.	Powell, 1985	Vitrinite	0.48
Relapse Creek	Lower Permian	Lower Freshwater Seq.	Powell, 1985	Vitrinite	0.49
Relapse Creek	Lower Permian	Lower Freshwater Seq.	Powell, 1985	Vitrinite	0.49
Wynyard, Inglis River	Lower Permian		Banks (unpublished)	Vitrinite	0.52
Barn Bluff	Lower Permian		Banks (unpublished)	Vitrinite	0.49
Preolenna	Lower Permian	Quamby Formation	Bendall, 1991	MPI	0.6
Oonah	Lower Permian	Quamby Fm (tasmanite)	Revill *et al*., 1994	MPI (=0.46)	0.54–0.67
Oonah–Relapse Creek	Lower Permian	Quamby Formation		T_{max} (av. 441)	0.6
NORTH					
Spreyton (mine)	Lower Permian	Lower Freshwater Seq.	MRT (unpublished)	Vitrinite	0.31
Mersey River, Latrobe	Lower Permian	Quamby Fm (tasmanite)	Russell (*in* Baillie, 1987)	Vitrinite	0.4
Great Bend Mersey River, Latrobe	Lower Permian	Quamby Fm (tasmanite)	Baillie, 1987	C29	0.5
Mersey River, Latrobe	Lower Permian	Quamby Formation	Harris, 1981	TAI (3+)	1.0–2.0
Great Bend Mersey River, Latrobe	Lower Permian	Quamby Fm (tasmanite)	Powell, 1985	TAI (2)	0.5–0.9
NORTHEAST					
Jubilee Colliery, Mt Nicholas	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.59
Mt Nicholas Colliery	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.52
Blue Upper seam (mine), Mt Nicholas	Upper Triassic	Unit 4	Bacon (1985)	Vitrinite	0.55
GY34 L1, Mt Nicholas	Upper Triassic	Unit 4	Wolff *et al*. (1981)	Vitrinite	0.55
GY34 M2, Mt Nicholas	Upper Triassic	Unit 4	Wolff *et al*. (1981)	Vitrinite	0.55
GY23 M1, Mt Nicholas	Upper Triassic	Unit 4	Wolff *et al*. (1981)	Vitrinite	0.61
Duncan seam, Fingal	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.56
Duncan seam, Fingal	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.61
Duncan seam, Fingal	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.66
Duncan seam, Fingal	Upper Triassic	Unit 4	Joint Coal Board, 1978	Vitrinite	0.67
Duncan seam, Fingal	Upper Triassic	Unit 4	Smyth (1980)	Vitrinite	0.61
Duncan seam, Fingal	Upper Triassic	Unit 4	Bacon (1985)	Vitrinite	0.54
Duncan seam DDH 43, Fingal	Upper Triassic	Unit 4	Smyth & Ledsam (1980)	Vitrinite	0.58
Un-named seam DDH 42, Fingal	Upper Triassic	Unit 4	Smyth & Ledsam (1980)	Vitrinite	0.59
East Fingal seam DDH 43, Fingal	Upper Triassic	Unit 4	Smyth & Ledsam (1980)	Vitrinite	0.58
Merrywood seam (mine), Merrywood	Upper Triassic	Unit 4	Bacon (1985)	Vitrinite	0.57
Seymour	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.54
Seymour	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.6
Adit, Douglas River	Upper Triassic	Unit 4	Ford & Bos (1984)	Vitrinite	0.64
Douglas River/Bicheno-10, 20 m	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.66
Douglas River/Bicheno-10, 65 m	Mid or upper Trias.	Unit 3 or 4	Banks (unpublished)	Vitrinite	0.63
Douglas River/Bicheno-10, 65 m	Mid or upper Trias.	Unit 3 or 4	Banks (unpublished)	Vitrinite	0.77
Douglas River/Bicheno-10, 121 m	Upper Permian	Ferntree Mudstone	Banks (unpublished)	Vitrinite	0.59
Douglas River/Bicheno-10, 268 m	Lower Permian	Lower Freshwater Seq.	Banks (unpublished)	Vitrinite	0.44
Douglas River/Bicheno-10, 268 m	Lower Permian	Lower Freshwater Seq.	Banks (unpublished)	Vitrinite	0.48
Cato Creek upper seam, Mt Nicholas	Lower Permian	Lower Freshwater Seq.	MRT (unpublished)	Vitrinite	0.53
Cato Creek lower seam, Mt Nicholas	Lower Permian	Lower Freshwater Seq.	MRT (unpublished)	Vitrinite	0.43
Huntsmans Creek, Mt Nicholas	Lower Permian	Lower Freshwater Seq.	MRT (unpublished)	Vitrinite	0.48
Huntsmans Creek, Mt Nicholas	Lower Permian	Lower Freshwater Seq.	MRT (unpublished)	Vitrinite	0.47
Fingal	Lower Permian	Lower Freshwater Seq.	Powell, 1985	Vitrinite	0.55
Douglas River/Bicheno-10	Lower Permian	Tasmanite	Bendall, 1991	MPI	0.6
Douglas River/Bicheno-10	Lower Permian	Tasmanite	Revill *et al*., 1994	MPI (0.36)	0.47-0.62
Douglas River/Bicheno-10	Lower Permian	Quamby Formation		T_{max} (av. 437)	0.5
Douglas River/Bicheno-10	Lower Permian	Quamby Formation	Domack, 1991 (*in* Bendall, 1991)	TAI (2)	0.5–0.9

Table 5

(continued)

Locality	*Age*	*Unit*	*Reference*	*Method*	*Ro or Re*
CENTRAL					
Serpentine Creek roadcut, Bronte	Permo-Triassic	Parmeener Supergroup	Harris, 1981	TAI (3+)	1.0–2.0
DDH 5021, 91′, Poatina	Permian?		Harris, 1981	TAI (2+)	0.5–0.9
DDH 5021, 795′, Poatina	Permian?		Harris, 1981	TAI (3)	1.0–2.0
DDH 5083, 941′, Poatina	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.61
Outcrop, Brady Formation, Poatina	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.57
East bank Coalmine Creek, Colebrook	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.55
Abandoned mine, Colebrook	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.54
100 m from dolerite, Langloh	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.6
Open cut, Langloh	Upper Triassic	Unit 4	Morrison & Bacon (1986)	Vitrinite	0.57
Golden Valley	Lower Permian	Lower Freshwater Seq.	Powell, 1985	Vitrinite	0.62
DDH 5039, Poatina	Lower Permian	Lower Freshwater Seq.	Banks (unpublished)	Vitrinite	0.5
DDH 5096, Poatina	Lower Permian	Lower Freshwater Seq.	Banks (unpublished)	Vitrinite	0.58
Golden Valley-1	Lower Permian	Golden Valley Group		T_{max} (av. 444)	0.7
Golden Valley	Lower Permian	Quamby Formation	Bendall, 1991	MPI	0.7
Golden Valley-1	Lower Permian	Quamby Formation		T_{max} (av. 442)	0.6
Road above Quamby Brook, Golden Valley	Lower Permian	Quamby Formation	Harris, 1981	TAI (2+)	0.5–0.9
Poatina	Lower Permian	Quamby Formation	Volkman & Holdsworth, 1989*b*	MPI	0.75
Tunbridge-1	Lower Permian	Quamby Formation	Bendall, 1991	MPI	1.35
Tunbridge-1	Lower Permian	Quamby Formation		T_{max} (av. 452)	ca. 1.0
Ross-RG146 ('Ross-2')	Lower Permian	Quamby Formation	Bendall, 1991	MPI	1.35
Poatina	Lower Permian	Quamby Formation	Domack, 1991 (*in* Bendall, 1991)	TAI(2)	0.5–0.9
Tunbridge-1	Lower Permian	Quamby Formation	Domack, 1991 (*in* Bendall, 1991)	TAI(3)	1.0–2.0
Ross-1 (Quoin)	Lower Permian	Quamby Formation	Domack, 1991 (*in* Bendall, 1991)	TAI(3)	1.0–2.0
Ross-2 (RG-146)	Lower Permian	Quamby Formation	Domack, 1991 (*in* Bendall, 1991)	TAI(3)	1.0–2.0
Golden Valley	Lower Permian	Quamby Formation	Powell, 1985	TAI(2)	0.5–0.9
SOUTH					
Abandoned mine, Ida Bay	Upper Triassic	Unit 4	Banks (unpublished)	Vitrinite	0.64
Styx Valley	Lower Permian	Woody Island Formation	Harris, 1981; Summons, 1981*a*	TAI (2)	0.5–0.9
Styx Valley	Lower Permian	Woody Island Formation		T_{max} (av. 454)	ca. 1.0
Quarry (seep), Lonnavale	Lower Permian	Woody Island Formation	Whythe & Watson, 1996	biomarkers	0.8
Quarry (seep), Lonnavale	Lower Permian	Woody Island Formation	Revill, 1996	biomarkers	late oil window
Eaglehawk Neck-1	Lower Permian	Woody Island Formation		PI (av. 0.5)	mature

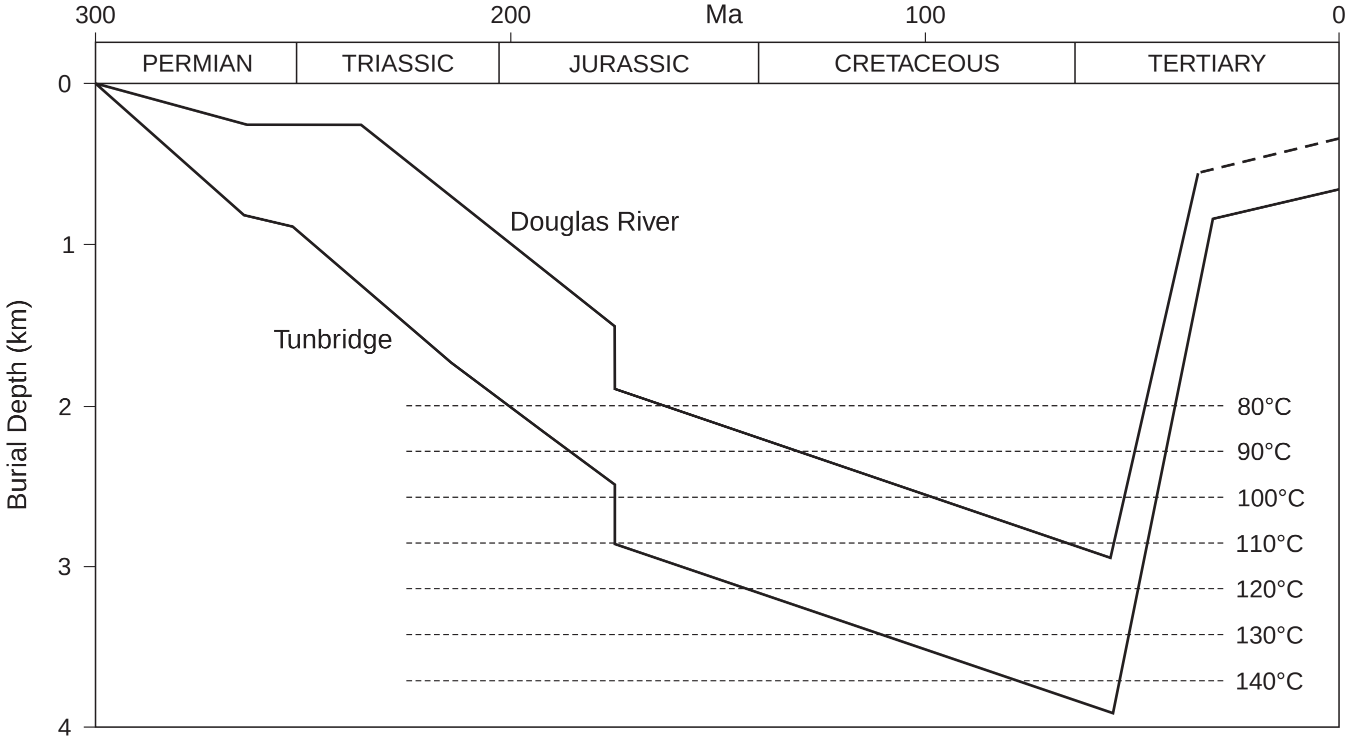

Figure 19

Burial history curves for the base of the Quamby Mudstone correlate at the Douglas River and Tunbridge drill holes. Assumptions and constraints are discussed in text.

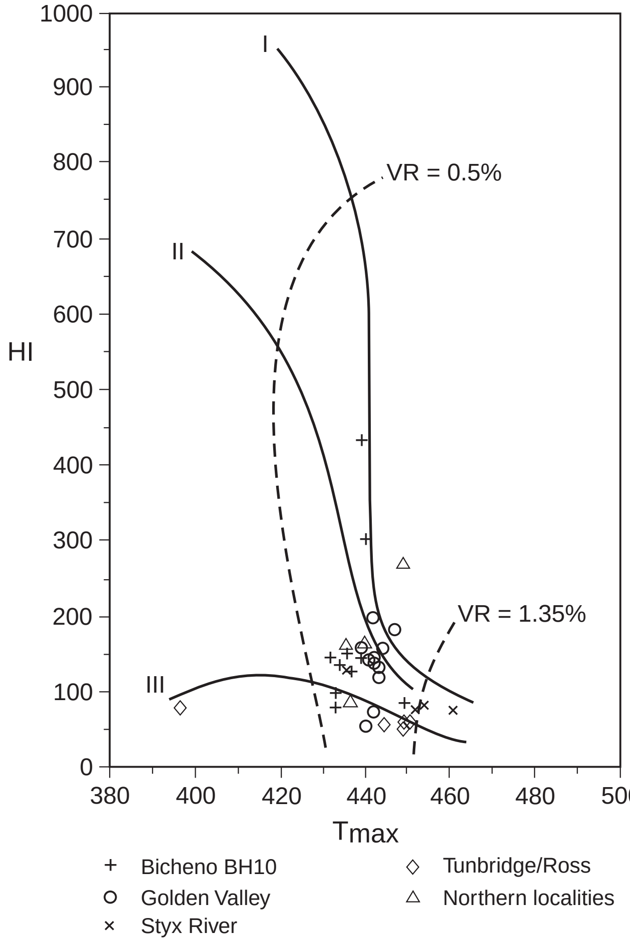

Figure 20

Hydrogen Index versus T_{max}, Woody Island Formation and Quamby Mudstone samples.

Quamby Mudstone (late oil–early gas window). Production indices are high (around 0.5).

There remains a possibility that heating by igneous intrusions has affected these drillhole sections. In the Tunbridge hole, the Quamby Mudstone contains several minor intersections of intrusive Tertiary basalt. In the Ross-2 (RG146) hole, the base of the Quamby Mudstone is 63 m above a 21 m thick dolerite intersection. In the Ross-1 (Quoin) hole, the base of the Quamby Mudstone is 85 m above a dolerite sheet that is at least 470 m thick (Clarke and Farmer, 1983; Forsyth, 1989*a*). The Woody Island Siltstone section in the Eaglehawk Neck drillhole is fully mature or overmature as suggested by high Production Indices and very low Hydrogen Indices, but this hole is close to dolerite (Leaman, 1997*b*).

Other data suggest widespread and similar levels of maturation in the Lower Permian in southern Tasmania, even in localities distant from dolerite intrusion. For example, T_{max} determinations on Woody Island Siltstone samples from Styx Valley, distant from dolerite, suggest similar or higher maturation than at Tunbridge Tier-1 (fig. 20). The MPI of the bitumen seep near Lonnavale (see below) implies a *Tasmanites*-bearing source (i.e. Woody Island Siltstone) with an equivalent vitrinite reflectance of 0.8% (Wythe and Watson, 1996); but Revill (1996) concluded that the bitumen was of upper oil window maturity. Vitrinite reflectance values from Unit 4 (Late Triassic) in the southern Midlands are 0.54 to 0.69% (early oil window). These values are unlikely to have been significantly

Table 6

Arrhenius TTI values for tasmanite (Type IB kerogen) and Woody Island Formation correlate (Type III kerogen) source rocks at Douglas River and Tunbridge, based on burial history curves of Figure 19 and resultant hydrocarbons evolved.

Douglas River

Temperature range	Exposure time (Ma)	Interval ending (Ma)	TTI(IB)	ΣTTI(IB)	TTI(III)	ΣTTI(III)	oil to gas TTI	oil to gas ΣTTI
100–110	32	68	2	2	0	0	0	0
110	6	59	1	3	0	0	0	0
110–100	2	57	0	3	0	0	0	0
			<5% oil generated from Type IB kerogen		0% hydrocarbons from Type III		0% oil cracked to gas	

Tunbridge

Temperature range	Exposure time (Ma)	Interval ending (Ma)	TTI(IB)	ΣTTI(IB)	TTI(III)	ΣTTI(III)	oil to gas TTI	oil to gas ΣTTI
100–110	5	170	0	0	0	0	0	0
110–120	32	138	10	10	2	2	0	0
120–130	32	106	50	60	9	11	1	1
130–140	31	75	250	310	46	57	4	5
140	16	59	270	580	50	107	4	9
140–130	2	57	20	600	3	110	0	9
130–120	3	54	5	605	1	111	0	9
120–110	2	52	1	606	0	111	0	9
110–100	3	49	0	606	0	111	0	9
			100% oil generated from Type IB kerogen		70% hydrocarbons from Type III		10% oil cracked to gas	

boosted by proximity to dolerite intrusion because the AFT data suggest these rocks were near 95°C before the mid-Cretaceous (see above). Unit 4 is ca. 1.3 km stratigraphically above the Woody Island/Quamby Formation equivalent (assuming no thick dolerite), which may therefore have attained at least the middle oil window assuming a moderate positive geothermal gradient at the time of the thermal maximum.

