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AN EVALUATION
OF THE OIL AND GAS POTENTIAL
OF TASMANIA

PREPARED FOR
MR MALCOLM BENDALL

BY
QUESTA AUSTRALIA PTY LTD

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INDEPENDENT GEOLOGIST REPORT

QUESTA AUSTRALIA PTY LTD

23 May 1992,

The Directors,
Condor Oil Pty Ltd,
84 Wells Parade,
BLACKMANS BAY TAS 7052

Dear Sirs,

This report has been prepared at your request for inclusion in a Prospectus to be issued by Condor Oil Pty Ltd.

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INTRODUCTION

Condor Oil Pty Ltd hold an Oil and Gas Exploration Licence which covers _____ hectares of onshore, eastern Tasmania. Numerous companies have demonstrated a strong interest in the oil and gas potential of the State's offshore sedimentary basins, but until recently, the hydrocarbon potential of Tasmania's onshore sedimentary basin areas has been largely ignored.

The proposed Condor Oil Pty Ltd "float" is unique in Australia in that the presence of commercial volumes of oil and gas in the onshore sedimentary basins of Tasmania has yet to be demonstrated. Onshore Tasmania has not been previously explored using modern exploration concepts and techniques. There are few well defined structures waiting to be drilled, and no promises of an early oil or gas discovery to be made. Although Condor has identified specific areas in Tasmania which offer considerable hydrocarbon potential and which ought to be and will be eventually drilled, there remains a considerable amount of work to be done before relatively low risk drilling locations might be sighted.

Until Condor Oil became interested, explorationists considered onshore Tasmania to have little hydrocarbon potential, based largely on past writings and understandings. New concepts and interpretations and recent investigations by Condor Oil have, however, shed a new light on the oil and gas prospectivity of Tasmania.

Condor Oil realised that there was considerable potential for commercial accumulations of oil and gas being present in Tasmania and commenced a programme in 1989 to verify (or deny) their original expectations. Information on historically reported oil "seepage" sightings has been collated and "seep" locations mapped to determine trends, sophisticated geochemical analyses have been performed to identify and quantify oil and gas source potential, detailed and extensive gravity and magnetic acquisition and interpretation have been carried out to better determine the structural configuration and magnitude of Tasmania's onshore sedimentary basin(s) and a small amount of seismic has been acquired to determine the feasibility of obtaining good and usable data in Tasmania. All of Condor's findings to date have been vary positive and progressive and indicate that Tasmania is prospective for oil and gas. Before a site for a petroleum exploration well can be considered, however, more information is needed on source rock and reservoir quality and distribution and more knowledge is required on the structural configuration of the subsurface sediments. In order to obtain further, required information, several fully corad boreholes will have to be drilled and geochemical, palaeontological and petrophysical analyses conducted on recovered rock samples. Petroleum exploration in Tasmania is still at a preliminary stage. The exploration program planned by Condor for the next two years will achieve many goals. It will greatly improve the geological knowledge and understanding of subsurface Tasmania. This will provide direction as to where Condor should intensify their exploration efforts and will hopefully lead to identifying structures which might contain commercial volumes of oil and gas.

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When Questa was first approached by Condor to prepare a geological summary of the hydrocarbon potential of Tasmania, we were a little hesitant. We, as many others considered Tasmania to have very little if any oil and gas potential. A paper presented by M. R. Bendall, a Director of Condor Oil, at the Australian Petroleum Exploration Association (APEA) Conference in 1991 enlightened us. A comprehensive literature review, discussions with other geoscientists including Dr. David Leaman, a prominent geophysical/geological consultant and long time resident of Tasmania, Dr. John Volkman, a chemical oceanographer and organic geochemist with CSIRO in Hobart and Mr Malcolm Bendall, the founder of Condor Oil, and a considerable amount of in-house burial history and maturation modelling, have led Questa to be optimistic about the potential for oil and gas in Tasmania.

As indicated above, the first serious and methodical investigations into the petroleum potential of Tasmania were initiated by Condor Oil in the 1980's, financed entirely by their own resources. Work carried out by Condor Oil in the past three years has led to some very encouraging results, providing a considerable degree of optimism that all of the criteria essential for hydrocarbon generation and accumulation could very well be present in Tasmania, and that commercial accumulations of oil and/or gas might be discovered in the near future with a concentrated and efficient exploration program, a program which is backed by sound scientific concepts and, very importantly, sufficient funding.

The elements necessary for oil and gas accumulations are:

- 1) The accumulation and preservation of organic rich source material within fine grained sediments (source rocks).
- 2) Deposition and preservation of porous and permeable reservoir rocks.
- 3) The presence of efficient, impermeable seals overlying reservoir quality rocks.
- 4) Trapping mechanisms formed by folding and/or faulting of rock sequences or involving lateral changes in rock composition (porosity and permeability variances).
- 5) Heating of preserved organic material to temperatures at which hydrocarbons are generated and expelled from source rocks. Generally about 1500 - 2000 metres of sediment overburden is required to generate the required temperatures. Trap mechanisms must be in place before conditions for hydrocarbon generation are achieved to prevent hydrocarbons from escaping to the Earth's surface.
- 6) Conduits to provide reservoirs access to hydrocarbons migrating from maturing source rocks. Conduits may be established by permeable reservoir rocks being adjacent to maturing source rocks. Faults may often also assist.

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7) Preservation of hydrocarbon accumulation(s) from excessive temperatures and, maintaining of trap integrity.

8) Sufficient pressure within hydrocarbon saturated reservoirs to facilitate movement of hydrocarbons from reservoir to surface production facilities. Pressure is usually induced by considerable thicknesses of rock overlying the reservoir horizon. Pressure may, however, be artificially induced.

The absence of any one of the first seven of the above criteria will preclude any chance of a hydrocarbon accumulation being present. Until Condor Oil began its investigations into the petroleum potential of the State, several of the above criteria were considered lacking. Currently, it appears that all of the elements are present, at least over considerable parts of the Condor Oil Permit area.

The difficulty now lies in identifying specific locations in which all of the elements are likely to be present and favourable. Before a drilling program with the specific intent of locating hydrocarbon accumulations can be initiated, considerable regional information must be obtained on source rock distribution, quality and maturation, on reservoir development and on basin structure. In order to obtain this basic information, boreholes without oil or gas objectives will have to be drilled and cores obtained and analysed. Specific target objectives must be defined and good quality seismic obtained to pin-point optimum drilling locations over valid and robust targets which exhibit generous hydrocarbon drainage areas.

PREVIOUS EXPLORATION FOR PETROLEUM IN TASMANIA

The first record of an interpreted, onshore petroleum occurrence in Tasmania was made more than 115 years ago. Some 200 examples of possible onshore petroleum seepages and bitumen occurrences in Tasmania have been reported during the past 100 years. From 1915 to 1940, there was considerable exploration for oil in Tasmania. This exploration was inspired by the numerous reports of oil "seepages" across the State and the occurrences of what now appears to be unrelated bitumens, on the west coast of Tasmania. To date some thirteen companies, including Condor Oil Pty Ltd, have actively explored for petroleum in the island State. A total of 127 exploration licences have been held and some forty shallow boreholes drilled. Almost all of the wells were drilled at the site of petroleum seepages without any real knowledge of subsurface structure and stratigraphy. Most wells were shallow and in spite of considerable early activity, not one company evaluated the Permian sedimentary sequence, largely because of limitations on drilling rig capacity, but also due to a lack of understanding of what constitutes hydrocarbon prospective rocks in Tasmania. Most wells entered near-surface Jurassic dolerite (volcanic) intrusions and many terminated within them. Until

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recently, there were no valid methods to predict the distribution and magnitude of dolomite stacks in the subsurface. In spite of all of the above, small volumes of oil and/or gas were reportedly recovered or observed in several of the drill holes.

Around the world, oil strandings, seeps and other surface petroleum occurrences have led to the discovery of significant subsurface oil accumulations. Before success can be met in pursuing the origin of such "seeps", however, the explorer must have a good knowledge of the structural history of the basin from which the seeps are originating, of the stratigraphy and structural geometry in the environs of recognised seeps and of the maturation history of potential source rocks. These are elements which have not been observed in petroleum exploration in Tasmania in the past.

GEOLOGICAL HISTORY

Pre-Cambrian quartzites, phyllites and dolomites which are exposed extensively in the central and northwestern part of Tasmania and which may date back as far as 1100 Ma, constitute the oldest rocks in the State. They are almost entirely of sedimentary origin and range from relatively unmetamorphosed subgreenschist facies sequences through to highly metamorphosed amphibolite facies. The sediments were severely deformed and intruded with granites during the Penguin Orogeny which occurred about 725 - 750 million years ago. Terrestrial sediments and shallow marine, predominantly quartzose, sandstones and dolomites, deeper marine mudstones and turbidites and basalts were deposited across the deformed surface during late Pre-Cambrian and Early Cambrian time.

A thick sequence of volcano-clastic sediments was deposited during Middle and Late Cambrian time. The sequence includes the arcuate zone of the mineral rich Mt. Read Volcanics, and the Dundas Group, which comprises conglomerates and finer grained clastics of a predominantly volcanic origin, deposited in a basin setting. Local interruptions of conglomerates suggest intermittent uplift of the basin margins. Tensional tectonics gave rise to horst and graben structural development.

The Ordovician is represented by the Denison and Gordon Groups. The Denison Group comprises a succession of predominantly siliciclastic sediments which were deposited in a spectrum of depositional environments ranging from braided stream and meandering stream through to deltaic and shallow and deep marine and indicate a late Cambrian to Early Ordovician marine regression, followed by a later Early Ordovician marine transgression. Late Cambrian submarine fans and other slope deposits are progressively overlain by shallow marine and later terrestrial deposits (regression), which are in turn progressively overlain from the southeast by a sequence of shallow marine silts and muds. Highland areas appear to have developed in the western and northwestern part of the State as is evidenced by conglomeratic alluvial fan complexes.

As stream gradients on the uplifted areas decreased, limiting clastic transport, carbonate deposition began to replace clastic deposition. Up to 2000 metres of Gordon Group carbonates overlie the Denison Group clastics in central Tasmania. Shallow marine to

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platform margin build-ups to deep water (>200m) carbonate and turbidite - graptolitic shale environments are present with rapid lateral and vertical facies changes noted.

The change from clastic deposition to carbonate deposition was gradual and considerable inter-fingering of the two rock types occurs. Dolomitization of inter and supratidal rocks is widespread and believed to have occurred shortly after deposition, although in some cases, rocks have been de-dolomitized. Limestone is richly fossiliferous in many places, the biota indicating deposition in warm, clear, shallow water. Evidence of evaporite producing conditions is seen in several places. Coral gardens appear to have been widespread and possible back reefs have been identified. Algal "lawns" are also reported to be widespread across the State.

Towards the end of the Ordovician, clastic material advanced rapidly across the carbonate platform, and the Gordon Group carbonates were conformably overlain by predominantly shallow marine silici-clastics of the Late Ordovician - Early Devonian Eldon Group. The Eldon Group comprises three major cycles of sandstone and siltstone, which, with a minor limestone contribution, reaches a thickness over 2000 metres. The greater coarseness of grains and the higher sand to shale ratios of the Eldon Group in western Tasmania, imply a source area in the west of the State. In the eastern part of the basin, basinal graptolitic, turbidite deposits were deposited (Mathinna Beds).

Lower Devonian and older rocks were extensively deformed during the Tabberabberan Orogeny. Approximately northwest to north-northwest trending folds developed across most of the State, but east-west trending folds developed in the northwest. Several laterally and vertically extensive, north-south trending thrusts developed and numerous and relatively large granitoids were discordantly intruded between about 348 and 395 Ma in northeastern Tasmania and 332 and 367 Ma in western Tasmania. Concordant colour alteration indices (CAI) indicate that Lower Palaeozoic sediments were heated to about 300°C adjacent to intrusions in the western part of the State. In central and southern Tasmania, Lower Palaeozoic sediments were heated up to an estimated 100°C, even where distant from the granitoid masses. This major heating event is relevant to the development of petroleum in Tasmania.

During the Late Carboniferous and Permian, glacial deposits (Lower Parmeener Supergroup) were deposited unconformably across the deformed, uplifted and eroded, older rocks. Lateral variations in lithofacies are considerable, particularly in the vicinity of topographic highs generated during the Tabberabberan Orogeny. As a result, rock unit nomenclature varies widely from place to place. Environments of deposition range from glacio-terrestrial (including glacio-lacustrine) to glacio-marine. The basal part of the Supergroup includes the Tasmanites oil shales, glacio-restricted marine deposits which have an extremely high organic content. Permian rock sequences typically are 600-1000 metres thick.