As shown below, burial history analysis is consistent with mature Early Permian in central and southern Tasmania.

Burial history analysis and time-temperature maturation modelling

Time as well as temperature is an important determinant of maturation. If the thermal history is known, maturation can be effectively modelled using a time-temperature index (TTI_{ARR}) method based on the Arrhenius equation, which takes into account the kinetic parameters (activation energy and frequency factor) of the particular source rock (Wood, 1988; Hunt, 1996).

Burial history analysis and TTI_{ARR} modelling has been attempted here for the tasmanite or equivalent horizon (base Woody Island Siltstone and correlates) at two locations in the Tasmania Basin; the Bicheno-10 drillhole near the eastern basin margin, and Tunbridge-1 near the basin's depocentre.

As suggested by the AFT data, maximum burial is assumed to have occurred in the Upper Cretaceous, with the 95° isotherm attaining the middle of the Upper Triassic Unit 4 at this time. Assuming a geothermal gradient of 35°C/km, a mid-Jurassic to Cretaceous succession about one kilometre thick is required (fig. 19). The sedimentation rate for this succession is assumed to have been constant. As indicated by the AFT data, rapid uplift and erosion is assumed to have occurred in the Early Tertiary.

The kinetic parameters for tasmanite kerogen (Revill *et al.*, 1994) are close to Type IB kerogen of Hunt (1996). Percent of total potential oil generated is calculated for Type IB kerogen (representing tasmanite), Type III kerogen (as found in the Woody Island Formation and correlates), and the cracking of oil to gas, using the TTI_{ARR} method as outlined in Hunt (1996) (Table 6).

The model shows that the tasmanite at Douglas River just attained the oil window with less than 5% of oil generated, in good agreement with the observations of Revill *et al.* (1994). The model suggests that no hydrocarbons have been generated from the more refractory Type III kerogen in this section. Modelling a substantially steeper geothermal gradient produces an unacceptably high degree of maturation in the tasmanite horizon, which is not in accord with observations.

In drillhole Tunbridge-1, the model indicates late oil window to early gas window conditions were attained at the level of the base of the Woody Island Siltstone correlate, consistent with the 1.35% vitrinite reflectance equivalent determined from MPI (Bendall, 1991). One hundred percent of oil would have been generated from a tasmanite horizon, 70% of hydrocarbons (mostly gas) would have been generated from the Type III kerogens of the Woody Island Siltstone correlate, and 10% of contained oil would have been cracked to gas.

The modelling suggests that lateral variation in maturation of the Woody Island Siltstone and correlates can be explained by known thickness variations in the Parmeener Supergroup, as the inferred burial histories of the two sites only differ in that Tunbridge-1 is known to have a substantially thicker Parmeener Supergroup section.

The mid-Permian and younger sediments have been removed by erosion at localities in the northern part of the basin (Oonah, Latrobe), so the original Parmeener thicknesses are unknown there. Triassic sections may have been relatively thin (Forsyth, 1989*b*), which may explain the immaturity of the Early Permian rocks in the northern part of the basin.

Effect of dolerite intrusions on maturation

Dolerite intrusions are likely to have locally enhanced the thermal maturity of submature rocks, and to have caused overmaturity close to intrusions. The effects are likely to be highly variable and unpredictable because of varying thermal diffusivities and fluid contents of the country rocks, and different intrusion geometries. Numerous Tasmania Basin vitrinite reflectance determinations of 1.3 to 4.0 (Table 5) attest to contact metamorphism by dolerite intrusion. Dolerite intrusion into or near Lower Permian potential source rocks seems to have been more widespread in southern Tasmania. For example, cross-sections partly based on gravity and magnetics show dolerite intruding the Lower Parmeener Supergroup over 60% of the area of the Hobart 1:50 000 scale map sheet (Leaman, 1976). In four out of six drillhole intersections in southern Tasmania, much or all of the Woody Island Siltstone is baked, apparently by dolerite (i.e. Shittim-1, Glenorchy-1, Granton-1, and Margate drillholes, leaving only the Styx and Eaglehawk Neck-1 wells with unmetamorphosed potential source rock intersections).

Discussion

A number of mutually supportive maturation indicators show that the Lower Permian potential source rocks are submature in the northern parts of the basin and mature (late oil or early gas window) in the central and southern parts of the basin (south of Ross-1), exclusive of the effects of the dolerite. Burial history modelling constrained by AFT data presents a consistent picture, and suggests that the known increase in thickness of the Parmeener Supergroup in the central and southern parts of the basin can account for the maturation trend. In detail, the pattern of maturation is likely to be complex, because of the effects of dolerite intrusions and the fact that Jurassic to Cretaceous faulting would have elevated potential source rocks to varying levels in the crust prior to the inferred Cretaceous burial temperature maximum. More data from central and southern Tasmania would be useful to assess ‘background’ (i.e. non-dolerite affected) levels of thermal maturation in Woody Island Formation correlates. Vitrinite reflectance data could be readily obtained from the Eaglehawk Neck drillhole, Bothwell drillhole (at the level of the Lower Freshwater Sequence) and outcrop in the Styx Valley area.

Potential Reservoirs

Basement formations

Palaeokarst, reefal or fractural reservoirs can be anticipated in the Ordovician Gordon Group limestone (Bendall *et al*., 1991; Burrett, 1992; Young, 1996). Voluminous, massive, crystalline secondary dolomite is known (e.g. Summons, 1981*b*) and may harbour significant intercrystalline porosity. The Gordon Group is dominated by quiet-water, platform-interior, peritidal micritic facies, but a calcarenitic, platform-margin facies occurs at Precipitous Bluff in far southern Tasmania (the Middle Ordovician New River Beds). Equivalents on the south coast are deep-water basinal shale (Burrett *et al*., 1984). A platform-margin belt trending ESE through Precipitous Bluff, and with a high probability of potential reservoirs, may be inferred beneath Tasmania Basin cover (Burrett, 1986). Migration paths would be minimal if the limestone was the source.

Sandstones in the Siluro-Devonian Eldon and Tiger Range Groups have also been mooted as potential reservoirs (e.g. Summons, 1981*a*; Burrett, 1986; Bendall *et al*., 1991), although no data are available on porosity and permeability. Pyrobitumens are reported to be common in vughs in Eldon Group sandstone near Zeehan in western Tasmania (Burrett, 1996).

Parmeener Supergroup

The main potential reservoir unit in the Lower Parmeener Supergroup is the Lower Freshwater Sequence. Marine sandstone and limestone, and the thick, clean quartz sandstone of Unit 2 of the Upper Parmeener Supergroup, are also possible reservoirs (Wiltshire, 1980; Maynard, 1996; Rao, 1997).

Lower Freshwater Sequence

This unit, known as the Faulkner Group in southern Tasmania and the Liffey Group, Mersey Coal Measures and Preolenna Coal Measures in the north, is a widespread succession, 20–40 m thick, of fluvial to paralic sandstone, siltstone, shale and coal. A palaeogeographic reconstruction (Banks and Clarke, 1987) (fig. 8) shows a broad sandy coastal plain with the sea lying to the southeast. The unit is dominated by well-sorted, cross-bedded quartz-rich fluvial sandstone in the north of the basin. The main coal developments are found around the landward margins (north) of the basin, at Preolenna, Latrobe and St Marys. Up to four seams may be present with an aggregate thickness of one metre. The sequence tends to become finer grained to the southeast. In the Hobart area and in the east (Maria Island, Eaglehawk Neck), micaceous siltstone and carbonaceous mudstone are predominant. The unit contains a marine intercalation in central and southeast Tasmania. South of Hobart the unit passes laterally into marine fossiliferous siltstone (Farmer, 1985; Clarke, 1989).

A study of the reservoir potential of the Lower Freshwater Sequence in eight drillholes spread across the basin from Golden Valley to Hobart (Maynard, 1996) found that there were considerable lateral and vertical variations in reservoir quality. The average porosity of the whole unit is 10.9%. In most sections, the middle 15–20 m of the unit has a range of fair to good reservoir potential. However, the Ross-RG146 and Tunbridge-1 drillholes, lying east of the other sections, had poor reservoir quality because of finer grainsize. An area of generally poor reservoir quality may be inferred to lie south and east of these drillholes (fig. 8).

Marine sandstone and limestone

Apart from the Lower Freshwater Sequence, a number of marine sandstone units within the enclosing, largely muddy glaciomarine succession are possible reservoirs.

In southern Tasmania the Bundella Formation is a shallow marine shelf deposit, underlying the Lower Freshwater Sequence, and consists of about 120 m of fossiliferous siltstone with minor sandstone and granule conglomerate (Clarke and Farmer, 1982; Farmer, 1985). Samples from the Shittim-1 well have porosities of 7.4 to 22.3% and horizontal permeabilities of 0.07 to 9 md (Woods, 1995; Farley, 1995). Much of the porosity is mouldic, resulting from the dissolution or decarboxylation of shelly fossils (Woods, 1995).

The Minnie Point Formation and correlative Malbina Formation comprise a shallow marine shelf deposit, consisting of 50–90 m of poorly-sorted, pebbly, feldspathic sandstone and siltstone (Farmer, 1985; Clarke, 1985) (fig. 7). Porosities of 14.1 to 16.6% have been measured in the Minnie Point Formation (Woods, 1995; localities not recorded).

The Risdon Sandstone is an offshore barrier bar deposit consisting of coarse-grained, cross-bedded sandstone, eight metres thick in the Cygnet area but generally thinner elsewhere (Farmer, 1985). Porosities of 13.7–14.7% have been measured on outcrop samples (Woods, 1995; localities not recorded). Thin section analysis shows much primary intergranular porosity to be occluded by quartz overgrowths. Most of the porosity is secondary, resulting from feldspar dissolution (Woods, 1995).

Marine limestone within the Lower Parmeener Supergroup may be potential reservoir rocks (Rao, 1997). The main limestone development is the Berriedale Limestone, consisting of about 60 m of interbedded, impure bioclastic limestone and calcareous shale. The limestone is typically a coarse-grained biosparite, with bryozoan and shelly fragments cemented by sparry calcite. Porosity is typically occluded by early diagenetic sparry calcite cement, or by compactive deformation of grains and growth of authigenic clay minerals (Rao, 1981; Turner and Calver, 1987, p. 21–24). It seems unlikely that the limestone would have retained significant primary porosity until the Jurassic–Cretaceous when hydrocarbons are likely to have been generated (see previous section).

The Berriedale Limestone and its lithological correlates have a rather restricted distribution in southeast and eastern Tasmania, from the Hobart area to Maria Island and up the east coast as far north as St Marys. The formation wedges out south of Hobart (Farmer, 1985), passes laterally into sandstone to the west (Maydena) and is represented by a period of non-deposition in central and northwest Tasmania (e.g. Poatina) (Clarke, 1989). Thinner limestone units (e.g. Darlington Limestone) are locally present in correlates of the Bundella Formation. Developments of limestone up to 20 m thick occur within the Quamby Mudstone southeast of Poatina (Matthews *et al*., 1996).

Well-sorted quartz sandstone of Unit 2 of the Upper Parmeener Supergroup is widespread, and typically about 200 m thick, with little or no interbedded shale or coal. From a lithological viewpoint, these sandstones are the best potential reservoirs in the basin (Wiltshire, 1980). Porosity determinations by water absorption average 12.7 ± 2.7%, n = 46 (Sharples *et al*., 1984). Mudstone in the overlying Cluan Formation (Unit 3) is a potential seal (Wiltshire, 1980).

Seals and Traps

The lower Palaeozoic rocks comprise a thrust-fold province (Leaman, 1991; 1992; 1996*a*) which could offer a broad spectrum of structural and stratigraphic trapping possibilities. Reservoirs within lower Palaezoic rocks could be sealed by shale in the Eldon and Tiger Range Groups in anticlinal traps (e.g. Burrett, 1986; Carne, 1992). Traps sealed by major Devonian thrust surfaces may be feasible (Bendall *et al*., 1991).

The base–Parmeener Supergroup unconformity is overlain by tillite and mudstone. Given a relatively late (post-Permian) timing of oil generation in the Palaeozoic section, or post-Permian tertiary migration of pre-Carboniferous hydrocarbon accumulations, various sub-unconformity traps are conceivable. Such accumulations could be reservoired in palaeokarst in Gordon Group limestone (Bendall *et al*., 1991) or Eldon Group sandstone in truncated anticlines (with, for example, Eldon Group shale as the lateral seal and the basal Parmeener unconformity as the top seal) (Carne, 1992).

Traps in the Palaeozoic rocks will be difficult to find, as the hypothesised mature source rocks are mostly concealed beneath Tasmania Basin cover (fig. 6) which may be difficult to penetrate seismically because of widespread dolerite (see later section).

In the Tasmania Basin succession, marine mudstone and silty mudstone in the Lower Parmeener Supergroup, and the Jurassic dolerite, are the most likely potential seals. Muddy lithologies comprise most of the Lower Parmeener, stratigraphically enclosing all the potential intrabasinal reservoir units except Unit 2 of the Upper Parmeener Supergroup. Traps created by fault offset of reservoirs are probably very common, but would rely on the integrity of the fault surface. Only the older (Jurassic–Early Cretaceous) fault traps could be expected to be charged with hydrocarbons. Many Jurassic faults are intruded by dolerite dykes, which may seal them against leakage unless later reactivated.

Lower Parmeener Supergroup mudstone is typically well jointed at surface, and the potential for both leakage and storage of hydrocarbons afforded by the network of fractures and bedding planes is uncertain. Units such as the Cascades Group and Ferntree Mudstone are excellent aquifers because of their well-jointed nature, but groundwater investigations show that such fractures tend to be closed at subsurface depths greater than about 30 m (e.g. Leaman, 1971), suggesting such fractures may be insignificant in terms of either leakage or storage of hydrocarbons.

Significant faulting in the Tasmania Basin probably continued at least into the late Tertiary. Fault planes generally behave as transmissive open fractures in tensional settings at shallow depths; moreover, fault planes can be expected to transmit hydrocarbons during fault movement (Downey, 1994). Rocks would have long since been fully lithified and of low ductility. Tertiary faulting or fault reactivation probably represents a significant risk to the integrity of traps that may have been charged in the Jurassic–Cretaceous thermal maximum. Exploration would best be focused on areas away from Tertiary faulting (Leaman, 1987).

Gentle structural domes in Parmeener Supergroup rocks have been identified by surface mapping at Hunterston (Fairbridge, 1949), Cygnet (Leaman and Naqvi, 1967; Farmer, 1985; Leaman, 1990) and Forcett. The Forcett and Hunterston domes have been targetted in the current drilling program by Great South Land Minerals Pty Ltd. The age of these structures is unknown, but relationships with intrusions suggest some may be Jurassic.

The abundance of steep normal faults and presence of vertical Jurassic feeders and dykes means that migration may have been predominantly vertical. Necessary vertical migration distances (e.g. Quamby Mudstone or Macrae Mudstone to Lower Freshwater Sequence) are not large. Migration up faults to stratigraphically higher reservoirs (Risdon Sandstone, Ross Sandstone) may also be possible. Rejuvenation of structures may have also affected sub-unconformity reservoirs.

Jurassic dolerite may be a potential semi-regional seal (Carne, 1992; Young, 1996). The presence of helium in cuttings gas samples from below two thick dolerite sheets in Shittim-1 (Burrett, 1997*a*) suggests that dolerite is a highly effective seal, as helium has the smallest effective atomic/molecular diameter of any gas, about half that of methane.

Known Hydrocarbon Occurrences

Large numbers of natural bitumen occurrences have been reported in Tasmania, particularly along the coast (see Appendix 1) but the coastal occurences are not thought to be derived from Tasmanian source rocks. Several distinct types of bitumen are now recognised. Biomarker analyses have shown that most types originate from oil seeps in Southeast Asia (Currie *et al*., 1992). Many contain an unusual isoprenoid alkane termed botryococcane, which is abundant in many Indonesian oils (McKirdy *et al*., 1986).

A second type of bitumen is jet-black, shiny and breaks with conchoidal fracture. A number of these were collected along the west coast of Tasmania last century and early this century (Twelvetrees, 1917). The bitumens dissolve completely in chloroform and contain aliphatic hydrocarbons (12.3–17.3%), aromatic hydrocarbons (4.4–10.6%) and uncharacterised asphaltenes (75.6–82.9%). Biomarker data confirm that the bitumens are not related to land-plant derived oils presently recovered from the nearby Bass, Otway and Gippsland Basins of southern Australia. The high proportions of C_{27} steranes and presence of C_{30} steranes, including dinosterane, suggested that the bitumens were derived from a marine source rock containing mainly marine organic matter. Biomarker maturity parameters were also very similar in all bitumens and consistent with those found in crude oils generated at an equivalent vitrinite reflectance of about 0.75. The source of these bitumens is still unknown, but may be associated with Mesozoic or Cainozoic offshore sediments that are poorly represented onshore (Volkman *et al*., 1992).