Triassic rocks are represented by up to 750-800 metres of fresh water, lacustrine and fluvial deposits of the Upper Parmeener Supergroup. In places, Triassic sediments rest directly on Devonian granites. The lower part of the upper Parmeener

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Supergroup commonly consists of granular conglomerate and coarse sandstone. The upper parts of the sequence are commonly represented by up to 400 metres of feldspathic and coal-rich sandstone. Dark grey shale horizons and subordinate coal measures occur throughout the sequence. Almost everywhere in Tasmania, rocks of the Permian Supergroup are regionally sub-horizontal, although contrary to many published reports, they are in many areas, highly deformed.

Extensive sills of dolerite fed by narrow feeder dykes were intruded during the Middle Jurassic. The intrusions, which presently extend over half of the land mass of Tasmania, were probably related to tensional stresses between continental blocks at the commencement of breakup of the Gondwanaland supercontinent. Within the dolerite swarm there are generally two or more stacked sills, each averaging about 200 to 350 metres in thickness. Large scale thrusting affected much of the State.

While thick (up to 8000 metres) accumulations of alluvial fan, fluvial and volcanic sediments were deposited in the newly formed Bass, Otway and Sorrell marginal basins which now occupy offshore Tasmania, only a relatively thin succession of non-marine and volcanic sediments were deposited in local depressions across onshore Tasmania. During the Late Cretaceous to Early Tertiary, a series of large scale, north to northwesterly trending horsts and grabens were formed as an extensional regime was set up and Antarctica fully separated from Australia. Up to a kilometre of mainly terrestrial sediments was deposited in the grabens. Syenite intrusions up to 300 metres in thickness and of Cretaceous age are not uncommon. At the end of the Eocene and in the earliest Oligocene, northwesterly directed compression rejuvenated many of the earlier formed structures, but this period of compression appears to have been centred more on the Gippsland and Otway basins to the north. Tertiary basalt flows are common throughout Tasmania with sheets up to 300 metres in thickness.

KNOWN PETROLEUM OCCURRENCES

In 1871, surface tar was reported from Prime Seal Island on the west coast of Flinders Island. Since that time, some 200 reports of possible, onshore, liquid petroleum and natural gas "seepages" and "flows" and bitumen occurrences in Tasmania have been documented, most of these before 1970 but some as recent as the late 1980's. Many of these were confirmed by government geologists of the time.

Samples and photographs of some of the tars collected from Tasmanian coastal beaches have been preserved in museums and libraries, further validating early reports, but geochemical analyses of beach collected bitumens strongly suggest that they are related to Tasmania's offshore basins. Unfortunately, although numerous, there are mainly only written, unconfirmed reports of seepages and shows in the interior of the State with very few preserved samples.

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Considerable enthusiasm is, however, justified by the abundance of records over the past century. One of the more dramatic excerpts is from a report by a consulting geologist to the Tasman Oil Company in 1921, concerning a property in the Derwent Valley:

"I have no hesitation in confirming Black's (Field Manager for the Tasman Oil Company) statement that oil exists at Barn Bluff, gas and oil seepages being plainly manifest during my recent inspection there. Also the geological features of the field generally indicate that large quantities of oil have unquestionably been produced by natural processes of distillation and may be confidently sought for in the Anti-Clines."

Although the word "field" is not applicable and the general tone of the full statement was intended to promote the Tasman Oil Company, reports such as the above provide encouragement that commercial volumes of oil may have accumulated in the subsurface in Tasmania. One would trust that the report was not entirely promotional in concept.

The only paper to look seriously at the possibility of oil in on-shore Tasmania was prepared 75 years ago by government geologist W. H. Twelvetrees. Numerous hydrocarbon occurrences were reported by Twelvetrees in 1915 and in 1917.

Seepages in Tasmania appear to be related to seismic activity as most of the sightings of seepages have been made directly after major earth tremors. Most sightings are within five years of the occurrence of either considerable, long term seismic activity or events greater than a magnitude of 4 on the Richter Scale. There have not been a large number of reports of petroleum shows since 1959 but then Tasmania has not experienced a major earth tremor since 1958. The figure shows the distribution of reported seeps in Tasmania (from Bendall 1990). Northeast - southwest trends in seep distribution are evident from the figure and these trends correspond very closely to established gravity and magnetic trends, which have been interpreted as representing deep seated (crustal) thrust faults and lineaments (Leaman and Richardson 1990). Seepage appears, therefore, to be related to movements along established fault lineaments during times of seismic activity.

Records are incomplete, but it appears that not more than about thirty-five boreholes have been drilled in Tasmania with petroleum objectives. Wells have been very shallow, the deepest being no more than about 500 metres. All wells drilled to date have been initiated solely on the basis of effusive oil or tar seepages, without any real knowledge of subsurface structure or stratigraphy. Nevertheless, oil was reported to have been recovered from a depth of 27 metres at Johnson's Well on Bruny Island in the south of Tasmania, and a small quantity of gas was reported to have been produced from a well at Port Sorell in the north. Reports describe storage of some of the light oil from Johnson's Well in drums. Minor oil and gas flows were reported from at least two other petroleum boreholes and from at least one water bore. Minor oil was recovered from a Tasmanites oil shale interval from the Ross No. 2 stratigraphic borehole, drilled to 480 metres in 1985 by the Department of Mines and a small and brief gas flow was reported by Dr. D. Leaman, from a stratigraphic borehole, while drilling

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through the Quamby Mudstone at Douglas River. Oil and gas have almost definitely been generated and it looks like low volume seepage has been occurring off and on over a large part of Tasmania.

"Seepages" in the Bruny Island region may represent migration updip along the pre Permo-Carboniferous unconformity surface to Jurassic induced faults disturbed during the Tertiary, from the concealed lower Palaeozoic basin some 10 to 20 kilometres to the west (Leaman, 1990).

There has not been a major earthquake episode in Tasmania since about 1958 and consequently reports of "seepages" in recent years have been minimal. Most of the early sightings were not confirmed by knowledgeable 'experts' and certainly not by geochemical analysis, and one would anticipate that bacterial action would have destroyed any evidence of many early occurrences. There have, however, been a large number of sightings over many years which provides in itself considerable credibility to their presence. In addition, the sightings, when located on a map of Tasmania, follow well defined lineament trends established by recent gravity and magnetic interpretations. These lineaments have been interpreted as deep seated thrust faults and there is therefore good reason to consider the "seepages" may have originated from subsurface hydrocarbon accumulations.