In 1995 bitumen was found in joints in Jurassic dolerite near Lonnavale in southern Tasmania by R. S. Bottrill of Mineral Resources Tasmania. Analysis by Whythe and Watson (1996) shows that this is an aromatic-naphthenic oil that has been subjected to light biodegradation. The abundance of C_{19}–C_{31} tricyclic terpanes suggests that the precursor organic matter was rich in *Tasmanites*. The presence of biomarkers of higher plant origin suggests some terrestrial input as well. Biomarker maturity parameters indicate that the bitumen was generated from a moderately mature source rock, with an equivalent vitrinite reflectance of approximately 0.8%. Revill (1996) also analysed this bitumen, and a 'swab' of associated oil staining. The latter has a well-developed *n*-alkane profile and a tricyclic component, expected of a thermally mature source containing *Tasmanites* (fig. 21). Biomarker data suggested to Revill that the bitumen was of greater thermal maturity (late oil window) than the swab sample, but the reasons for this are not yet understood.

Traces of hydrocarbon gases have been detected in some wells drilled by Great South Land Minerals Pty Ltd. During drilling of Shittim-1, a hotwire gas detector provided a continuous record of methane released from returning drilling fluids ('cuttings gas') in the 800 m–TD interval. Concentrations were typically 0.1–1%, but the method involves considerable air contamination and the results are of semi-quantitative value only. The rocks intersected were fractured, contact-metamorphosed Truro Tillite and Bundella Formation, Jurassic dolerite and Proterozoic phyllite basement (Burrett, 1997*a*).

A number of cuttings gas samples from the 1640–1751 m interval (Proterozoic metamorphic rocks) in Shittim-1 were analysed by AMDEL. Large corrections are necessary for air contamination. Air-corrected compositions are dominated by nitrogen (up to 98%), with hydrogen the next most abundant constituent (0.5–8% air corrected). Methane levels were mostly 0.1–1% (except for one sample at 31%). The methane has a $\delta^{13}C$ value of -50 to -59‰, which is at the low (negative) end of the thermogenic range. CO_2 levels are low (mostly less than 1%). Significantly, traces of C_2–C_6 alkanes are present (Burrett, 1997*a*). Helium is present in most of the samples, with air-corrected levels up to 4.8%, but mostly less than 1%.

Several gas samples described as 'choke swab' from 1568 m have relatively slight air correction and have air-corrected contents of around 0.04% helium, 5% methane and 0.001% ethane (Anon., 1997).

A hydrocarbon extract from a core sample of the Proterozoic metamorphic rocks was analysed. The GC trace is similar to that of an extract from Ordovician Gordon Group limestone in that alkanes maximise at *n*-C_{18} and the Pr/Ph ratio is about 1 (Burrett, 1997*a*).

Nearby drillhole Jericho-1 also yielded cuttings gas samples with low levels of methane (mostly less than 1%, air corrected) and trace C_2–C_6 hydrocarbons, while drilling in contact-metamorphosed Lower Parmeener Supergroup and dolerite. The $\delta^{13}C$ value of one methane sample (640 m depth) is -33.5‰ (Burrett, 1997*b*).

The presence of trace C_2–C_6 hydrocarbons in the contact-metamorphosed Lower Parmeener succession, dolerite and phyllite basement in Shittim-1 and Jericho-1 is of interest. The hydrocarbons may have migrated into the section, perhaps from unknown Ordovician basement to the west (Mulready, 1995; Burrett, 1997*a*), although the lithologies appear to be relatively impervious. The presence of helium suggests that the Tasmania Basin section is a highly effective seal, at least against vertical migration. The methane and other hydrocarbons most likely originated from maturation of the host rocks during dolerite emplacement. The hydrocarbons — predominantly gaseous — would have been expelled both upward and downward away from the vicinity of the hot intrusions, and later could have migrated back into the fractured, contact-metamorphosed country rocks and dolerite after the intrusions cooled.

Cuttings gas from 50, 90 and 96 m in drillhole Lonnavale-1 contain low levels of C_1 to C_7 hydrocarbons (Burrett, 1997*b*).

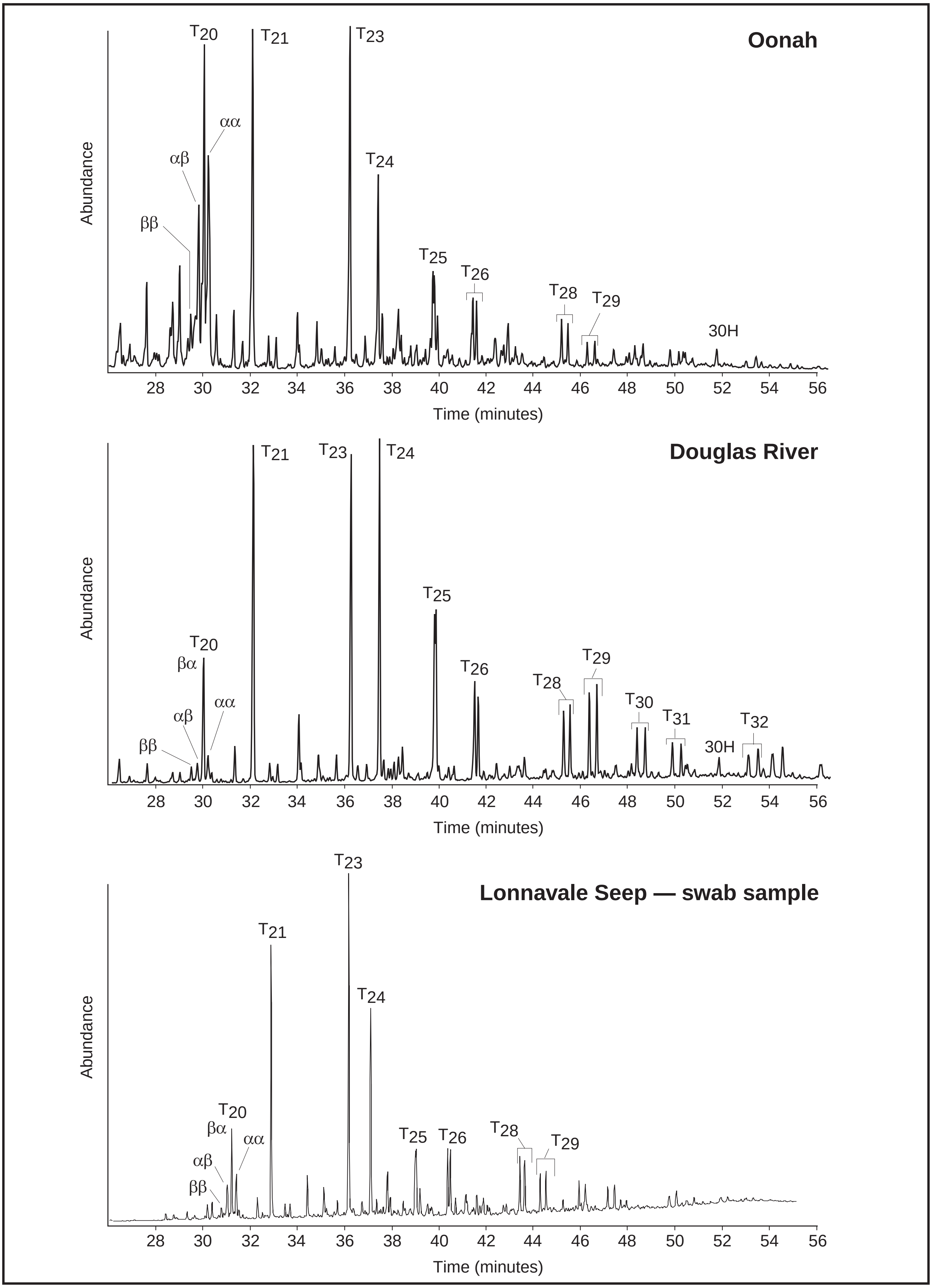

Figure 21

m/z 191 Mass chromatograms showing tricyclic hydrocarbon distributions in samples from Oonah (immature), Douglas River (mature) and the Lonnavale swab sample. (Numbers refer to the number of carbons, α and β refer to stereochemistry at carbons 13 and 14.)

Exploration Issues

In the course of normal exploration of substantial basins, seismic methods would be applied almost exclusively to initially provide a regional framework for stratigraphic relationships and suggest the nature of any structuring. Follow-up work merely provides detail about zones which may contain targets. Use of other geophysical methods may assist orientation of seismic surveys or illuminate basin morphology but these are rarely employed unless particular problems are encountered. This industry standard approach is simply not realistic nor possible in the Tasmania Basin. One principal cause and several subsidiary reasons can be cited for this. The Jurassic dolerite and the ramifications of its complex tangle of intrusions, coupled with very high velocity characteristics and absorption of energy, and its common presence at surface accounts for nearly all of the difficulties. Issues of high relief terrain, poor access, yet to be established ideal acquisition and processing options, and cost in this environment are subsidiary problems.

Considerable work has been undertaken to resolve the seismic-dolerite problem as there is little doubt that no other aspect of the pre- or post-Carboniferous sequences or structures pose any special difficulty and, in the absence of dolerite, standard methods and specifications could be employed. Research has shown that where dolerite is exposed variations in weathering lead to complex signal deterioration and loss of coherence due to very high velocities and extreme variations in velocity (e.g. Richardson and Leaman, 1981; Leaman, 1996*a*). The base of the intrusion is rarely seen in these conditions and the sequence below the intrusion is shadowed for up to one second; some further experiment is required to define acquisition and processing parameters. Where the dolerite occurs within section, but not at surface, existing surveys have been more successful (Leaman, 1978, Leaman, 1987 — Bruny Island; Leaman, 1996*a* — AGSO lines T4–5). In no case has an interpreted seismic line been drilled to confirm that the reflections inferred are due to dolerite boundaries although satisfactory sections have been obtained. No profile is longer than a few kilometres and none have been located which might test important structures; the emphasis has been on the discovery of workable and economic survey parameters. Longer lines inevitably mean that some portions will traverse exposed dolerite which is a more difficult problem. Where thick, low velocity materials are exposed at surface, standard specifications and the method work well (e.g., Leaman, 1978; Richardson and Leaman, 1981; Leaman and Richardson, 1980; Leaman, 1996*a*). It appears that very small charges, close geophone and array spacings and deep shot holes are essential where dolerite is exposed. Vibroseis methods have yet to be proven more effective.

In the absence of significant seismic coverage, or the chance to acquire it, evaluation of the basin depends upon the use of other methods and this situation will continue after seismic methods have been refined due to the complexities of the structures. Other methods are here taken to mean surface geological mapping, consideration of faults and fault histories (many are complex with involvement in Jurassic intrusion sequences), lithostratigraphic thickness and facies changes, petrological and petrophysical variations in dolerite which indicate aspects of intrusion form, and gravity and magnetic methods.

Although much of the basin sequence has been exhumed, surface mapping is of limited value in predicting subsurface structure. While the typical relief in the terrain is of the order of the thickness of many parts of the sedimentary cover sequence, dolerite intrusions may double the thickness and appear unpredictable in form and distribution. An example of the integration of all types of information to deduce regional structural and stratigraphic patterns, and some indication of dolerite forms, was provided by Leaman (1990). The exploration problems of the Tasmania Basin can only be resolved in this comprehensive manner; seismic methods may assist and are ultimately required for target definition once particular regions have been identified for survey.

Gravity and magnetic surveys are an essential component of any appraisal of dolerite intrusions and their contribution to a particular profile. Techniques have been established for this element of interpretation (e.g. Leaman, 1972, Leaman and Richardson, 1981; Leaman, 1987) but these are time-consuming and require detailed data sets with a line spacing generally less than 500 m and with some segments of the survey at much denser line spacing. No such data exist at the time of writing but a new NGMA aeromagnetic survey proposed for parts of the Midlands will provide adequate resolution in magnetic data to resolve dolerite shapes and relationships in detail.

The exploration issues associated with the cover sequence of the Tasmania Basin may be resolved with reasonable mapping and potential field coverage; that is, the dolerite and faulting relationships can be resolved and understood. Any seismic surveys directed at structures, such as facies traps or local doming within the cover, will remain difficult because of the shallowness of targets and the relatively high velocities (>3500 m/s) of the cover rocks.

The exploration issues associated with the structures and sequences beneath the Late Carboniferous unconformity include all aspects noted above, but also require some resolution of deeper structure. As deeper structures include thrust stacks and repeated sequences of folded rocks it may be anticipated that seismic methods may prove less than ideal. Only the limited profiles of Leaman (1978) and Leaman and Richardson (1980) are relevant to this topic and do offer some cause for optimism. Surface mapping is of little use, other than for inspection of the content of pyroclastic rocks (see

Leaman, 1990), and initial exploration will depend primarily on potential field methods. These have already proven able to separate major sequences (Leaman, 1996*b*) and to define primary structures (Leaman, 1990; 1991; 1992; 1996*b*). A more regional review has been provided by Gunn *et al*. (1996).

A continuing program of stratigraphic drilling is required to supplement and verify initial interpretations and allow iteration of analysis. Such analysis may then be coupled with inferences of fault history (including avoidance of zones with demonstrated Tertiary movements), seepage patterns if these can be established, and underlying structural trends. The abnormal demands to be made of any exploration program in central Tasmania reflect the complex fault history dating from the mid-Jurassic and the associated complex of dolerite intrusions. Fortunately the problems are soluble but at some additional cost. This exploration cost disadvantage may be offset against the benefits accruing to any find in the relatively thin sequences amid dense infrastructure.

Discussion and Conclusions

Onshore Tasmania, in contrast to its offshore waters, has had a long but sporadic history of petroleum exploration. The State's onshore petroleum potential has yet to be satisfactorily tested by modern methods. Of the many petroleum seeps reported over the years, only the occurrence at Lonnavale can be interpreted as genuine migrated hydrocarbons derived from indigenous source rocks (Appendix 1). Nonetheless, two play concepts may be considered of interest.

The play concept involving an Ordovician source remains essentially hypothetical. The Gordon Group contains voluminous, promising source-rock facies (warm-water platform carbonates), but the few samples analysed so far are poor in organic matter and no viable source rock (i.e. TOC > 0.5%) has yet been identified. Systematic analysis would need to be undertaken to evaluate the source potential, and could be initiated on available drillcore from the Lune River and Maydena areas.

The question of timing of oil expulsion from an Ordovician source is complex because these rocks have undergone two major phases of burial and uplift. Hydrocarbon generation during the second (Permian to Cretaceous) burial phase is only viable if source rocks attained temperatures similar to or greater than those reached during the Devonian. If hydrocarbons were generated only during the Devonian, exploration would need to focus primarily on traps preserved well beneath the Carboniferous erosion level. Only later migration of such accumulations, or a later (Cretaceous) pulse of hydrocarbon generation, could charge subunconformity traps and reservoirs within the Tasmania Basin.

The greatest present difficulty in pursuing this play concept is the problem of target definition. Most traps would underlie Tasmania Basin cover, and in most areas the systematic use of seismic reflection methods is inhibited by the problems discussed above. There are no obvious targets in outcropping Gordon Group or Tiger Range Group in southern Tasmania, although Leaman (1990) does suggest gross anticlinal trends for further analysis.

The Tasmania Basin contains an exploration play based on a source in the Woody Island Formation and correlates, provided adequate reservoir capacity has been retained after intrusion, faulting and erosion.

The tasmanite is an excellent potential source (Type I kerogen), but it is thin (<2 m) and patchy in its distribution, and significant accumulations have yet to be found outside the thermally immature northern parts of the basin. The discovery of a migrated *Tasmanites*-derived bitumen in southern Tasmania indicates that this source is locally present and has generated hydrocarbons in the mature, southern part of the basin.

TOC and Rock-Eval pyrolysis data show that the Woody Island Formation and correlates enclosing the tasmanite horizon are organically lean. Corrected Hydrogen Index values show that moderate liquids and gas potential exists. Expulsion efficiencies of liquids will be high, being aided by gas expulsion. The relatively large thickness present in the middle of the basin (>200 m) make this the most attractive potential source interval in the basin, even if a mature oil shale equivalent to the thickest known development is widespread, which is doubtful.

Various maturation criteria (including vitrinite reflectance, biomarker indicators, and Rock-Eval T_{max}) demonstrate that the source rocks are submature in the northern and northeastern parts of the basin, but have reached the late oil window, and possibly the gas window, in the central and southern parts of the basin. Apatite fission track analysis suggests peak thermal conditions in the Cretaceous. Simple burial history modelling suggests that the thickness of the post-Early Permian Parmeener Supergroup section was an important control on geographic variation of maturation of the Woody Island Formation and correlates.

Heating by Jurassic dolerite intrusion undoubtedly caused local maturation and overmaturation of source rocks in a manner very difficult to predict in the subsurface. The observation that the Lower Parmeener Supergroup is intruded by thick dolerite over 60% of the area of the Hobart Quadrangle, and that the Woody Island Formation is baked in most drillhole intersections in southern Tasmania, suggests that this phenomenon is very widespread in the southern parts of the basin. Dry gas would presumably have been the main hydrocarbon produced under such circumstances.