GEOCHEMISTRY

Potential Source Rocks

Until the late 1980's, explorers and geoscientists had very little knowledge regarding the actual source(s) of the tars, bitumens and natural gas occurrences across the State. The original explorers of New River (circa 1915 - 1925) conjectured, and perhaps correctly, that the Gordon Limestone was the primary source of the abundant oil seeps and tars. Similarities were drawn between the Gordon Limestone and time equivalent, prolific oil producing limestones in the U.S.A. It has been presumed by more recent investigators, however, that oil generated and revealed as "seeps" was derived from the Permian oil shales. Although organically very rich and often oil saturated themselves, these rocks were not, however, considered to have ever been sufficiently buried to achieve temperatures necessary for the generation of significant hydrocarbons.

Today, as a result of considerable work initiated primarily by Condor Oil and analyses carried out by CSIRO, the BMR and AMDEL, there is considerable evidence that carbonates, shales and evaporates of the Gordon Limestone Group and shales and coals of the lower Permian Supergroup all have the potential to have generated significant volumes both oil and gas. Other known potential source rocks include Pre-Cambrian shales and dolomites.

The Gordon Limestone was formed under shallow water, marine conditions. Dark graptolitic shales and evaporite sequences within the Group should provide excellent, oil prone, source potential.

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The frequent occurrences of pyrite in conjunction with carbonaceous shales implies an anaerobic and toxic environment, which is vital for the preservation of algal and other oil prone organic material.

Most "seepage" sites are adjacent to or overlie areas known to contain Ordovician and older rocks, or are related to drainage catchments containing such rocks. Organic geochemistry reveals a very close similarity between hydrocarbons extracted from Ordovician Limestones from Ida Bay and those obtained from the surface sediments at the drilling site of the Johnson's Well on Bruny Island. Geochemical analyses of two soil samples from Johnson's Well revealed only traces of hydrocarbons. The low concentrations of petroleum derived hydrocarbons indicate that petroleum seeps are no longer active at Johnson's Well, but provide some evidence for their former presence. These analyses indicate that neither the oil from Bruny Island, nor the coastal bitumens were generated from the Tasmanites oil shales.

Hydrocarbons isolated from Ordovician limestones from Lune River and Queenstown show distributions of biomarkers characteristic of mature crude oils. Although the Gordon Limestone has been identified as the most likely source for the hydrocarbons in southern Tasmania, it is not known whether it remains a source across the entire State. The very limited number of samples analysed precludes authoritative conclusions and judgements to be made. Considerably more investigations must be initiated.

The Parmeener Supergroup also includes intervals of organically rich, oil and gas prone source rocks. Very little work has been completed on the organic petrology of the Parmeener Supergroup, but that which indicates the unit is highly variable both in a lateral and a vertical sense, with total organic carbon values (TOC's) ranging from just a trace, to more than 30 percent in oil shales and coals. Organic quality too, is highly variable with some samples particularly rich in exinite (oil prone) and other samples consisting of predominantly inertinite (neither oil nor gas prone). Sampling within the Parmeener Supergroup has been very limited to date (seventeen samples from Douglas River, Ross River and Tunbridge borehole No. 2, analysed by BMR) and samples on hand may not be representative of the unit as a whole. Nevertheless, results are very encouraging.

It appears the Tasmanites oil shales provide the best potential source interval in Tasmania. The oil shale had been mined at Latrobe from 1910 to 1932, with artificial distillation resulting in the recovery of 939,221 litres (248,114 gallons) of oil. Total organic carbon (TOC) values within the Tasmanites range up to 30 percent and higher and even on world standards, provides an exceptionally rich, Type 1, oil prone source rock. The Tasmanites in north and northwest Tasmania consists of a single celled algae known as Tasmanites punctatus, which has a H/C ratio of about 1.5 and an O/C ratio of about 0.12. It may thus be considered as representing the optimum type of oil source rock.

The Tasmanites oil shales appear to be sporadically developed across Tasmania, being patchy in areal extent and thin where present. Considerable work will have to be undertaken to determine their geographical distribution. The potential source rock is

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particularly prominent in the north of the State near the base of the Quamby Formation. Nevertheless, it has been identified in numerous outcroppings and drillholes, and may be of a greater geographic distribution than currently recognised.

Banks (1968) described oil shale and cannel coal from the top of the Mersey Coal Measures. These potential source rocks are similar to the Tasmanites oil shales in their thin and patchy distribution and in their organic richness.

A rock sample of lower Permian mudstone from Poatina, and stratigraphically related to the Quamby Mudstone, was analysed by CSIRO. The sample was grey in colour and had a noticeable petroleum-like odour when broken open. The sample was found to contain considerable amounts of hydrocarbon having the characteristic distribution found in mature crude oil. Biomarkers were distinctly different from those found in Ordovician carbonates and it is believed (Volkman 1989) the Quamby Mudstone hydrocarbons were indigenous to the rocks from which they were extracted. Thin, oil shale intervals are commonly present within the Quamby Mudstone sequence. A borehole drilled beside the Douglas River Bridge as part of the Tasmanian Department of Mines coal assessment program flowed gas during penetration of the formation (Leaman - pers comm). Geochemical analysis indicated the formation to be geochemically mature, albeit only marginally mature, at the Douglas River location.

Dark grey shale and subordinate coal horizons occur throughout the Parmeener Supergroup sequence and these too could offer considerable source potential.

Unusual tars obtained from Bridgewater and other locations appear to be derived from higher plants, indicating a Permian source.

ORGANIC MATURATION

There have been numerous misconceptions concerning the maturity of organic material contained in potential source rocks in Tasmania. Many investigators believed (and many still believe), the early Palaeozoic sequence constituted effective basement, having neither reservoir nor source potential. Clarke, Farmer and Gulline, in their paper published in "Economic Geology of Australia and Papua New Guinea, Volume 3-Petroleum" published by the Australian Institute of Mining and Metallurgy in 1976, refer only to sediments of the Upper Carboniferous to Triassic Parmeener Supergroup and these sediments alone constitute what is referred to as the Tasmania Basin, even today.

Due to insufficient depths of burial, Parmeener Supergroup sediments were considered to be nowhere sufficiently mature for the generation of commercial volumes of oil and/or gas. The high organic content of the Tasmanites oil shales was well known, but explorationists considered the unit was everywhere insufficiently mature for the generation and release of significant quantities of hydrocarbons.