The Lower Freshwater Sequence is the only sufficiently persistent and voluminous reservoir unit to be of interest in the Lower Parmeener Supergroup, with the possible exception of the Risdon Sandstone. Reservoir quality in the Lower Freshwater Sequence is doubtful in the central and southeastern parts of the basin, south and east of the Tunbridge–Ross area, where this unit becomes finer grained. The porosity of clastic reservoirs is impaired by proximity to dolerite (Woods, 1995). It is doubtful whether appreciable porosity in the Berriedale Limestone and its lithologic correlates survived until the most likely time of hydrocarbon migration in the mid-Jurassic to mid-Cretaceous.

Unit 2 of the Upper Parmeener Supergroup is a voluminous and good-quality potential reservoir, but is limited by the present depth of erosion in the basin and by the greater necessary vertical migration distances. The basin is now uplifted and largely exhumed, but no empty reservoirs stained with oil residues have been found (Maynard, 1996). However this does not exclude the possibility of past gas accumulations.

Jurassic dolerite and mudstone of the Lower Parmeener Supergroup are potential semi-regional seals. Jurassic or Cretaceous faults are common, offering potential traps. However Tertiary faults pose a major risk to seal integrity, as they were tensional and formed at relatively shallow crustal depths in non-ductile lithologies, and they would have post-dated hydrocarbon migration.

In conclusion, on current knowledge hydrocarbons reservoired in the Lower Freshwater Sequence or Unit 2 of the Upper Parmeener Supergroup and sourced from Woody Island Formation and correlates seem to offer the simplest play in onshore Tasmania. The Woody Island Siltsone potential source rock can now be regarded as being thermally mature in the central and southern parts of the Tasmania Basin. One example of migrated hydrocarbons (sourced from *Tasmanites*) is known.

Major risks to explorers involve the problems associated with target definition, the effect of Tertiary faulting on trap integrity, destruction of hydrocarbons and reservoir porosity close to the ubiquitous dolerite intrusions, and the viability of the Lower Freshwater Sequence as a reservoir in the central and southern parts of the basin. A hydrocarbon play based on a source in Ordovician to Devonian sediments is extremely difficult to evaluate on present information, which is particularly deficient in whether viable source rocks or reservoirs exist, the timing of hydrocarbon generation, and knowledge of pre-Carboniferous structure beneath the Tasmania Basin.

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15. Summary of reports and information on Bruny Island in connection with supposed oil finds. Department of Mines File MIN 237.

16. Nye, P. B. 1930*b*. *Geological surveys made in the search for oil.* Department of Mines File MIN 237.

17. J. T. Moate, Managing Director Adelaide Oil Exploration Company Ltd, to A. McIntosh Reid, 23 January 1930. Department of Mines File MIN237.

18. A. McIntosh Reid, Director of Mines, to J. T. Moate, 27 January 1930. Department of Mines File MIN 237.

19. Enquiry into the matter of the organisation of the Mines Department, February 1930; documented in Bacon, C. A. 1996. A brief history of the Department of Mines — 1882 to 1996. *Record Tasmanian Geological Survey* 1996/07.

20. *Bruni Island Company Prospectus*. Tasmaniana Collection 622-338 BRU.

21, 22. Department of Mines Annual Report, 1916 p. 43.

23. Circular 300/89 from the Prime Minister to Premier of Tasmania, 10 August 1921.

24. TCAE School of Environmental Design: Bruny Island — A Regional Planning Study 1980.

25. *The Mercury* 1 November 1939. Oil bore fraud says member.

26. Secretary of Mines to Minister for Mines, 1 November 1939.

27. *The Mercury* 2 November 1939. Tamar oil search company holds no permit to operate. Ministers disclosure. Shares total 1500.

28. *The Advocate* 3 November 1939. Cowardly attack. Oil company's reply to Dr Lewis. Not operating without permit.

29. *The Mercury* 3 November 1939. Search for Oil Director .... Attack.

30. *The Examiner* 3 November 1939. Reply to accusation of oil fraud. Operating on Permit from Warden of Mines.

31. *The Mercury* 4 November 1939. Search for Oil. Permit related to minerals.

32. *The Examiner* 4 November 1939. Permit for mining but not oil.

33. Secretary for Mines to Minister for Mines, 7 November 1939.

34. Secretary for Mines to Minister for Mines, 8 November 1939.

35. Clarke and Gee, Solicitors to Hon. T. H. Davies, Minister for Mines, 10 November 1939.

36. Minister for Lands and Works (Hon. T. H. Davies) to the Hon. Attorney General, 14 November 1939.

37. Oil bubble burst (press cutting circa November 1939).

38. *Sun* 21, 1939. Assault in cafe alleged (where Max Steinbuchel of Producers Oilwell Supplies was accused of assaulting a diner in Mario's Cafe, Melbourne).

39. *Sun* 22, 1939. Wanted to thank Jury. American not guilty of assault.

40. *The Advocate* 23 November 1939. Search for oil in Tasmania. Minister threatened with legal action.

41. *The Examiner* 23 November 1939. Minister asked to retract.

42. *The Mercury* 25 November 1939. Search for oil. Directors statement.

43. R. N. K. Beedham, Solicitor General to the Attorney General 4 December 1939.

44. Clarke and Gee to the Hon. T. H. Davies, Minister for Mines, 4 December 1939.

45. Minister for Mines to Clarke and Gee, Solicitors, 6 December 1939.

46. *The Examiner* 23 March 1968.

47. Memo from I. E. Corby, Secretary and Accountant to Director of Mines, 22 February 1955.

48. Mrs A. J. Smith to Minister for Works, 16 October 1955.

49. Memo from Director of Mines to Minister for Mines, 6 November 1956.

50. Minister for Mines to Mrs A. J. Adams-Smith, 8 November 1956.

51. *The Examiner* 23 March 1968.

52. J. M. Rayner, Director Commonwealth Department of National Development, to Director of Mines, 28 September 1960.

53. J. G. Symons, Director of Mines, to Director of Bureau of Mineral Resources, 3 October 1960.

54. J. M. Rayner, Director Commonwealth Department of National Development, 25 October 1960.

APPENDIX 1

Reports of oil and gas in Tasmania

Location	Reported by	Date reported	Material reported	Reported observations	Conclusions	Status
Hummock Island (Prime Seal Island)	Charles Gould	1871	bitumen	stray lump of bitumen (Twelvetrees, 1917).	bitumen stranding	C
Sandy Cape	T. B. Moore	1876	bitumen	small pieces of bitumen, very soft (Twelvetrees, 1915).	bitumen stranding	C
Macquarie Harbour	T. B. Moore	1876	bitumen	small pieces of bitumen, not numerous, near Farm Cove (Twelvetrees, 1915).	bitumen stranding	C
Mainwaring River	T. B. Moore	1876	bitumen	stranded bitumen (Twelvetrees, 1915).	bitumen stranding	C
Farm Cove	T. B. Moore	1895	bitumen	stranded bitumen (Twelvetrees, 1915).	bitumen stranding	C
Port Davey	P. Hutchings	1895	bitumen	stranded bitumen, piece given to Geological Survey (Twelvetrees, 1915).	bitumen stranding	C
Derwent Valley	?	1910	bitumen	bituminous exudations reported on banks of River Derwent, 2 miles from Glenora railway station (Annual Report Director of Mines, 1910, p.36).	probably associated with Tertiary lignite (Annual Report Director of Mines, 1910, p. 36).	U
Chudleigh	M. Petterd	1910	asphaltum	on east bank of Mersey River, black, actile, burns with dense smoke and strong odour, occurs in aluminous shale.	possibly weathered coal from Mersey Coal Measures — high sulphur content would account for smell on burning, fissile nature when weathered; or could be lignite or compressed vegetable matter from Quaternary alluvium. Geological map shows Gog Range Greywacke and alluvium 4 miles from Chudleigh.	U
New River Beach	Smith, Adams, Glover	1912	bitumen	large pieces of asphaltum, one weighing more than a hundredweight (Twelvetrees, 1915).	bitumen stranding	C
Cape Sorell–Point Hibbs	L. Hills	1914	bitumen	stranded bitumen along whole coastline (Hills, 1914).	bitumen stranding	C
Rocky Boat Harbour	Adams	1914	bitumen	stranded bitumen (Twelvetrees, 1915).	bitumen stranding	C
South Cape Bay	Bolton Brothers	1914	bitumen	stranded bitumen (Twelvetrees, 1915).	bitumen stranding	C
Bruny Island	Bruni Island Petroleum Co.	1915	oil	two seepages of liquid bitumen; been active for 50 years (Bruni Island Petroleum Co. prospectus).	seeps not visible to Guy Andrew in 1915 as "cold weather had caused points of bitumen exit to close" (Bruni Island Petroleum Co. prospectus). Wade (1915) could find no evidence of these two seeps.	U
Cape Barren Is.	?	1915	bitumen	stranded bitumen (Twelvetrees, 1915).	bitumen stranding	C
Wynyard	?	1915	bitumen	stranded bitumen on beach (Twelvetrees, 1915).	bitumen stranding	C
Deep Creek (Port Davey)	?	1915	bitumen	stranded bitumen, "found in considerable quantity, about a quarter of a ton having been brought to Hobart for inspection" (Twelvetrees, 1915).	bitumen stranding	C
Cox Bight	?	1915	bitumen	stranded bitumen in a bay east of Cox Bight (Twelvetrees, 1915).	bitumen stranding	C
New River		1915	asphaltum	3 miles up New River and on coastline (Twelvetrees, 1915).	bitumen stranding due to tidal influences	C
West Tamar	W. Twelvetrees	1917	oil	vague reports reaching Department of Mines suggesting the existence of oil scums or oozings.	not examined officially, no samples of exuding material submitted.	U
Newstead	W. Twelvetrees	1917	oil	as above	as above	U

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Evandale	W. Twelvetrees	1917	oil	as above	as above	U
Longford	W. Twelvetrees	1917	oil	as above	as above	U
Penguin	E. Eastall	1920	gas	bubbles in a river (E. Eastall to L. Hills, December 1920).	Hills replied "the bubbles were neither unique nor unusual" (L. Hills to E. Eastall, 14 December 1920).	F
Port Sorell	J. H. Moate	1920	oil	saw oil on water at gap at Port Sorell (Adelaide Oil Exploration Co Interim Report to Shareholders).	various possible origins.	U
East Devonport	J. H. Moate	1920	oil	seepage seen on Marshall's and Saddler's properties; viewed at 7.30 pm a seep appeared "luminous" (*ibid*).	not inspected	U
Scottsdale	E. Nasson	1920	oil	'skim' noticed on pile of loam when wet (E. Nasson to Govt Geologist, 20.9.20).	various possible origins, but not a petroleum seep.	F
Lawrenny	C. Brock	1920	oil	material in borehole sent to Mines Department.	material found to be organic matter in clay; distillate of this gives a tarry matter (Asst Govt Geologist to C. Brock, 6.12.1920).	F
Spring Bay	Fiedler	1920	oil	oil claimed to exist (W. Wallace to Government Geologist).	not investigated	U
Somerset	A. Richardson	1921	oil	rock in back yard which when put in fire makes 'a fair report' (G. Richardson to Mines Department, 8 July 1921).	considered to be sandstone (L. Hills to G. Richardson, 12 July 1921).	F
Rosevale	various	pre 1921	oil	statements have been made that oil and oil shale occur at Rosevale (Hills, 1921*b*).	investigations have found lignite but no oil shale or oil (Hills, 1921*b*).	F
Barn Bluff	A. G. Black	1921	oil, gas	oil and gas seepages plainly manifest, large quantities of oil have been produced & may confidently be sought in anticlines (*London Times Supplement* 29.1.1921).	loose blocks of cannel coal present in moraines near Barn Bluff, one piece 16 feet square in area (Reid, 1919).	F
Nook	A. M. Reid	1923	oil, gas	scum of oil on water in shaft 10′ deep dug next to a fault with coal on one side and sandstone on the other (Reid, 1923*a*).	considered to be oil escaping on a fault plane (Reid, 1923*a*).	U
Nook	A. M. Reid	1923	oil, gas	another occurrence downstream (Reid, 1923*a*).	considered by Reid to be genuine (Reid, 1923*a*).	U
Mersey Valley	A. M. Reid	1923	oil, gas	seeping from Tertiary strata, noticed where tree stumps have been removed by fire on Rockcliffe's land. By probing beneath the crust of peaty clay, oil was found in two places and natural gas was "everywhere" (Reid, 1923*b*).	considered by Reid to be genuine (Reid, 1923*b*).	U
Thirlstane	A. M. Reid	1923	oil, gas	escape of oil and gas reported (Reid, 1923*a*).	not verified by Reid (Reid, 1923*a*).	U
Sassafras	A. M. Reid	1923	oil	seeps near hill, on Syke's land, oil detected during heavy rain (Reid, 1923*b*).	films of iron oxide issuing at many points (Reid, 1923*b*).	F
Sassafras	P. Roche	1923	oil	seep noticed during periods of heavy rainfall, near top of hill in Tertiary strata (Reid, 1923*a*).	considered by Reid to be genuine (Reid, 1923*a*).	U
Sassafras	A. M. Reid	1923	gas	bore 8 of the Adelaide Oil Exploration Co (Iles bore) was discontinued at 1100′ due to an inrush of sand; bore intersected bed of sand containing natural gas under enormous compression; strong odour of gas accompanied outbreak (Reid, 1923*a*).	considered by Reid to be an occurrence of gas.	U
Pot Bay	D. Hogman	1925	oil	oil noticed 30–40 m above beach.	inspection in 1999 failed to locate material.	U
King Island	A. B. Pritchard	1927	bitumen	stranded bitumen (Pritchard, 1927).	stranding of large piece of bitumen on granite rocks near Pass River.	C
Bruny Island	A. M. Reid	1929	oil	at Johnson's Well, when bedrock struck oil globules rise to surface (Reid, 1929).	considered by Reid to be genuine (Reid, 1929).	U

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Bruny Island	A. M. Reid	1929	oil	an oily scum on backwaters of Myles Creek (Reid, 1929).	considered by Reid to be genuine (Reid, 1929).	U
Bruny Island	A. M. Reid	1929	oil	reports of oil in wells near Andrew's bore (Reid, 1929).	probably contamination (Reid, 1929).	U
Bruny Island	A. M. Reid	1929	oil	in a small creek flowing into Great Bay (Reid, 1929).	occurrence below high tide mark, might be derived from floating material brought in by tide (Reid, 1929).	U
Bruny Island	A. M. Reid	1929	oil	showing of oil in an inlet north of Cape Frederick Henry (Reid, 1929).	samples tested; waste substance discharged from vessels (Reid, 1929).	F
Bruny Island	A. M. Reid	1929	bitumen	at north end of Myles Beach (Reid, 1929).	from shipwreck circa 1860 of cargo of tar: sample resembled creosote (Reid, 1929).	F
Bruny Island	A. M. Reid	1929	resin	found in paddocks by ploughing (Reid, 1929).	resin from the local grass trees (Reid, 1929).	F
Henty River	J. Robertson	1929	gas	sticks poked into alluvium in the river bed produced bubbles which could be ignited.	marsh gas (Nye, 1929*a*).	F
King Island		1929	asphaltum	lump of asphaltum found in 1927 near Pass River re-examined.	lodged into place (on granite rocks) by sea action (Blake, 1929).	C
Hobart	Broughton	1930	oil	sample left at Mines Department.	material is organic, derived from animal dung, probably that of bats (Nye to Broughton, 13 October 1930).	F
Castle Forbes Bay	J. H. Moate	1930	oil	enclosed newspaper cuttings reporting oil discovery at Castle Forbes Bay (J. H. Moate to A. M. Reid, 24 January 1930).	a black organic substance resulting from alteration of vegetable matter (A. M. Reid to J. H. Moate, 29 January 1930).	F
Mengha		1930	oil	an oily substance was noted in post holes 18" deep dug near house (Nye, 1930*a*).	mixture of clay and water seen in holes (Nye, 1930*a*).	F
Stoodley	A. Wright	1930	oil	reported a spring which after rain was impregnated with an oily substance (A. Wright to Govt Geologist, 29.8.1930).	bottle of water examined and found to contain precipitates of iron oxide (P. B. Nye to A. Wright, 8 September 1930).	F
Dunalley	H. G. Gray	1930	oil	sample of material said to contain free oil brought in for testing (A. M. Reid to L. H. Bath, 27 January 1930).	sample of brown sand did not contain any trace of natural oil (A. M. Reid to Gray, 8 February 1930). Deemed by Nye (1930*b*) to be colouration due to iron oxides and organic matter.	F
Cradoc	W. J. Armstrong	1931	oil gas	brown sand at top of shaft (Nye, 1931). bubbling through water in base of shaft 3–4' deep (Nye, 1931).	tested for liquid petroleum and for a yield of crude oil after distillation — nil result; considered by Nye to be marsh gas (Nye, 1931).	F
Leprena	G. H. Smith	1931	oil	seepage of dark brown colour, smells like carbide (G. H. Smith to P. B. Nye, 19 January 1931).	sample analysed and found to be seawater with clay and decomposed seaweed (P. B. Nye to G. H. Smith, 9 February 1931).	F
Flinders Island		1931	oil	oil bearing material allied to coorongite occurs in bed of a small artificially drained lagoon.	not related to petroleum (Carey, 1945).	F
Golden Valley	B. Whittle	1932	gas	gas reported at several localities (B. Whittle to Chairman of Shale Oil Committee); after poking a stick and stirring up bottom of ponds, bubbles appear (Nye, 1933).	considered to be methane or marsh gas (P. B. Nye to L. H. Bath, 22 March 1933). Sample collected by Nye did not contain any petrol (file note L. H. Bath, 7 December 1932).	F