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In more recent years, as initial geochemical data was obtained, researchers became aware of the excellent source potential of Ordovician and older sequences across Tasmania, but another misconception led many to believe that hydrocarbons generated from within the early Palaeozoic sequence would have escaped when strata were deformed and uplifted, and anticlinal closures breached during the Devonian Tabbardaharen Orogeny. These researchers believed that hydrocarbon generation from the Early Palaeozoic and Pre-Cambrian sequence would have been initiated in response to high heat flows introduced into the basin during the orogeny. With no effective seals, migrating and entrapped hydrocarbons would have found their way to the Earth's surface where they would have been destroyed by bacterial and weathering action. The particularly high basin temperatures were interpreted from conodont colour alteration index (CAI) values from Early to Middle Palaeozoic marine carbonate rocks of western and west central Tasmania. Low vitrinite reflectance values from unconformably overlying Permian Supergroup sediments suggested that the major heat input into the pre-Carboniferous sequence occurred prior to Permian Supergroup deposition.

Isograds of CAI values in western and northwestern Tasmania form an arcuate belt following the outcrop of the early Palaeozoic rocks around Pre-Cambrian metamorphic basement rocks. Regional metamorphism in western and northwestern Tasmania is interpreted to have been in excess of 300°C immediately adjacent to igneous intrusions. Low CAI values, however, in the southwest and central Tasmania, suggest that if Gordon Group source rocks are present at depth, and there is strong suggestion that they are, they are currently within the oil and gas windows. Maturation modelling suggests that it is unlikely that hydrocarbons would have been expelled from these more basinward sediments (at least from the upper part of the Gordon Group) until after a considerable and protective Permian Supergroup cover (seal) was in place. Over large parts of the State, therefore, the Gordon Group offers considerable hydrocarbon potential.

Until very recent time, no mature source rocks of Permian - Carboniferous age were thought to exist in Tasmania. Recent investigations by CSIRO, the Bureau of Mineral Resources (now the Australian Geological Survey Organisation) in Canberra, The Tasmanian Department of Mines, Amdel Core Laboratories and others have demonstrated that organic sediments within the Tasmania Basin are in the oil window, with vitrinite reflectance values ranging from 0.7% (lower oil window) at the edge of the basin to 1.35% (upper oil window) towards the centre of the basin. The 1.35% value was estimated on the basis of spore colouration interpretations. The Methyl Phenanthrene Index (MPI) measured from the aromatic fractions of hydrocarbons extracted from Permian rocks in the basin, indicates a similar range of maturity for the basin. One might ask how this can be, given relatively shallow depths of burial experienced by the Upper Palaeozoic sediments. Tasmania currently has a relatively high heat flow which is up to twice the world average of 60 mW/m². Present geothermal gradients onshore Tasmania are 30 - 40°C/km and up to 600 and 700°C/km (Surmons 1981) and there is strong evidence that geothermal gradients were higher in the past. Recent zircon and apatite fission track data (Hillis - Bidel verbal communication to M. Bendall in 1991) appears to

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confirm a Cretaceous heating event which is predicted from Maturation Modelling. A Jurassic heating event is also quite probable.

Gravity and magnetics and surface outcrop data indicate greater thicknesses of sedimentary sequence than previously thought in Garden and other basin depressions, and a post Permian Supergroup cover in the order of 2.0 to 2.5 kilometres is interpreted for the central basin area.

All of the geochemical evidence to date indicates that within Tasmania there is a wide range of maturation levels, from early mature to extremely over mature (post wet gas preservation), for Ordovician and older sediments. Permian Supergroup sediments appear to range from immature to marginally mature on the edges of the Tasmania Basin, to fully mature for peak generation of oil and gas at the centre of the basin. This makes much of onshore Tasmania prospective for hydrocarbons.

RESERVOIRS

Very little definitive data is available on the reservoir potential of the sedimentary rock sequence in Tasmania, but several potential reservoirs are present within the Gordon 'Limestone' Group and the Permian Supergroup.

Until the 1980's, it was believed that Pre-Permian sedimentary rocks were present only in western Tasmania. It has now been demonstrated that a Lower Palaeozoic and Upper Pre-Cambrian sequence extends as far east as Ross, Oatlands and Sorell. There is thus, a thick (up to several thousand metres) and geographically extensive, sedimentary sequence in which well developed reservoirs should be present.

Coral 'gardens' appear to have been common across much of Tasmania during the Upper Ordovician, but to date no authentic bioherms have been identified. C. F. Burrett (Summons T. G. 1981) postulates that the coralline facies at the top of the Benjamin limestone in the Florentine Valley was a backreef, with a yet to be discovered forereef to the east. Forereef development would be anticipated and would have migrated westward (landward) from the southwest with the westward transgressing sea.

Thick sections of Ordovician reef and shelf limestones appear to have been re-crystallized (at Lune River at least) and have high porosity, where the limestone was exposed during the Teberaberan Orogeny, and karst and weathering porosity was developed.

Secondary dolomites are known from several places in the Gordon Group. At Lune River, secondary dolomites were formed through the action of hypersaline brines which developed in supratidal depressions. The dolomite at Lune River is porous and vuggy. The Eldon Group comprises alternating sequences of sandstone and siltstone with minor limestone. The Group has a high sandstone to shale ratio and should therefore offer considerable reservoir potential. No data relevant to its porosity or permeability, however, is available.

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Until very recently, it was believed that reservoir conditions within the Permian/Triassic sequence were virtually nonexistent. Several potential reservoir intervals are, however, present. These include the Liffey and Risdon Sandstones.

The Permian Liffey Sandstone is a very important and recognised potential reservoir objective. The unit is the first semi-regional, coarse, clastic unit (? reservoir) above the Tasmanites oil shales. Effective porosities of one small sample, as measured by Amel Laboratories in 1981, range from 10.66 to 11.00 percent.

Sandstones which constitute the Malbina Formation, the Triassic Ross Sandstone and the Permian Risdon Sandstone should also be considered as potential reservoirs although artesian flows through these units are uncommon. Porosity - permeability data is apparently totally lacking for these units. A strong hydrocarbon smell is present in outcropping Risdon Sandstone at Risdon, a suburb of Hobart after which the unit was named. Basal Permian conglomerates and tillites provide further potential.

Mudstones generally provide source rock or seal potential, but the Quamby Mudstone seemingly offers in addition to these, reservoir potential. The formation includes the organically very rich Tasmanites oil shales and, independent of the oil shales, could prove itself to be an effective source rock in places. Where seen in outcrop, the formation is highly fractured. The fracturing may very well have been induced by pressure unloading, resulting from uplift and erosion accompanying Jurassic and Tertiary deformation, or alternatively the formation may have been highly water saturated prior to uplift and the fracturing could therefore be related to shrinkage from de-watering. In the subsurface, the Quamby Mudstone does not appear to be commonly fractured, although fractures were observed in at least one shallow borehole (EHP Styx River) and gas appears to have flowed from the formation in the Douglas River borehole.

The mudstone has porosities as high as 30 percent as might be presumed from a fine grained rock, but matrix permeability would be expected to be very low. If there is sufficient fracture development within the unit in the subsurface, the matrix, if hydrocarbon saturated, would be expected to contribute significant volumes of hydrocarbon into the fracture network. Where encountered to date, however, in stratigraphic and water boreholes, the formation has not provided significant flows of water, suggesting the formation is generally poorly permeable.

SEALS

Intraformational seals are abundant within both the Lower Palaeozoic (Gordon Group) and Upper Palaeozoic (Parmener Supergroup) sequences. There has been, however, considerable concern that anticlines formed during the Tabberabberan Orogeny would have been breached during an extensive period of erosion which accompanied and followed the orogeny. The concern is that hydrocarbons generated during this time would have escaped to the Earth's surface, there being no effective vertical seals to hold any significant accumulations. The concern appears to be largely unwarranted.

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The thought process which generates the concern implies either that the vertical succession of pre-Permian rocks constitute one continuous, extensive and thick reservoir, or that all potential reservoirs have been breached. Both of these possibilities are very unlikely. The breaching of Devonian generated anticlines has been documented in outcrop, but the degree of breaching is expected to vary according to the relative position of structures in the basin and the degree of structural relief imposed upon the anticlines as a result of the orogeny.

Up to 420 metres of shale, siltstone and mudstone (Bell Shale) has been recognised at the top of the Eldon Group (Baillie 1939). Its original actual thickness is unknown but may have exceeded 1500 metres. This would provide a competent and conformable seal, where not entirely eroded away, for underlying reservoirs. It is quite possible and perhaps even probable, that the Bell Shale has been preserved on some of the lower relief anticlines in the centre of the basin. The formation is certainly present in synclines and on the flanks of anticlines over at least parts of Tasmania. Anticlines truncated beneath the Pre-Permian unconformity surface may form effective trapping mechanisms with the Bell Shale providing a lateral seal and Permo-Carboniferous tillites, and fine grained clastics providing the vertical (top) seal. Maturation modelling suggests that over much of Tasmania, the main phase of oil and gas generation from potential source rocks of the Gordon Group would not likely have been reached until after Permian deposition had commenced.

Late Permian and post Permian siltstones, shales and marls and Jurassic dolerites present imposing semi-regional top seals for the Parmeener Supergroup reservoirs.

STRUCTURE

Pre-Permian rocks are concealed across more than half of Tasmania and the described source rocks and reservoir rocks of the Gordon Limestone Group are rarely exposed where the Parmeener cover is absent. Pre Cambrian rocks are exposed in the west and Ordovician to Devonian turbidites are exposed in the northeast. Borehole data is limited to the east of the State and very few wells have fully penetrated the Parmeener Supergroup cover. Over much of the State, the geology of the pre Permo-Carboniferous sequence is unknown. Gravity and magnetics interpretations by Dr. D. E. Leaman indicates Ordovician to Devonian sediments to be present under a relatively thick Parmeener and Tertiary cover in central Tasmania.

Only a paucity of seismic data is available and the limited onshore record sections acquired have been of generally poor resolution. A high velocity surface layer coupled with stacked, near surface Jurassic dolerite sheets have made it very difficult to obtain good seismic data. Acquisition and processing problems associated with such difficult conditions are now being assessed and it is hoped that all major difficulties can be overcome. The inability to acquire good quality seismic data beyond the base Parmeener unconformity would be of considerable concern.

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Fair seismic data has already, however, been obtained in some locations with clear, albeit discontinuous, reflections being observed over many seconds of record. At one locality, records to two-way times of 11 seconds (mantle levels) were obtained. Most records, however, appear blind for times in excess of 300 - 900 ms, or below the base Parmeener Group Unconformity.

Gravity and magnetics, where properly integrated, have a proven record for subsurface structural assessment and are together ideal for targeting areas for more detailed (and considerably more expensive) seismic reconnaissance.

Preliminary and in places detailed gravity and magnetics analyses and interpretations have been made by Dr. Leaman for the eastern part of the State. Although much of Dr. Leaman's work remains provisional, the gravity and magnetics data in association with surface geology, has delineated several areas of particular merit, all of which include Silurian and/or Ordovician rock sequences. It is evident that pre-Devonian rocks are highly folded. Dr. Leaman's work has established large scale, basement involved thrust sheets. In some locations, rock sequences appear to be repeated more than once as a consequence of the thrusting. Overthrust structures have subsequently been established by drilling. Structures are complex and considerable work is required to sort the main features out. In western Tasmania, westward trending Devonian thrusts are interpreted to have overprinted pre-existing east facing thrusts.

Evidence is strong that Cambrian and Ordovician sequences have been preserved beneath the Upper Carboniferous unconformity in numerous locations and in places, Gordon Group carbonates are interpreted to be thick, particularly in synclinal positions. Interpretations indicate that in southern Tasmania, Ordovician - Devonian rocks overlap older Palaeozoic and Precambrian rocks and may be traced to outcrops of the Gordon Group in the Picton River area.

Descriptions in the literature suggest that Parmeener Supergroup (Permian - Triassic) sediments are essentially flat lying and undeformed. Generally speaking, and in comparing the Supergroup with the highly deformed and underlying Early Palaeozoic succession, this may be considered true. Nevertheless, Permo-Triassic sediments have been considerably deformed and effective trap mechanisms involving these sediments are expected.

Supratenuous folding (drape) of Permian sediments across on undulating pre-Permian unconformity surface would generate passive structuring through differential compaction of sediments. On a much larger scale, Jurassic compression resulted in extensive, large scale thrusting which involved Permo-Triassic sediments.

Structures formed during Devonian, Jurassic and other times were reactivated during periods of Tertiary movements.

The emplacement of massive igneous intrusions at various times throughout Tasmania's geological history further deformed the sedimentary sequence.

Tasmania appears to be a typical fold-thrust province. The interpretation by Leaman indicates that several minor and large

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scale thrusts are stacked and the entire overthrust system has been folded and intruded, and in places reactivated.