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Unknown	R. White	1932	oil	visited a place 40 years ago, sure there was oil present, bubbling out of ground with area bare of vegetation (R. White to P. B. Nye, 24.10.1932).	re-visited: area now ploughed and under cultivation (R. White to P. B. Nye, 24.10.1931); probably a spring with mineral salts deposited on ground (P. B. Nye to R. White, 23 November 1932).	U
D'Entrecasteaux Channel	Lloyd Owens	1933	oil	drops of oil rising to surface close to shore (L. Owens to Government Mineralogist, 7 November 1933).	advised to collect a sample and forward to Department of Mines for testing (P. B. Nye to L. Owens, 7 November 1933).	U
Legerwood	W. Bartlett	1936	oil	petrol coming into a (water) well (W. Bartlett to Major Davis, 5 February 1936).	well polluted, probably from nearby storage of petroleum oils (W. Williams to Minister for Mines, 21 April 1936).	F
Huntington Tier	P. Reid	1938	bitumen	asphalt found on floor of sandstone cave. Reported to DOM in 1978 (D. Green to Chief Geologist, 2 June 1978). Material sampled in 1999. No evidence of emission from cave wall or fractures.	not bitumen; does not dissolve in organic solvent.	F
Ross	C. Davis	1939	oil	scum in puddles (Blake, 1939).	multi-coloured scum in puddles was iron oxide (Blake, 1939).	F
Ross	C. Davis	1939	gas	bubbles seen when alluvium in bottom of ditches poked with a shovel (Blake, 1939).	bubbles deemed to be marsh gas (Blake, 1939).	F
Unknown	Robert Taylor	1939	oil	found an oil field and traced it for a long way (R. Taylor to Minister for Mines, 19 July 1939).	offered a geological inspection of the area (Secretary for Mines to R. Taylor, 27 July 1939).	U
Colebrook	Percy Clark	1941	oil	a show of oily fluid which comes out of the ground during wet periods (P. W. Clarke to W. H. Williams, 5 June 1941).	requested to forward a sample for testing (Director of Mines to P. W. Clarke, 11 June 1941).	U
South Arm	F. Sproule	1941	oil	oil in well dug by the Army on Cape Direction 24 years ago (Lucarelli, 1965).	no inspection made	U
Strahan	W. Holmes	1942	asphaltum	quantity of pitch washed up onto Ocean Beach. During a storm water offshore was coloured black and after storm passed pieces of pitch found on beach. Two hundred pounds collected (K. A. Rae to Minister for Mines, 5.12.1947).	found to be similar to the asphaltum deposited elsewhere on the Tasmanian coastline (K. A. Rae to Minister for Mines, 5.12.1947).	C
Burnie	Miss E. Joyce	1942	oil	submitted sample of 'flowing oil'.	sample submitted was a bottle of water containing fungus. The cork had been in contact with an essential oil (Director of Mines to E. Joyce, 19 February 1942).	F
Bridport	A. Thorpe	1944	oil	oil in puddles in road gravel quarries; lease taken out by divining from these spots (D. E. Thomas to Director of Mines, 21 February 1944).	puddles found to be full of tadpoles and mosquito larvae; quarries in granite. Water discoloured by mud and vegetation (D. Thomas to Director of Mines, 21 February 1944). Samples taken contained no mineral oil (Director of Mines to A. Thorpe, 17 March 1944).	F
Flinders Island	F. Henwood	1945	oil	thought Flinders Island would be prospective for oil due to presence of limestones, which were favourable indicators of same (Carey, 1945).	no concrete evidence of any oil (Carey, 1945).	F
Port Davey	H. Keid	1945	asphaltum	piece of bitumen on foreshore, 4 ounces	coastal bitumen	C
Tarraleah	H. Harris	1946	gas	knows of a wet boggy gully and when walk bubbles will come up which can be lit with a match (H. Harris to Secretary for Lands, 2 June 1946).	considered to be marsh gas from rotting vegetation (Director of Mines to G. Harris, 11 July 1946).	F

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South Flinders Island	S. W. Carey	1946	peat	highly inflammable deposit in a drained swamp, on distillation yields 80% oil and tar (Carey, 1946).	a semi-peat composed of algal bodies similar to coorongite (Carey, 1946; Cane, 1966).	F
Redpa	Burt	1948	oil	sounds heard in wells dug in 1928 were analogous to thumping and booming sounds heard in Rumanian oil wells as described in a magazine (T. Hughes to Director of Mines, 31 March 1948).	no concrete evidence of oil and nothing to suggest rocks are oil bearing (T. Hughes to Director of Mines, 12 May 1948) (Hughes, 1948).	F
Strahan	H. Fletcher	1953	oil	brown stain on sand; iridescence on wet sand not enough to be collected (J. Elliston to Director of Mines, 10.1.1952).	scum caused by decay of small organisms (Hughes, 1953).	F
Strahan	H. Fletcher	1953	oil	an area of 'black' water seen off Ocean Beach (Hughes, 1953).	water swirling around either decayed vegetation or maybe the effect of fine-grained ilmenite (Hughes, 1953).	F
Henty River	H. Fletcher	1953	oil	seep reported (Hughes, 1953).	investigation revealed no sign of oil seepages or what may even be mistaken for oil seepages (Hughes, 1953).	F
Hobart	W. Pott	1954	gas	at a place within 50 miles of Hobart there is gas below ground 'two spades' deep (W. Pott to Mr Reece, 5 July 1954).	various possible causes.	U
King Island	Adams	1955	bitumen	had found bitumen on beach near Pass River in 1925. Applied for a lease (Corby to Director of Mines, 22 February 1955).	beach stranding of bitumen (Pritchard, 1927; Blake, 1929; Dickinson, 1943).	C
Longford	Eva Marchant	1956	oil	reported that on land once owned by husband a well was sunk and water of an 'oily nature' found reflecting all the colours of the rainbow (E. Marchant to Minister for Mines, 16 February 1956).	iridescence due to decomposing vegetable matter or oxides of iron (J. G. Symons to E. Marchant, 21 February 1956).	F
King Island	Mrs A. I. Smith	1956	bitumen	bitumen found below high tide mark; inaccessible at high tide or during rough weather (Mrs A. Smith to J. G. Symons, 23 April 1956).	bitumen stranding	C
unknown	E. A. Haigh	1957	gas	reporting an observation of gas bubbles in water seen in 1920 (E. Haigh to J. G. Symons, 24 May 1957).	feature probably has now ceased to operate (J. G. Symons to E. Haigh, 6 June 1957).	U
Cambridge	F. W. Evans	1957	oil	traces reported, located by divining four to five years previously (A. H. Blissett to Director of Mines, 9 December 1957).	inspection revealed seepage of peaty water but no trace of mineral oil (Blissett, 1957).	F
Kingston	Mrs Wilkinson	1958	oil	scum on dam (phone message from Mrs Wilkinson to Department of Mines, 22 December 1958).	probably iron oxide	U
Hamilton	W. C. Inglis	1958	oil	films on water (A. B. Gulline to Director of Mines, 1 October 1958).	iron oxide (A. B. Gulline to Director of Mines, 1 October 1958.	F
Burnie	Mrs E. Davey	1960	oil	was told by a friend 50 years ago that his boots became covered in oil while eating his lunch next to a river (E. Davey to Mr E. Reece, 21 March 1961).	various possible origins	U
Central Highlands	K. Slater	1960	oil	spring water coming out of hill has an oily film on surface and nearby pools also covered; coats vegetation next to pools (Slater to Mines Department, 3 May 1960).	geologist called but was unable to locate. Mr Slater requested to provide more details (J. G. Symons to K. Slater, 8 July 1960).	U
Detention River	C. R. Pyke	1960	oil	on surface of Detention River during a flood (Hughes, 1960).	inspection revealed no trace of oil (Hughes, 1960).	F
Mt Cameron	F. W. Ford	1960	bitumen	report of bitumen find on coast between Mt Cameron and Green Point; he had used in 1920–25 to mend a boat (F. Ford to Mines Department, 4 April 1960).	bitumen stranding	C

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Marrawah	A. J. Wigg	1960	bitumen	found small pieces of bitumen on a beach near Marrawah (A. J. Wigg to Director of Mines, 10 June, 1960).	bitumen strandings, washed up by the sea (J. G. Symons to A. J. Wigg, 14 June 1960).	C
Unknown	L. E. Costello	1961	oil		two samples tested by Department of Mines, tests negative for oil (J. G. Symons to L. E. Costello, 24 October 1961).	F
Burnie	L. F. Egan	1962	oil	foundations for HEC substation at South Burnie uncovered a layer of carbonaceous material and sand (L. Egan to Director of Mines, 22 June 1962).	described by G. Everard as sand coated with black organic material (G. Everard to Director of Mines). Test revealed no oil (Certificate of Analysis, 20 June 1963).	F
Burnie	Adams	1962	oil	seepage behind paper mill (J. G. Symons to L. F. Egan, 17 July 1962).	no investigation recorded	U
Launceston	Mr Carroll	1962	oil	In 1923 a sample of oil in water was collected from water flowing from bank into Distillery Creek (R. W. Morris to Director of Mines, 16 October 1962).	no oil found on visiting site, place on bank sampled in 1923 has eroded away (R. W. Morris to Director of Mines, 16 October 1962).	F
Bridgenorth	Mr W. Rattray	1962	oil	after rain, water with an oily surface 'seeps out from a hill' (W. Rattray to Premier E. Reece, 12 April 1962).	S. M. Rowe found films of oil oxide and a greenish black gelatinous plant material that could be mistaken for oil (S. M. Rowe to Director of Mines, 15 May 1962).	F
Marrawah (?)	C. Hine	1962	oil		sample of mud analysed (locality not stated); contained no oil (W. St C. Manson to C. Hine, 2 October, 1962).	F
Table Cape	Jackson	1963	gas	report of seeing bubbles offshore from Table Cape 25 years previously (K. Burns to Director of Mines, 3 April 1963).	enquiries revealed no other person had seen bubbles, including two cray fishermen who had been setting pots in area for 15 years (K. Burns to Director of Mines, 3 April 1963).	F
Tamar Valley	E. G. Hall	1964	oil	oil deposits discovered by divining (M. J. Longman to Director of Mines, 23 February 1965).	no surface indications of oil, no samples of oil available, just a belief in divining abilities (M. J. Longman to Director of Mines, 23 February 1965).	F
Ulverstone	C. Flowers	1965	bitumen	bitumen seen in a stretched pebble conglomerate (J. G. Symons to C. Flowers, 25 November 1965).	sample of bitumen sent in to Mines Department is same as that used in road construction; is not likely that the bitumen is naturally occurring (J. G. Symons to C. Flowers, 25 November 1965).	F
Fossil Bluff	Mrs S. Veenstra	1965	oil	knows of places where oil is flowing out of the ground (Mrs S. Veenstra to Director of Mines, 7 April 1965).	seepages from side of hill along the shoreline, pools of stagnant water covered by iron oxide films (W. L. Matthews to Director of Mines, 13 September 1965).	F
Launceston	W. Thurlow	1965	oil	oil seep in gutter outside toilets in Elizabeth Street, Launceston, has existed for 50 years, more noticeable after rain (W. Thurlow to Minister for Mines, 25 September 1965).	sample examined and found to contain no petroleum oil (L. F. Egan to Director of Mines, 8 November 1965).	F
Lebrina	L. L. Hill	1965	oil	film on water in puddles (L. L. Hill to Director of Mines, 6 October 1965).	stagnant stretches of water in swamp and isolated puddles carry a surface film of iron compounds (D. J. Jennings to Chief Geologist, 9 November 1965).	F

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Forth River	H. E. Flight	1966	gas	extrusion of gas bubbles in water below high tide mark on a mud flat (H. Flight to Director of Mines, 8 April 1966).	probably methane type gas emanating from Tertiary sediments below the muds (B. Noldart to Chief Geologist, 22 April 1966).	U
King Island	W. Liveridge	1966	oil	advised that he had divined an oilfield west-south-west of King Island whilst on a plane "which (he) can do" (Liveridge to Secretary, Department of Mines, 8 November 1966).	reply that area held by Haematite Explorations Pty Ltd (Director of Mines to W. Liveridge, 15 November 1966).	U
Sassafras	Egan	1966	oil	samples submitted for analysis.	clay containing a green organic stain (H. Wellington to Director of Mines, 28 September 1966).	F
Cradoc	D. Leaman	1967	oil	seepages of bituminous material or oil reported (Leaman, 1967).	probably ferruginous films (Leaman, 1967).	F
Table Cape	Miss A. Jackson	1967	oil, gas	reported her grandfather found an oil and gas seepage in 1916; a dark brown substance bubbling to surface. Can only be seen at low tide when sea is calm (W. L. Matthews to Director of Mines, 11 July 1967).	inspection revealed no trace of oil (W. L. Matthews to Director of Mines, 11 July 1967).	F
Penguin	J. M. Bates	1968	oil	oil seepage seen in drainage ditch dug into boggy ground; most noticeable after rain (T. Bates to Mines Department, 4 June 1968).	various possible origins	U
Prion Bay	Harry Ackerley	1974	bitumen	pale blue material, greasy like plasticine, came out of the sea and rolled up the beach in balls, burnt readily, seen in 1950's (H. Ackerley to J. G. Symons, 9 February 1974).	bitumen stranding	C
Kimberley	W. L. Matthews	1978	gas	gas reported associated with a thermal spring (Matthews, 1978).	analysis determined the gas to be of biogenic (bacterial) origin (Baillie, 1992).	F
Bagdad	D. Green	1978	bitumen	bitumen reported from floor of sandstone cave (D. Green to Chief Geologist, 2 June 1978). New sample collected 1999.	not bitumen; does not dissolve in organic solvent.	F
Maydena	BHP	1980	oil	traces of petroleum hydrocarbons in water in drill hole (25 mg/l) (BHP, 1982*b*).	not considered significant by explorer. Hole intersected Woody Island Siltstone. Various possible origins.	T
Railton	K. Brydon	1981		asphaltic material in weathered outcrop of rock, burnt with a tar odour and left an ash residue (D. Green to Chief Geologist, 4 June 1981).	plans made to collect samples, possibly coal.	U
Bruny Island	Janice Higgins	1987	oil	remembered oily smell in garden at Killora as a child; carrots needed cleaning to reduce oily diesel-like smell; oil scum on creek near house in summer (Morrison, 1987).	no oily smell or residue noticed on inspection (Morrison, 1987). Kerosene was often sprayed on carrots to reduce weeds at the seedling stage in home gardens.	F
Bruny Island	Conga Oil P/L	1987	oil	scum in cattle hoof prints and scum in toilet (Morrison, 1987).	toilet used dam water and was permanently discoloured; no cattle on land — a normal ¼ acre block (Morrison, 1987).	F
Bruny Island	A. Bain	1987	oil	possible oil seep (Morrison, 1987).	water with a metallic blue scum seeping from eucalypt bark and offcuts from sawmill (Morrison, 1987).	F
Bruny Island	Conga Oil P/L	1987	oil	scum from surface of dam on probable site of Johnson's Well (Morrison, 1987).	traces of biogenic and petroleum hydrocarbons detected (Volkman, 1987*a*).	T
Bruny Island	Conga Oil P/L	1987	oil	mud from dam as above (Morrison, 1987).	traces of biogenic and petroleum hydrocarbons detected (Volkman, 1987*a*).	T