MATURATION MODELLING

In order to obtain at least some understanding of the maturation histories of potential source rock horizons in Tasmania, maturation modelling was conducted by Questa, using techniques similar to those introduced by Russian Geologist N. V. Lopatin in 1971. Models were constructed for two potential source rock intervals, the Gordon Group (Ordovician) and the Tasmanites oil shales (Permo-Carboniferous). Maturation modelling requires a knowledge of both the depositional (and erosional) and the geothermal history of a basin. Our current knowledge of these two entities in Tasmania is poor, but nevertheless, some meaningful findings have resulted from the modelling which has been performed.

The depositional history of onshore Tasmania remains clouded due to the considerable erosion which has taken place along basin edges, and the concealing nature of Tertiary and upper Permian sediments in the centre of the basin. Seismic coverage is almost nonexistent. There have been several periods of deformation which have affected the basin, but it remains uncertain as to how much sediment may have been removed through erosion during tectonic activity and through Permian glaciation. Questa is not aware of any complete or even nearly complete measured stratigraphic sequences in the basin. Gravity and magnetics along with measured outcrop intervals and a minimal amount of bore-hole information provide considerable insight regarding current stratigraphic thicknesses. It still remains difficult, however, to gauge the amount of sediment which may have been removed during the Tabberabberan Orogeny, the Cretaceous uplift and during the latter part of the Tertiary. Up to three (3) kilometres is suggested by Hills et al (APEA).

There is considerable indication to suggest that geothermal gradients in Tasmania have remained high since at least Devonian time and that there have been several major heating events, the most recent being during the Cretaceous. The degree and extent of these heating episodes remain largely unknown.

In most basins, a good impression of basin heatflow can be obtained through comparing results of maturation modelling with results obtained through quantitative geochemical analyses. One must first, however, have some knowledge of the depositional history of the basin.

Very little geochemical work has been carried out to determine the maturation of source rocks in Tasmania, certainly not enough to answer the required questions. The analyses which have been completed do, however, demonstrate that there is a considerable volume of potential source rock in Tasmania within the oil window and they also provide some standards on which to evaluate the results of maturation modelling.

Maturation modelling indicates that over much of Tasmania, source rocks within the Ordovician Gordon Group would not have reached the conditions required for significant generation and release of

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hydrocarbons until after deposition of a protective Permo-Carboniferous cover. Anticlines breached during the Tabberabberan Orogeny would most probably not have contained any significant volumes of oil or gas at the time of breaching. Modelling also supports the results obtained from direct geochemical analysis in indicating that the Tasmanites oil shales should be sufficiently mature for the generation and release of large volumes of oil over much of central Tasmania. The abundance of Type I algae Tasmanites punctatus in the Tasmanites oil shales suggests that oil would have been generated from this unit at relatively low temperatures. Conditions suitable for the main phase of oil generation and expulsion from Permian source rocks are interpreted to have been achieved during Cretaceous time.

Gordon Group source rocks, where overlain by a full sequence of Eldon Group and younger sediments, are probably matured beyond the wet gas preservation deadline and are therefore probably prospective only for dry gas (methane). In such situations, however, oil and wet gas generated from the Gordon Limestone while the intra-group source rocks were at shallower depths of burial, may have been preserved through upwards migration along fracture and fault planes and unconformity surfaces, into stratigraphically younger and less deeply buried rocks. Towards and on the edges of the main basin, the full post Gordon Group sedimentary sequence is not present and Gordon Group source rocks would consequently be less mature, and in places remain prospective for oil and wet gas.

PLAY CONCEPTS

As there are numerous and varied potential reservoir objectives and source rocks ranging in age from Pre-Cambrian to Triassic, as the geothermal history of source rocks, in particular those within the Gordon Group, varies considerably, both regionally and locally, across the State and as structuring of the stratigraphic sequence has been complex, there being at least three significant periods of structural deformation which affected the basin, many possible play concepts can be envisaged.

Both structural and stratigraphic hydrocarbon trapping mechanisms are foreseen. Conventional and simple closed anticlinal structures up to four kilometres long and involving Ordovician to Devonian carbonates and clastics, are believed to occur at the base of the Parmeener Supergroup unconformity. Similar or larger closures should be present beneath major thrust surfaces and these should include sequences of up to four kilometres in thickness. Where Gordon Group carbonates were folded, uplifted and exposed to the atmosphere during and immediately after the Tabberabberan Orogeny, palaeo-karst reservoirs may be expected beneath Parmeener Supergroup seals. Subconformity karsts and sandstones could provide significant hydrocarbon trapping potential.

Hydrocarbon trapping potential of Parmeener Supergroup sediments is seen where reservoir/seal pairs drape across Devonian induced horst blocks and other topographic highs.

Conventional anticlinal development is also seen in Parmeener Supergroup sediments, the result of Jurassic and Tertiary earth movements.

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Specific prospect definition will not, however, be possible until more knowledge about the subsurface stratigraphy of Tasmania is acquired and until better, more definitive, structural control is obtained. With perhaps the exception of the "seeps" themselves, there is insufficient geological information at this time to initiate or even to consider a wildcat drilling program. The origin of the hydrocarbons seen as "seepages" at fault exposures is unknown. Hydrocarbons may be migrating some considerable distances, both laterally and vertically along fault planes towards the earth's surface where they are revealed as "seeps". It is essential that boreholes be drilled specifically for the purpose of obtaining much needed information on source rock and reservoir quality, on the stratigraphic succession in general and on the structural configuration of the subsurface sequence. The positions of the proposed stratigraphic boreholes will be determined largely on the basis of reported hydrocarbon seeps and gravity and magnetic results. Stratigraphic drilling should considerably reduce the risk of future, more expensive, conventional, wildcat drilling.

Areas known to exhibit particular hydrocarbon potential are Johnson's Well on Bruny Island, Douglas River, and Ross in east central Tasmania. Sorrell, Hamilton and Southport are also of considerable interest.

Hackintosh Reid, the then Director of Mines, in 1929 confirmed oil and gas seeping into Johnston's Well on Bruny Island. The Tasmania Oil Company was formed to evaluate the origin of the "seepage" and a borehole was drilled. Upon drilling through a mudstone into a sandstone at 30 metres, the well is reported to have flowed oil and gas, the oil being collected into drums until all available were filled. Very little was known about the accumulation, but the well was abandoned and no further interest shown in the well until 1987, when samples of the mud around the well were analysed and traces of oil with an apparent Ordovician signature identified.