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Bruny Island	Conga Oil P/L	1987	oil	scum from dam floor as above (Morrison, 1987).	traces of biogenic hydrocarbons detected (Volkman, 1987*a*).	F
Bruny Island	Conga Oil P/L	1987	oil	scum from Hazell's dam 100 m north of Johnson's Well (Morrison, 1987).	traces of biogenic hydrocarbons detected (Volkman, 1987*a*).	F
Bruny Island	Conga Oil P/L	1987	oil	scum on waterhole 200 m west of Andrew's bore (Morrison, 1987).	traces of biogenic and petroleum hydrocarbons present (Volkman, 1987*a*).	T
Bruny Island	Conga Oil P/L	1987	oil	soil sample, Johnson's Well (Morrison, 1987).	traces of biogenic and petroleum hydrocarbons present (Volkman, 1987*a*).	T
Bruny Island	Conga Oil P/L	1987	oil	scum and sediment from Miles Creek at mouth of creek (Morrison, 1987).	traces of biogenic and petroleum hydrocarbons present (Volkman, 1987*a*).	T
Cradoc	Conga Oil P/L	1987	oil	scum on creek water from farm (Morrison, 1987).	traces of biogenic hydrocarbons (Volkman, 1987*a*).	F
Bruny Island	S. Forsyth	1988	bitumen	sample found of bitumen-impregnated sandstone at Little Taylors Bay on ledge about one metre above high tide mark. Black brittle tar on weathered sandstone (Volkman and O'Leary, 1990*b*).	bitumen may have been thrown into position by a very high tide, or placed there by visitors; not actively seeping bitumen (Forsyth, pers. comm.). Possibly derived from man-made petroleum products, or could be products of dolerite heating of organic-rich but immature sediment.	X
Bridgewater	M. Bendall	1988	bitumen	tar allegedly found years ago when water pipe installed, sample collected in 1988. Two samples, one of tarry material and one of underlying rock.	no evidence to show that hydrocarbons in tar and rock were related; tarry material has been subject to high temperature burning (Volkman and Holdsworth, 1989*a*). Could possibly be pieces of tar from installation of water pipe, when pipes were coated with pitch or bitumen.	X
Barnes Bay	D. E. Leaman	1988	bitumen	bitumen found above high tide mark at Barnes Bay. A more extensive search in 1998 discovered a large patch of bitumen below high tide mark.	Determined to be a heavy tar unrelated to known Tasmanian source rocks.	B
Marion Bay	P. Baillie	1990	gas	gas bubbling out of sand in intertidal area (Baillie, 1990).	analysis concludes gas is of biogenic origin (Baillie, 1990).	F
Tunnack	M. Bendall	1990	bitumen	medium-coarse grained sandstone with bituminous matrix (Volkman and O'Leary, 1990*b*).	possibly derived from man-made petroleum products; or could be products of dolerite heating of organic-rich but immature sediment.	X
Smithton	P. Baillie	1992	gas	gas was reported seeping into standing water in a paddock; been active for 50 years.	analysis determined the gas to be carbon dioxide of geothermal origin (Baillie, 1992).	F
Douglas River	M. Bendall	1993	gas	gas escaping from drill hole (Revill and Volkman, 1993).	gas determined to be of biogenic origin (Summons, 1993).	F
Bruny Island	Conga Oil P/L	1994	gas	bubbles appeared when stick poked into dam (Johnson's Well) and stirred around in mud on bottom of hole.	sample of gas analysed and determined to be of biogenic origin (Revill and Volkman, 1994).	F
Bruny Island	M. Bendall	1994	gas	gas bubbles in water in pit near old brick kilns.	sample of gas analysed and determined to be of biogenic origin (Revill and Volkman, 1994).	F
Bruny Island	M. Bendall	1994	tar	tar on rock chip samples from drill hole Shittim 1 (transcript ABC Radio interview, January 1995).	analysed by MRT laboratory; found to possibly be manganese oxide.	F

Location	Reported by	Date reported	Material reported	Reported observations	Conclusions	Status
Bruny Island	M. Bendall	1994	tar	tar in rock samples from Shittim 1; samples brought to MRT for analysis.	XRD analysis showed to be smectite clays and other minerals (Bottrill, 1995).	F
Bruny Island	M. Bendall	1995	oil	oil suspected in core from Shittim 1; rock had peculiar smell.	smell due to water; minute traces of hydrocarbons from two different source types found; probably due to contamination (Revill, 1995).	U
Lonnavale	R. Bottrill	1995	bitumen	bitumen and a liquid found with zeolites in fractures in dolerite in road quarry.	found to be generated from *Tasmanites*.	V
Zeehan	M. Bendall	1996	bitumen	suspected bitumen found in an ore body at the Comstock prospect, near Zeehan. Black crumbly material with a sulphurous smell.	XRD analysis showed material to be galena with some protographite.	F

The total of 139 reports of oil and gas can be summarised as:

C — Reports of coastal bitumens: 24

V — Petroleum hydrocarbons confirmed by analysis and sourced from Tasmanian rocks: 1

T — Petroleum hydrocarbons — detected in trace amounts by modern analysis: 6

F — Investigated reports shown phenomena other than petroleum hydrocarbons: 67

U — Unverified/ not investigated reports: 37

X — Possibly bitumens derived by dolerite heating immature organic sediments: 3

B — Bitumen, but not from any known Tasmanian source rock: 1

APPENDIX 2

Bores drilled for petroleum exploration in Tasmania to 1998

Bore	Drilled By	Location	AMG co-ords	Latitude	Longitude	Year Drilled	Total Depth (m)
Andrews	G. Andrew (Bruni Island Oil Company)	Bruny Island	EN309128	43°14.2′S	147°22.8′E	1915	131
	Summary log: 0–34 m sand, clay; 34–131 m limestone.						
	C. A. Brock	Hamilton	DN795925	42° 31′S	146°45′E	1920	158
	Summary log: Tertiary sediments overlying sandstone.						
Driscoll (Reid 21)	Mersey Valley Oil Co. (No. 1)	Sassafras	DQ555321	41°15.7′S	146°28.1′E	1922	91
	Summary log: 0–9 m clay; 9–91 m Permian mudstone and sandstone.						
Ingram (Reid 22)	Mersey Valley Oil Co. (No. 3)	Sassafras	DQ555310	41°16.3′S	146°28.1′E	1922	242
	Summary log: 0–4 m clay; 4–146 m Permian sandstone and mudstone; 146–225 m conglomerate; 225–242 m basement quartzite, schist and conglomerate.						
Bourkes	Mersey Valley Oil Co. (No. 2)	Sassafras	DQ547301	41°16.7′S	146°27.5′E	1922	115
	Summary log: 0–3 m clay; 3–28 m mudstone and sandstone with basalt pebbles; 28–44 m conglomerate; 44–64 m quartzite; 64–80 m dolerite; 80–115 m quartz/conglomerate.						
Racecourse (Reid 24)	Mersey Valley Oil Co. (No. 4)	Latrobe	DQ532353	41°13.9′S	146°26.7′E	1922	305
	Summary log: 0–1 m clay; 1–294 m Permian sandstone and mudstone; 294–305 m conglomerate and quartzite.						
Atkinsons (Reid 25)	Mersey Valley Oil Co. (No. 5)	Latrobe	DQ532335	41°14.9′S	146°26.5′E	1922	59
	Summary log: 0–5 m clay; 5–47 m mudstone and sandstone; 47–59 m quartzite and schist.						
Staggs (Reid 26)	Mersey Valley Oil Co. (No. 6)	Latrobe	DQ535353	41°13.9′S	146°26.7′E	1922	305
	Summary log: 0–3 m clay, weathered Permian sandstone; 4–402 m sandstone, mudstone, conglomerate and shale (302–305 m dolerite).						
Camerons (Reid 16)	Adelaide Oil Exploration Co. (No. 5)	Latrobe	DQ497335	41°14.9′S	146°24.0′E	1922	192
	Summary log: 0–5 m gravel and clay; 5–151 m Permian mudstone; 151–186 m Permian conglomerate; 186–192 m Precambrian(?) schist						
Smiths (Reid 17)	Adelaide Oil Exploration Co. (No. 6)	Spreyton	DQ454359	41°13.6′S	146°20.9′E	1922	141
	Summary log: 0–12 m sand and clay; 12–131 m Permian mudstone and sandstone; 131–141 m quartzite.						
Allisons (Reid 18)	Adelaide Oil Exploration Co. (No. 7)	Tarleton	DQ465341	41°14.6′S	146°21.7′E	1922	101
	Summary log: 0–5 m clay, 5–90 m Permian mudstone; 90–101 m quartzite.						
Kites (Reid 12)	Adelaide Oil Exploration Co. (No. 1)	On ML 4777M	DQ543234	41°20.4′S	146°27.2′E	1922	172
	Summary log: 0–148 m Permian mudstone and sandstone; 148–172 m quartzite.						
Hoggs Bridge (Reid 13)	Adelaide Oil Exploration Co. (No. 2)	near Hoggs Bridge	DQ547237	41°20.2′S	146°27.5′E	1922	90
	Summary log: 0–82 m Permian mudstone; 82–90 m quartzite.						
(Reid 14)	Adelaide Oil Exploration Co. (No. 3)	Native Plain	DQ551235	41°20.3′S	146°27.8′E	1922	158
	Summary log: 0–155 m Permian mudstone; 155–158 m quartzite.						
(Reid 15)	Adelaide Oil Exploration Co. (No. 4)	Native Plain	DQ554230	41°20.6′S	146°28.0′E	1922	253
	Summary log: 0–5 m clay; 5–218 m Permian mudstone and sandstone; 218–253 m basement of slaty mudstone and quartzite.						
(Reid 27)	Adelaide Oil Exploration Co. (No. 10)	Merseylea Bridge	DQ566211	41°21.6′S	146°28.9′E	1922	288
	Summary log: 0–6 m gravel and clay; 6–279 m Permian mudstone and sandstone; 279–288 m conglomerate.						
Windy Ridge	?	Moriarty	DQ574369	41°13.1′S	146°29.5′E	1923	?
	No log available.						
Haines (Reid 33)	Mersey Valley Oil Co. (No. 7)	East Devonport	DQ501389	41°12.0′S	146°24.3′E	1923	87
	Summary log: 0–6 m clay; 6–87 m Permian sandstone and mudstone.						
Hermitage (Reid 28)	Mersey Valley Oil Co. (No. 8)	Moriarty	DQ384359	41°13.5′S	146°15.9′E	1923	204
	Summary log: 0–12 m basalt; 12–132 m mudstone, clay and sand; 132–204 m dolerite.						
Parsons (Reid 31)	Mersey Valley Oil Co. (No. 9)	Sassafras	DQ605359	41°13.6′S	146°31.7′E	1923	351
	Summary log: 0–18 m clay, gravel and conglomerate; 18–116 m basalt; 116–351 m mudstone, soft sandstone and lignite.						

Bore	Drilled By	Location	AMG co-ords	Latitude	Longitude	Year Drilled	Total Depth (m)
Iles	Adelaide Oil Exploration Co. (No. 8)	Harford	DQ613363	41°13.4′S	146°32.3′E	1923	336
(Reid 29)	*Summary log:* 0–8 m clay and ironstone; 8–118 m basalt; 118–124 m tuffaceous material; 124–127 m basalt; 127–336 m clay and sand with lignite; 336 m quartz sand.					Gas reported	
Burgess	Adelaide Oil Exploration Co. (No. 9)	Harford	DQ608343	41°14.5′S	146°31.9′E	1923	355
(Reid 30)	*Summary log:* 0–18 m clay, sand, soft sandstone; 18–168 m basalt; 168–339 m clay, gravel, lignite; 339–355 m dolerite.						
Watlings (Reid 32)	Adelaide Oil Exploration Co. (No. 11)	Quoiba	DQ457383	41°12.2′S	146°21.1′E	1923	?
Northdown	?	Northdown Beach	DQ561431	41°9.7′S	146°28.6′E	1924	?
Beacon	No log available, bottomed in dolerite.						
Northdown	?	Northdown Beach	DQ580448	41°8.8′S	146°30.0′E	1928	206
Foreshore	*Summary log:* 0–7 m pebbles; 7–206 m Permian sandstone, mudstone and quartzite; 206 m Precambrian(?) quartzite.						
Johnsons	A. G. Black	Bruny Island	EN317170	43°11.9′S	147°23.4′E	1930	52
Well	(Tasmanian Oil Exploration Co.)			Oil stained water reportedly struck at 27 m.			
Danbury	W. R. Richmond	Launceston	EQ050176	41°23′S	147°3′E	1939	?
Park	(Producers Oilwell Suppliers P/L)	Spot chosen by patent oil finder, shallow hole drilled.					
Parkers Ford	C. G. Sulzberger	Port Sorell	DQ610408	41°11.0′S	146°32.1′E	1967	305
	Summary log: 3–38 m sand; 38–151 m basalt; 151–180 m sand; 180–305 m dolerite.						
Elphington 1	C. G. Sulzberger	Squeaking Point	DQ624394	41°11.7′S	146°33.1′E	1967	381
	Summary log: 0–332 m sand and clay; 332–381 m dolerite.						
Browns 1	C. G. Sulzberger	Squeaking Point	DQ619399	41°11.5′S	146°32.7′E	1967	335
	Summary log: 0–256 m sand and clay; 256–335 m dolerite.						
Hardys 1	C. G. Sulzberger	Harford	DQ618364	41°13.4′S	146°32.7′E	1967	381
	Summary log: 0–5 m sand and clay; 35–95 m basalt; 95–366 m sand and clay; 366–381m dolerite.						
DP1	C. G. Sulzberger	Bracknell	DP999885	41°39.3′S	146°59.9′E	1968	687
(Badcocks)	*Summary log:* 0–670 m Tertiary sediments, clay, sand, wood fragments, gravel, bottomed in dolerite.						
DP2	C. G. Sulzberger	Hagley	DQ980024	41°31.8′S	146°58.6′E	1970	831
(Fairview)	*Summary log:* 0–792 m Tertiary sediments as above, bottomed in dolerite.						
Rosevale 1	C. G. Sulzberger	Rosevale	DQ926162	41°24.3′S	146°54.7′E	1974	50
	Summary log: clay, dolerite at base.						
Rosevale 2	C. G. Sulzberger	Rosevale	DQ927157	41°24.6′S	146°54.8′E	1974	50
	Summary log: clay, dolerite at base.						
Shittim 1	Great South Land Minerals	Bruny Island	EN339160	43°12.48′S	147°25.00′E	1995–1997	1751
Jericho 1	Great South Land Minerals	Bruny Island	EN316170	43°11.95′S	147°23.21′E	1997	640
Lonnavale 1	Great South Land Minerals	Lonnavale	DN840456	42°56.50′S	146°48.27′E	1997	557
Pelham 1	Great South Land Minerals	Gretna	DN953841	42°35.69′S	146°56.45′E	1997	503
Other holes which have encountered gas							
Conara	Mines Department	Conara	EP353697	41°49.9′S	147°25.5′E	1990	30
railway yard	*Summary log:* 0.6 m clay; 6–16 m sandy clay; 16–24 m sand; 24–30 m clay.						
Chilvers'	Mines Department	Cleveland	EP336714	41°48.5′S	147°24.3′E	1963	48
property	*Summary log:* 0–20 m clay and sand; 20–30 m clay and quartz gravel; 30–32 m clay and decomposed wood fragments; 32–38 m gravel; 38–48 m sand and clay, bottomed in dolerite.						

Thirty-nine holes have been drilled for oil/gas, plus two others in which gas was reported.
Some details in this table were derived from Burns (1963, 1964) and Reid (1924).

APPENDIX 3

Offshore oil wells, Tasmanian waters

Well	Spud Date	Status	Well Category	Latitude	Longitude	Rig	Oil/gas Recoveries
Wells drilled in Bass Basin							
Barramundi 1	24.09.1999	P & A	Exploration	39°39′42″S	145°44′3″E	Sedco 702	
White Ibis 1	01.06.1998	Suspended	Exploration	39°57′49.16″S	145°15′17.28″E	Northern Explorer III	gas
Yolla 2	09.04.1998	P & A	Appraisal	39°51′33.82″S	145°48′38.53″E	Northern Explorer III	gas
Flinders 1	29.11.1992	P & A	Exploration	40°22′51.810″S	145°40′18.690″E	Ocean Epoch	
King 1	30.10.1992	P & A	Exploration	39°35′24.331″S	145°31′01.780″E	Ocean Epoch	
Seal 1	11.02.1986	P & A	Exploration	39°21′48.979″S	144°52′52.700″E	Atwood Margie	
Chat 1	15.01.1986	P & A	Exploration	40°10′53.430″S	146°41′54.955″E	Atwood Margie	
Pelican 5	28.12.1985	P & A	Appraisal	40°20′43.472″S	145°51′49.296″E	Diamond M Epoch	gas
Koorkah 1	27.11.1985	P & A	Exploration	39°37′57.000″S	145°09′05.000″E	Diamond M Epoch	
Yolla 1	08.06.1985	Suspended	Exploration	39°50′18.890″S	145°48′20.550″E	Robert F Bauer	gas/oil
Tilana 1	05.09.1985	P & A	Exploration	39°53′36.730″S	145°58′41.970″E	Diamond M Epoch	gas
Tas Devil 1	27.08.1984	P & A	Exploration	40°44′16.206″S	146°09′44.958″E	Diamond M Epoch	
Squid 1	16.07.1984	P & A	Exploration	40°11′53.547″S	146°18′27.456″E	Diamond M Epoch	
Pipipa 1	04.05.1982	P & A	Exploration	40°23′14.000″S	145°41′45.000″E	Southern Cross	
Pelican 4	17.01.1979	P & A	Appraisal	40°21′40.020″S	145°52′15.360″E	Ocean Endeavour	gas
Nangkero 1	24.04.1974	P & A	Exploration	40°04′24.161″S	145°58′41.952″E	Glomar Conception	
Aroo 1	04.03.1974	P & A	Exploration	39°47′30.325″S	145°26′47.976″E	Glomar Conception	minor gas
Toolka 1A	14.01.1974	P & A	Exploration	39°24′35.678″S	145°23′45.108″E	Glomar Conception	
Yurongi 1	03.07.1973	P & A	Exploration	39°55′29.936″S	146°15′58.866″E	Glomar Conception	
Konkon 1	13.05.1973	P & A	Exploration	39°12′19.584″S	145°03′39.721″E	Glomar Conception	
Narimba 1	31.08.1973	P & A	Exploration	40°16′18.080″S	145°43′53.581″E	Glomar Conception	
Dondu 1	30.05.1973	P & A	Exploration	39°59′12.520″S	146°13′02.600″E	Glomar Conception	
Durroon 1	22.10.1972	P & A	Exploration	40°32′02.940″S	147°12′48.490″E	Glomar Conception	
Tarook 1	03.10.1972	P & A	Exploration	40°02′36.950″S	145°40′28.560″E	Glomar Conception	
Poonboon 1	29.08.1972	P & A	Exploration	40°08′15.190″S	145°55′01.290″E	Glomar Conception	minor gas
Pelican 3	01.05.1972	P & A	Exploration	40°15′44.990″S	145°51′50.000″E	Glomar Conception	
Pelican 2	28.07.1970	P & A	Exploration	40°18′28.426″S	145°49′12.270″E	Ocean Digger	gas
Cormorant 1	11.06.1970	P & A	Exploration	39°34′22.800″S	145°31′35.700″E	Ocean Digger	gas/oil
Pelican 1	19.03.1970	P & A	Exploration	40°20′20.800″S	145°50′37.100″E	Ocean Digger	gas
Bass 3	11.02.1967	P & A	Exploration	39°59′51.000″S	145°16′57.000″E	Glomar 3	gas
Bass 2	14.04.1966	P & A	Exploration	39°53′09.000″S′	146°18′15.000″E	Glomar 3	
Bass 1	21.07.1965	P & A	Exploration	39°46′18.000″S	145°44′03.000″E	Glomar 3	
Wells drilled in Otway/Sorell Basins							
Cape Sorell 1	05.07.1982	P & A	Exploration	42°08′09.646″S	145°01′45.840″E	Diamond M Epoch	
Whelk 1	06.03.1970	P & A	Exploration	39°53′57.080″S	143°33′20.900″E	Ocean Digger	
Clam 1	09.07.1969	P & A	Exploration	40°51′52.419″S	144°12′55.153″E		
Prawn A1	29.12.1969	P & A	Exploration	39°21′23.420″S	143°06′41.890″E	Ocean Digger	
Wells drilled in Gippsland Basin							
Sailfish 1	12.10.1971	P & A	Exploration	39°27′24″S	148°37′54.4″E	Glomar Conception	
Bluebone 1	16.09.1969	P & A	Exploration	39°24′24.296″S	147°50′52.740″E	Glomar 3	
Mullet 1	09.01.1969	P & A	Exploration	139°13′02″S	147°51′22″E	Glomar 3	

APPENDIX 4

Tenements held to search for oil in Tasmania

Location	Held By	Date	Licence/lease	Type of Tenement
North Bruny Island	Bruni Island Petroleum Company	1915	Licences to Search	6 Licences to Search, 320 acres each
Recherche Bay	Asphaltum Glance & Oil Syndicate	1915	LTS	Licence to Search, 640 acres
New River	Asphaltum Glance & Oil Syndicate	1915	LTS	4 Licences to Search, 320 acres each
Bruny Island	R. J. P. Davey	1918	LTS 6	Licence to Search, 3200 acres
Bruny Island	R. J. P. Davey	1918	LTS 6	Licence to Search, 3200 acres
North Bruny Island	W. H. T. Brown	1918		Licence to Search, 1400 acres
Elderslie	Stella Chapman	1919	LTS 8	Licence to Search, 3000 acres
Elderslie	S. Chapman	1919	LTS 8	Licence to Search, 3000 acres
Elderslie	V. A. Chipman	1920	LTS 12	Licence to Search, 3200 acres
Elderslie		1920	LTS 13	Licence to Search, 3200 acres
Elderslie	J. Fritzoni	1920	LTS 90	Licence to Search, 100 acres
Elderslie	J. Fritzoni	1920	LTS 91	Licence to Search, 45 acres
Elderslie	H. Thomas	1920	LTS 93	Licence to Search, 2560 acres
Elderslie	E. M. Mathias	1920	LTS 94	Licence to Search, 1400 acres
Elderslie		1920	LTS 112	Licence to Search, 500 acres
Port Davey	Donellan & others	1920	LTS 40	Licence to Search, 200 acres
Port Davey	W. T. A. Cleveland	1920	LTS 41	Licence to Search, 3200 acres
South Bruny Island	V. A. Chipman	1920	LTS 12	Licence to Search, 3200 acres
Bruny Island	C. C. Brown	1920		Licence to Search, 500 acres
Barn Bluff	C. C. Manton & A. G. Black	1920		Licence to Search, 3200 acres
Barn Bluff	A. G. D. Bernaceli	1920		Licence to Search, 3200 acres
Barn Bluff	P. Evans	1920		Licence to Search, 3200 acres
Cradle Mountain	The Granville Prospecting & Mining Company NL	1920		Licence to Search, 3200 acres
Mt Olympus	L. G. Thompson	1920		Licence to Search, 3200 acres
Narcissus River	L. M. Stackhouse	1920		Licence to Search, 3200 acres
Port Davey	M. J. Donellan, C. Smith & J. Jones	1920	LTS 40	Licence to Search, 3200 acres
South Bruny Island	S. Perry	1920	LTS 13	Licence to Search, 3200 acres
Barn Bluff	W. A. Mudie	1920		Licence to Search, 3200 acres
Barn Bluff	A. L. Nichols	1920		Licence to Search, 3200 acres
Mt Achilles	C. C. Reilly	1920		Licence to Search, 3200 acres
Barn Bluff	E. Hawson	1920		Licence to Search, 3200 acres
Port Davey	W. T. A. Cleveland	1920	LTS 41	Licence to Search, 3200 acres
Coal Hill to Mt Byron, Lake St Clair	T. McDonald	1920		Licence to Search, 3200 acres
Davey River	W. T. A. Cleveland	1920		Licence to Search, 3200 acres
Dulverton	E. Morse	1921	LTS 76	Licence to Search, 380 acres
Railton	F. D. Kite	1921	LTS 77	Licence to Search, 239 acres
Mersey	S. Stewart	1921	LTS 79	Licence to Search, 1382 acres
Preolenna	Margetts & Margetts	1921	LTS 80	Licence to Search, 200 acres
Between Lagoon River and Interview River	F. W. Heritage	1921		Licence to Search, 3200 acres
Mt Pelion	A. Baker	1921		Licence to Search, 3200 acres
Mt Pelion	T. B. Harrington	1921		Licence to Search, 3200 acres
Mt Pelion	R. Duncan	1921		Licence to Search, 3200 acres
Mt Pelion	E. J. Stott	1921		Licence to Search, 3200 acres
Mt Pelion	C. H. Augas	1921		Licence to Search, 3200 acres
Mt Pelion	L. W. Mudie	1921		Licence to Search, 200 acres
Mt Pelion	J. West	1921		Licence to Search, 3200 acres
Mt Pelion	J. T. Moate	1921		Licence to Search, 3200 acres
Mt Pelion	T. B. Harrington	1921		Licence to Search, 3200 acres
Mt Pelion	J. N. Duncan	1921		Licence to Search, 3200 acres
Mt Pelion	A. W. Duncan	1921		Licence to Search, 3200 acres

Location	Held By	Date	Licence/lease	Type of Tenement
Mt Pelion	A. L. Kirkham	1921		Licence to Search, 3200 acres
Mt Pelion	R. P. Kirkham	1921		Licence to Search, 3200 acres
Mt Pelion	R. H. Nicholson	1921		Licence to Search, 3200 acres
Barn Bluff	A. J. Forster	1921		Licence to Search, 3200 acres
Douglas River	H. G. R. McWilliams	1921		Licence to Search, 2000 acres
Mt Pelion	Jean Irene MacKenzie	1921		Licence to Search, 3200 acres
Mt Pelion	F. W. James	1921		Licence to Search, 3200 acres
Mt Pelion	K. B. C. Kirkham	1921		Licence to Search, 3200 acres
Mt Pelion	E. L. Potter	1921		Licence to Search, 3200 acres
Mt Pelion	S. V. V. Moate	1921		Licence to Search, 3200 acres
Mt Pelion	L. M. Beckwith	1921		Licence to Search, 3200 acres
Barn Bluff	Lena Adele Mofflin	1921		Licence to Search, 3200 acres
Barn Bluff	R. A. Mofflin	1921		Licence to Search, 3200 acres
Barn Bluff	R. J. McCutcheon	1921		Licence to Search, 3200 acres
Barn Bluff	G. B. McCutcheon	1921		Licence to Search, 3200 acres
Mt Pelion	G. Adams	1921		Licence to Search, 3200 acres
Mt Pelion	S. C. Hocking	1921		Licence to Search, 3200 acres
Mt Pelion	R. Sharples	1921		Licence to Search, 3200 acres
Preolenna	Margetts & Margetts	1921	LTS 80	Licence to Search, 200 acres
Mt Pelion	F. W. R. Reid	1921		Licence to Search, 3200 acres
Dulverton	E. Morse	1921	LTS 76	Licence to Search, 380 acres
Railton	F. D. Kite	1921	LTS 77	Licence to Search, 239 acres
Mersey	J. Stewart	1921	LTS 79	Licence to Search, 1382 acres
South Bruny Island	V. A. Chipman	1921		Licence to Search, 3200 acres
South Bruny Island	S. Perry	1921		Licence to Search, 3200 acres
South Bruny Island	C. C. Brown	1921		Licence to Search, 500 acres
Barn Bluff	G. Simson Hope	1921		Licence to Search, 3200 acres
Barn Bluff	A. W. Craig	1921		Licence to Search, 3200 acres
Barn Bluff	H. B. Denniston	1921		Licence to Search, 3200 acres
Adventure Bay	J. L. Frizoni	1921	LTS 90	Licence to Search, 100 acres
South Bruny Island	J. L. Frizoni	1921	LTS 91	Licence to Search, 45 acres
North Bruny Island	H. Thomas	1921	LTS 93	Licence to Search, 2560 acres
North Bruny Island	E. M. Mathias	1921	LTS 94	Licence to Search, 1400 acres
North Bruny Island	W. C. Bart	1922	LTS 101	Licence to Search, 1000 acres
Latrobe	Victas Oil Shale	1922	LTS 95	Licence to Search, 20 acres
Latrobe	G. D. Mendell	1922	LTS 100	Licence to Search, 310 acres
Latrobe	Mersey Valley Oil Co. Ltd	1922	LTS 113	Licence to Search, 159 acres
Railton	R. Richards	1922	LTS 115	Licence to Search, 1000 acres
Inglis River	J. A. Wauchope	1922	LTS 97	Licence to Search, 720 acres
Inglis River	J. A. Wauchope	1922	LTS 97	Licence to Search, 720 acres
Inglis River	J. A. Wauchope	1922		Licence to Search, 150 acres
Inglis River	J. A. Wauchope	1922		Licence to Search, 40 acres
Mersey, Latrobe	G. D. Mendall	1922	LTS 100	Licence to Search, 310 acres
Port Davey	W. C. Bart	1922	LTS 101	Licence to Search, 1000 acres
South Bruny	W. T. Rofe	1922	LTS 112	Licence to Search, 500 acres
Kermode Franklin Rivulet	Mersey Valley Oil Co. Ltd	1922		Licence to Search, 1000 acres
Latrobe	Victas Oil Shale	1922	LTS 95	Licence to Search, 20 acres
Latrobe	Mersey Valley Oil Co. Ltd	1922	LTS 113	Licence to Search, 159 acres
Railton	R. Richards	1922	LTS 115	Licence to Search, 1000 acres
Strahan	H. E. Evenden	1923	LTS 138	Licence to Search, 3200 acres
Harford	W. B. Cocker	1923	LTS 117	Licence to Search, 61 acres
Port Sorell	R. C. Grubb	1923	LTS 120	Licence to Search, 640 acres
Harford	W. B. Cocker	1923		Licence to Search, 61ac, 2r, 4p
Burgess	J. A. Wanchope	1923		Licence to Search, 660 acres
Mersey	D. M. C. Griffin	1923		Licence to Search, 2510 acres

Location	Held By	Date	Licence/lease	Type of Tenement
Port Sorell	R. C. Grubb	1923		Licence to Search, 640 acres
Harford	W. B. Cocker	1923	LTS 117	Licence to Search, 61 acres
Port Sorell	R. C. Grubb	1923	LTS 120	Licence to Search, 640 acres
Port Sorell	G. N. Levy & A. Brown	1923		Licence to Search, 500 acres
Port Sorell	J. D. Johnstone	1923		Licence to Search, 640 acres
Port Sorell	E. Baker	1923		Licence to Search, 3200 acres
Franklin Rivulet	L. J. Douglas	1923		Licence to Search, 1028 acres
Burgess	F. M. McDonald	1923		Licence to Search, 30 acres
Burgess	E. J. McDonald	1923		Licence to Search, 300 acres
Port Sorell	J. H. Addison	1923		Licence to Search, 400 acres
Burgess	H. D. Green	1923		Licence to Search, 84 acres
Port Sorell	R. W. MacKenzie	1923		Licence to Search, 2450 acres
Port Sorell	T. S. F. MacKenzie	1923		Licence to Search, 1000 acres
Barn Bluff	G. R.	1923		Licence to Search, 3200 acres
Barn Bluff	L. Mudie	1923		Licence to Search, 3200 acres
Barn Bluff	E. E. Black	1923		Licence to Search, 3200 acres
Barn Bluff	R. Stoneham	1923		Licence to Search, 100 acres
Strahan	H. E. Evenden	1923	LTS 138	Licence to Search, 3200 acres
Strahan	Mersey Valley Oil Co. Ltd	1923		Licence to Search, 3200 acres
New River	F. T. Boddy	1924	LTS 146	Licence to Search, 3200 acres
Henty River	J. A. Wauchope	1924		Licence to Search, 3200 acres
Barn Bluff	B. H. Edwards	1924		Licence to Search, 3200 acres
Barn Bluff	B. D. Reynolds	1924		Licence to Search, 3200 acres
New River	F. T. Boddy	1924	LTS 146	Licence to Search, 3200 acres
New River	E. Hawson	1924		Licence to Search, 3200 acres
New River	F. W. Heritage	1924		Licence to Search, 3200 acres
Quamby Brook	Osmaston Shale Prospecting Syndicate	1925	LTS 165	Licence to Search, 640 acres
Flowerdale	D. Berechree	1925	LTS 158	Licence to Search, 83 acres
New River	E. F. Heritage	1925		Licence to Search, 3200 acres
New River	H. E. Evenden	1925		Licence to Search, 3200 acres
Flowerdale	D. Berechree	1925	LTS 158	Licence to Search, 83 ac, 3r, 27p
Quamby Brook	Osmaston Shale Prospecting Syndicate	1925	LTS 165	Licence to Search, 640 acres
Barn Bluff	G. S. Hope	1926		Licence to Search, 3 sq. miles, 1920 ac.
King Island	O. Bonney	1928	LTS 170	Licence to Search, 100 acres
King Island	O. Bonney	1928		Licence to Search, 100 acres
North Bruny Island	G. F. Boddy	1928		Licence to Search, 800 acres
North Bruny Island	H. M. Boddy	1928		Licence to Search, 800 acres
North Bruny Island	A. G. Black	1928		Licence to Search, 800 acres
North Bruny Island	M. Hayton	1928		Licence to Search, 300 acres
South Bruny Island	A. H. Jackson	1929		Licence to Search, 180 acres
North Bruny Island	A. J. Miller	1929		Licence to Search, 299 acres
King Island	A. J. Adams	1929	10103/M	Mining Lease, 588 acres
North Bruny Island	J. McD. Hay	1930		Licence to Search, 800 acres
King Island	L. Gatenby	1930		Licence to Search, 100 acres
Lady Barron	A. A. Summerhayes	1936	LTS 189	Licence to Search, 2100 acres
Lady Barron	Austral Oil Drilling Co.	1936	LTS 190	Licence to Search, 2600 acres
Lady Barron	C. S. Demaine	1936	LTS 191	Licence to Search, 2200 acres
Lady Barron	A. W. Inray	1936	LTS 192	Licence to Search, 3000 acres
Flinders Island	A. A. Summerhayes	1936	LTS 189	Licence to Search, 2100 acres
Flinders Island	Austral Oil Drilling Syndicate NL	1936	LTS 190	Licence to Search, 2600 acres
Flinders Island	C. S. Demaine	1936	LTS 191	Licence to Search, 2200 acres
Flinders Island	A. W. Inray	1936	LTS 192	Licence to Search, 3000 acres
Launceston (Danbury Park)	W. R. Richmond	1939		Permit to Enter over 3520 acres applied for; Warden granted prospecting rights to W. Richmond over ¼ acre

Location	Held By	Date	Licence/lease	Type of Tenement
Launceston (Danbury Park)	H. E. Evenden	1940	LTS 197	Licence to Search, 3200 acres
Port Davey	H. E. Evenden	1940	LTS 197	Licence to Search, 3200 acres
Flinders Island	Austral Oil Drilling Syndicate	1945		Prospecting Leases over 30,000 acres
King Island	Mrs A. S. Adams-Smith	1955	LTS	Licence to Search, 588 acres
King Island	S. Adams	1957	LTS	Licence to Search, 3200 acres
King Island	A. H. Adams	1957	LTS	Licence to Search, 3200 acres
King Island	R. S. J. & F. J. Adams	1957	LTS	Licence to Search, 2711 acres
King Island	Alice J. Smith	1957	LTS	Licence to Search, 2420 acres
King Island	J. R. G. Adams	1957	LTS	Licence to Search, 3196 acres
	C. Sulzberger	1959	EL 10/59	Exploration Licence
	Broken Hill Co. Pty Ltd	1960	EL 1/60	Exploration Licence 28,975 sq. miles
King Island	J. A. Adams	1961	LTS 209	Licence to Search, 80 acres
King Island	W. M. Westley	1961	LTS 210	Licence to Search, 1840 acres
King Island	S. P. J. Adams	1961	LTS 211	Licence to Search, 2680 acres
Preolenna	W. M. Adams	1961	LTS 212	Licence to Search, 2560 acres
Southeast Tasmania	A. G. Gill	1965	EL 17/65	Exploration Licence
West & southwest coasts	Esso Australia Inc.	1965	EL 18/65	Exploration Licence
	Nudec Petroleum Exploration Co. P/L	1965	EL 19/65	Exploration Licence
	Nudec Petroleum Exploration Co. P/L	1965	EL 18/65	Exploration Licence
Southeast Tasmania	EZ Co. of Australia Ltd	1965	EL 17/65	Exploration Licence, 8000 km²
North & southwest coasts	Esso Australia Inc.	1965	EL 18/65	Exploration Licence
	Nudec Petroleum Exploration Co. P/L	1966	EL 6/66	Exploration Licence
	Nudec Petroleum Exploration Co. P/L	1967	EL 15/67	Exploration Licence, 349 km²
West Coast	Amoco Aust. Petroleum Co. & Tasman Oil Co. Inc.	1975	EL 5/75	Exploration Licence, 517 km²
	Nudec Petroleum Exploration Co. P/L	1978	EL 10/78	Exploration Licence
East Coast	Meekatharra Minerals	1978	EL 25/78	Exploration Licence, 510 km²
East Coast	Meekatharra Minerals	1980	EL 33/80	Exploration Licence
Midlands	Victor Petroleum and Resources Ltd	1980	EL 31/80	Exploration Licence, 9500 km²
East Coast	Meekatharra Minerals	1981	EL 20/81	Exploration Licence, 510 km²
Southern Tasmania	Conga Oil Pty Ltd	1984	EL 29/84	Exploration Licence, 4395 km²
Southern Tasmania	M. Bendall	1986	EL 6/86	Exploration Licence, 50 km²
Southern Tasmania	Conga Oil Pty Ltd	1986	EL 7/86	Exploration Licence, 296 km²
Southern Tasmania	Conga Oil Pty Ltd	1986	EL 52/86	Exploration Licence, 481 km²
Southern Tasmania	Conga Oil Pty Ltd	1986	EL 53/86	Exploration Licence, 493 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 8/87	Exploration Licence, 317 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 9/87	Exploration Licence, 359 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 10/87	Exploration Licence, 491 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 11/87	Exploration Licence, 430 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 12/87	Exploration Licence, 498 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 13/87	Exploration Licence, 469 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 14/87	Exploration Licence, 120 km²
	Parish	1987	EL 45/87	Exploration Licence, 136 km²
Southern Tasmania	Conga Oil Pty Ltd	1987	EL 46/87	Exploration Licence, 390 km²
Southern and Central Tasmania	Conga Oil Pty Ltd	1988	EL 1/88	Exploration Licence, 24 000 km²
East Coast	Conga Oil Pty Ltd	1990	EL 17/90	Exploration Licence, 231 km²
Southern Tasmania	Great South Land Minerals Pty Ltd	1996	EL 19/95	Exploration Licence, 3121 km²
Northern Tasmania	Great South Land Minerals Pty Ltd	1996	EL 21/95	Exploration Licence, 5353 km²
Eastern Tasmania	Great South Land Minerals Pty Ltd	1998	SEL 13/98	Special Exploration Licence, 30 356 km²

The tenements listed above have been issued to search for oil/gas. The list excludes Permits to Enter held over private property in the Mersey Valley during the 1920–30's; such Permits were held for oil shale and/or liquid oil. The table also excludes permits held for oil shale.

APPENDIX 5

Rock-Eval Pyrolysis analyses

Sample	Well/location	Depth (m)	Rock type	T_{max}	S1	S2	S3	TOC	PI	HI	OI	S1+S2
BLACK RIVER DOLOMITE (Proterozoic)												
7047	Forest 1	826.0	mudstone	311	0							
7048	Forest 1	828.0	mudstone	408	0							
7049	Forest 1	1026.0	dolomite	247	0							
7050	Forest 1	1043.0	mudstone	395	0.52	0.14			0.79			0.66
8475	Forest 1	1015.0	dolomite	219	0	0	0		0	0	0	
KANUNNAH SUBGROUP (Proterozoic)												
7043	Forest 1	667.0	mudstone	436	0							
7044	Forest 1	668.0	mudstone	275	0							
7045	Forest 1	675.0	mudstone	302	0							
8474	Forest 1	76.0	mudstone	359	0	0	0		0	0	0	
FLORENTINE VALLEY MUDSTONE (Lower Ordovician)												
5730			mudstone	423	0	0	0					0
GORDON GROUP (Ordovician)												
5722			algal laminate	280	0	0	0					0
5723	Ida Bay	outcrop	limestone	286	0	0	0					0
5724			limestone	248	0	0	0					0
5725	Settlement Road		siltstone	280	0	0	0					0
5729	Benders Quarry	outcrop	shale	454	0.04	0.04	0		0.50			0.08
5731	(Westfield Formation?)	outcrop		280	0	0	0					0
5733	Stan Murray Road			321	0	0	0					0
5734	Queenstown Q1	outcrop	limestone	233	0	0	1.23	0.08		0	1538	0
5735	Queenstown Q2	outcrop	limestone	346	0	0.02	0.74	0.20	0.00	10	370	0.02
5726	(Westfield Formation?)			321	0	0	0					0
8477	Grieves Siding ZB1007	277	dolomite	400	0	0	0	0.18				
8478	Lune River BH2	56.5	limestone	224	0	0	0	0.17				
BELL SHALE (Devonian)												
8471	Oceania 13	66.1	siltstone	219	0	0	0	0.01				
8472	Oceania 13	70.1	pelite	329	0	0	0	0.17				
8473	Oceania 13	73.2	siltstone	383	0	0	0	0.18				
PARMEENER SUPERGROUP (Carboniferous-Triassic, undifferentiated)												
1988	Bass Highway	outcrop		437	0.02	0.04	0.07	0.11	0.33	36	64	0.06
BASAL TILLITE AND CORRELATES (Carboniferous)												
1989	Bass Highway	outcrop		401	0.01	0.02	0.17	0.10	0.33	20	170	0.03
	Shittim-1	1034		427	0	0	0.13	0.57	0.00	0	22	0
TASMANITE OIL SHALE												
1995	Mersey Great Bend	outcrop	oil shale	444	12.5	304	5.6	31.30	0.04	971	18	316.5
1996	Hellyer Gorge	outcrop	oil shale	449	1.3	38.9	2.5	5.43	0.03	716	46	40.2
	Douglas River		oil shale	446	6.28	147.5	0.15	17.00	0.04	868	1	153.78
5800	Douglas River	321.05	oil shale	449	8.01	152	0	16.99	0.05	895	0	160.01
5802	Tunbridge 1	676.4	oil shale	458	0.56	0.92	0	2.80	0.38	33	0	1.48
1	Oonah	outcrop	concentrate	446	30.8	590.8	2.3	63.05	0.05	937	3	621.6
2	Oonah	outcrop	oil shale	443	3.6	65.2	0.3	6.96	0.05	937	4	68.8
5	Oonah	outcrop	oil shale	440	1.4	54.4	2.2	8.06	0.03	675	27	55.8
6	Oonah	outcrop	concentrate	444	22.8	535	32	61.35	0.04	872	5	557.8
8	Mersey Great Bend	outcrop	oil shale	436	0.03	19.3	0.3	2.58	0.002	748	11	19.33

Sample	Well/location	Depth (m)	Rock type	T_{max}	S1	S2	S3	TOC	PI	HI	OI	S1+S2
WOODY ISLAND FORMATION AND CORRELATES (excluding tasmanite)												
D1	Bicheno-10	330.0	mudstone	434	0.69	2.25	0.05	1.67	0.23	135	3	2.94
D2	Bicheno-10	325.3	mudstone	433	0.40	1.02	0.07	1.05	0.28	97	7	1.42
D3	Bicheno-10	320.3	mudstone	439	3.20	10.48	0.10	2.42	0.23	433	4	13.68
D4	Bicheno-10	315.2	mudstone	437	0.31	1.22	0.06	0.97	0.20	126	6	1.53
D5	Bicheno-10	309.3	mudstone	433	0.18	0.74	0.08	0.94	0.20	79	9	0.92
D6	Bicheno-10	304.9	mudstone	440	0.94	5.16	0.01	1.72	0.15	300	1	6.10
D7	Bicheno-10	301.3	mudstone	432	1.10	1.67	0.11	1.18	0.40	142	9	2.77
D8	Bicheno-10	295.6	mudstone	439	0.16	0.72	0.05	0.50	0.18	144	10	0.88
D9	Bicheno-10	291.6	mudstone	436	0.21	1.20	0.02	0.81	0.15	148	2	1.41
8481	Bicheno-10	327.0	mudstone	449	0.40	0.71	0.01	0.84	0.36	85	1	1.11
	average			437	0.76	2.52	0.06	1.21	0.24	169	5.21	3.28
E1	Eaglehawk Neck-1	378.9	mudstone		0.16	0.09	0.01	0.83	0.64	11	1	0.25
E2	Eaglehawk Neck-1	372.0	mudstone		0.09	0.14	0.03	0.66	0.39	21	5	0.23
E3	Eaglehawk Neck-1	365.1	mudstone		0.13	0.08	0.01	0.71	0.62	11	1	0.21
E4	Eaglehawk Neck-1	355.2	mudstone		0.06	0.10	0.03	0.60	0.38	17	5	0.16
E5	Eaglehawk Neck-1	348.3	mudstone					0.35				
	average				0.11	0.10	0.02	0.63	0.51	15	3.04	0.21
G1	Golden Valley-1	182.5	mudstone	439	0.35	1.21	0.08	0.76	0.22	159	11	1.56
G2	Golden Valley-1	171.4	mudstone	442	0.30	1.44	0.05	0.72	0.17	200	7	1.74
G3	Golden Valley-1	161.8	mudstone	444	0.20	1.10	0.01	0.70	0.15	157	1	1.30
G4	Golden Valley-1	152.3	mudstone	441	0.25	0.92	0.01	0.64	0.21	144	2	1.17
G5	Golden Valley-1	143.2	mudstone	442	0.27	1.17		0.83	0.19	141		1.44
G6	Golden Valley-1	134.2	mudstone	443	0.25	1.17	0.05	0.87	0.18	134	6	1.42
G7	Golden Valley-1	125.3	mudstone	442	0.27	1.30	0.01	0.90	0.17	144	1	1.57
G8	Golden Valley-1	112.6	mudstone	440	0.16	0.36	0.08	0.63	0.31	57	13	0.52
G9	Golden Valley-1	103.3	mudstone	443	0.34	1.25	0.08	1.03	0.21	121	8	1.59
1990	Golden Valley-1	135.9	mudstone	442	0.16	0.49	0.05	0.67	0.25	73	7	0.65
1991	Golden Valley-1	170.4	mudstone	447	0.29	1.74	0.07	0.95	0.14	183	7	2.03
	average			442	0.26	1.10	0.05	0.79	0.20	138	6.26	1.36
S3	Styx Valley	outcrop	mudstone	454	0.57	0.77	0.01	0.94	0.43	82	1	1.34
S5	Styx Valley	outcrop	mudstone	453	0.22	0.30	0.14	0.73	0.42	41	19	0.52
S6	Styx Valley	outcrop	mudstone	461	0.42	0.60	0.02	0.81	0.41	74	2	1.02
S7	Styx Valley	outcrop	mudstone	468	0.39	0.45	0.04	0.95	0.46	47	4	0.84
S8	Styx Valley	outcrop	mudstone		0.10	0.16	0.06	0.53	0.38	30	11	0.26
S10	Styx Valley	outcrop	mudstone	452	0.48	0.57		0.75	0.46	76		1.05
S11	Styx Valley	outcrop	mudstone	436	1.10	1.48	0.05	1.16	0.43	128	4	2.58
S13	Styx Valley	outcrop	mudstone	451	0.22	0.22		0.51	0.50	43		0.44
	average			454	0.44	0.57	0.05	0.80	0.44	65	7.09	1.01
T1	Tunbridge-1	702.0	mudstone	460	0.36	0.25	0.01	0.68	0.59	37	1	0.61
T2	Tunbridge-1	685.9	mudstone		0.22	0.15		0.50	0.59	30		0.37
T3	Tunbridge-1	671.0	mudstone		0.21	0.18	0.03	0.42	0.54	43	7	0.39
T4	Tunbridge-1	653.7	mudstone	397	0.95	0.98	0.01	1.24	0.49	79	1	1.93
T5	Tunbridge-1	637.6	mudstone	445	0.86	0.54	0.03	1.31	0.61	41	2	1.40
T6	Tunbridge-1	622.4	mudstone	449	0.62	0.55	0.03	1.08	0.53	51	3	1.17
T8	Tunbridge-1	588.5	mudstone	445	0.69	0.62	0.02	1.13	0.53	55	2	1.31
T10	Tunbridge-1	557.5	mudstone	451	0.43	0.48	0.03	0.82	0.47	59	4	0.91
T12	Tunbridge-1	525.8	mudstone	450	0.40	0.50	0.02	0.86	0.44	58	2	0.90
T14	Tunbridge-1	495.8	mudstone	462	0.23	0.21	0.01	0.63	0.52	33	2	0.44
5801	Ross-2	409.3	mudstone	447	0.15	0.09	0.00	1.19	0.63	8	0	0.24
8480	Ross-1	388.0	mudstone	435	0.14	0.38	0.00	0.80	0.27	48	0	0.52
	average			444	0.44	0.41	0.02	0.89	0.52	45	2.17	0.85

Sample	Well/location	Depth (m)	Rock type	T_{max}	S1	S2	S3	TOC	PI	HI	OI	S1+S2
1992	Andersons Creek BH	124.4	mudstone	445	0.02	0.10	0.08	0.33	0.17	30	24	0.12
1993	Andersons Creek BH	129.5	mudstone	425	0.02	0.11	0.09	0.29	0.15	38	31	0.13
1994	Hellyer Gorge	outcrop	mudstone	363	0.00	0.05	0.33	0.36	0.00	14	92	0.05
1997	Relapse Creek area (float)	outcrop	mudstone	449	0.65	4.37	0.31	1.61	0.13	271	19	5.02
3	Oonah	outcrop	mudstone	437	0.04	0.89	0.73	1.01	0.04	88	72	0.93
4	Oonah	outcrop	mudstone	440	0.07	1.30	0.34	0.78	0.05	166	43	1.37
7	Oonah	outcrop	mudstone	436	0.10	1.80	0.60	1.10	0.05	163	54	1.90
	Average (northern localities)			428	0.13	1.23	0.35	0.78	0.09	110	48.02	1.36
5732	?		mudstone	453	1.75	1.22	0.00	1.26	0.59	97	0	2.97
Golden Valley Group and correlates												
1998	Musselroe Bay BH 1A	17.1 (56′)	mudstone	459	0.03	0.02	0.17	0.44	0.60	5	39	0.05
2000	Golden Valley-1	16.6 (54.5′)	siltstone	435	0.47	3.64	0.13	4.25	0.11	86	3	4.11
5727	Golden Valley Mudstone		mudstone	448	0.52	1.11	0	0.93	0.32	119	0	1.63
5728	Golden Valley Mudstone		mudstone	450	0.32	0.71	0	0.72	0.31	99	0	1.03
Lower Freshwater Sequence												
1999	Musselroe Bay BH 1A	12.8 (42′)	mudstone	277	0.03	0.02	0.07	1.90	0.60	1	4	0.05
2002	Relapse Creek Area	outcrop	coal	442	7.3	101	5.2	32.90	0.07	307	16	108.3
2003	Relapse Creek Area	outcrop	coal	444	10.1	102	5.2	26.20	0.09	389	20	112.1
2004	Relapse Creek Area	outcrop	coal	445	6.6	68.9	4.9	32.10	0.09	215	15	75.5
Berriedale Limestone												
8469	Granton 1	80	limestone	436	0	0	0	0.29	0.00			0
8470	Grange 1	130	limestone	415	0.1	0	0	0.19	1.00			0.1
Upper Parmeener Supergroup (Unit 4)												
2001	Fingal BH 9	64.3	coal	434	3.5	109	6.1	34.20	0.03	319	18	112.5
8476	Fingal Tier DDH 60	466	mudstone	441	0.05	3.69	0	2.65	0.01	139	0	3.74