Condor Oil plans to drill a stratigraphic well east of the original "Murray" borehole. It is intended that the hole will be drilled in late 1992 to a depth of at least 700 metres and will penetrate the entire Parmesner Supergroup interval and may possibly, depending upon shows, maturation indications etc, be continued to intersect considerable Lower Palaeozoic section. As several stacked thrust sheets are interpreted to be present in the Bruny Island area, a very thick sequence of Upper Pre-Cambrian and Lower Palaeozoic rock is probable. There are no intentions to evaluate the full sequence. It is hoped that information will be obtained on source rock (in particular the Quamby mudstone - Tasmanites oil shales) quality and maturity and on reservoir distribution and quality.

Condor intends to follow up the stratigraphic drilling with a conventional petroleum exploration well. Condor have already acquired 260 kilometres of marine seismic data near Bruny Island and in Storm Bay. Although most of the data proved to be of very poor quality, a strong seismic event could be traced the length of one seismic traverse at a depth of about 2 seconds TWT - an implied depth of 3-4 kilometres. It is probable that additional seismic

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will be acquired offshore and possibly onshore Bruny Island, and the well drilled in late 1994 or early 1995.

Condor also plans to drill a stratigraphic borehole to further evaluate a flow of gas reported by D. E. Leaman, from a borehole which was being drilled through the Quamby Mudstone in a coal assessment well at the Douglas River bridge. Two seams of Tasmanites oil shale were identified (C. Calver et al, 1984) and free oil was observed in core. Analysis of the oil indicated it to be marginally mature. Should the results of a stratigraphic well prove encouraging, a conventional oil exploration well will be drilled to assess production potential.

Condor also intends to drill (tentatively 1993-1994) a stratigraphic evaluation well, 20 kilometres to the west of the Ross No. 2 borehole, to evaluate source (in particular the Tasmanites oil shales) maturity and quality and reservoir potential at that location. The Ross No. 2 well was drilled in 1985 by the Department of Mines to a depth of 480 metres. Core recovered from the hole revealed small amounts of live oil upon cutting and a Tasmanites horizon was identified at 410 metres.

It would be premature to consider the actual drilling of petroleum exploration (wildcat) wells before 1994-1995.

There is considerable evidence to suggest that the most prospective part of Tasmania for oil and gas will be the east central part (Central Plateau) of the State. The evidence comprises gravity and magnetic data and extrapolations of surface geology. There is, however, absolutely no subsurface information for this part of the State. No boreholes have been drilled, even to shallow horizons. Condor intend to drill as a priority, several stratigraphic wells in central Tasmania, to evaluate the hydrocarbon potential of this promising area. The first of these wells is scheduled for early 1993. An abundance of "seeps" provides optimism for commercial accumulations of oil (and gas) in the subsurface, and it is hoped that the stratigraphic and other geological information to be obtained from stratigraphic drilling, coupled with gravity and magnetic interpretations and seismic data, will provide considerable insight as to where these accumulations might be positioned. Results of the stratigraphic drilling in this part of Tasmania may prove to be discouraging but Questa is confident results will be positive and will lead to the drilling of a petroleum exploration well.

Borehole information is essential, not only to provide stratigraphic, geochemical and structural information, but also to provide control points for seismic velocity information. Processing of acquired seismic has been hampered in part by a lack of subsurface velocity knowledge.

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NEAR- SURFACE DOLERITES AND OTHER IGNEOUS INTRUSIONS

Near surface dolerite intrusions and feeder dykes have perhaps more than anything else discouraged oil and gas exploration in Tasmania. Several thousand cubic kilometres of magma formed what might be perceived as a nearly continuous body through the Permian and Triassic sediments over almost all of the State. Up to three dolerite sills have been recognised within the Permian Supergroup sequence, the lowest of these being located near the pre-Permian unconformity.

The Jurassic dolerites reflect considerable seismic energy in the upper surface, leaving predominantly low frequency energy to define structurally deeper horizons. Reflector shadows appear beneath the dolerites. The high velocity inherent to the dolerites along with topographic effects, impose considerable static difficulties. Seismic processing problems are being assessed. It is simply a matter of not being able to see (seismically) through the dolerite bodies which may each be as thick as 200 - 350 metres. The problem can theoretically be overcome through sophisticated seismic processing and acquisition techniques.

Expert gravity/magnetics interpretation can resolve where the dolerites are of least significance and this will assist the location of both future seismic lines and well locations.

Stocks of porphyritic syenite and a radial dyke system of various porphyries occur at Port Cygnet and are thought to be of Cretaceous age. Tertiary basalt flows are common throughout Tasmania with sheets up to 300 metres in thickness.

The abundance of igneous intrusions and volcanic sediments throughout the stratigraphic sequence across much of Tasmania is on first impression discouraging, but the major portion of the sedimentary section appears to have been relatively unaffected by the volcanics, contact metamorphism being of minimal extent. It may be viewed that the high heat flows associated with the intrusions were necessary to bring Permian source rocks to a state of organic maturity and the intrusions themselves would have generated structures capable of trapping migrating hydrocarbons.

CONCLUSIONS

Tasmania is prospective for oil and gas; there is no longer any reason to say otherwise. Although it remains uncertain as to whether or not significant hydrocarbon accumulations will ultimately be found, evidence suggests that there is a very good chance that commercial accumulations of oil and gas are present in the subsurface. A carefully planned and methodical exploration program should reveal optimum drilling locations and hopefully identify accumulations of significance.

Onshore Tasmania appears to have all of the criteria of a potential hydrocarbon province. Organically rich, oil prone source rocks have been identified and analysed geochemically. The Tasmanites oil shales are of particularly good source rock quality and there is very good evidence that potential source units lie within the oil window across much of Tasmania. Considerable work remains to

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be carried out on reservoir distribution and quality, but several potential, porous reservoirs have already been identified. Permeability relationships must still be verified. The integrity of seals has been challenged many times in the past, but there appear to be an abundance of seals. Structures have not been adequately defined, there being very limited seismic control in Tasmania, but the Tasmania Basin (in particular the Early Palaeozoic basin which underlies it) appears to be a typical thrust-fold province which should offer a broad spectrum of structural and stratigraphic trapping possibilities. Maturation modelling indicates that structures were formed prior to the primary periods of peak oil and gas generation.

Numerous past reportings of oil and gas seepages provide considerable encouragement and small volumes of oil and gas have been recovered from shallow boreholes. What appears to be the most prospective region of Tasmania, the central (Derwent Valley) part of the State, has not been penetrated by a well bore, not even in the near surface.

Even small accumulations of oil and/or gas would prove to be commercially attractive in Tasmania, as distances to potential markets and ports are nowhere large and land access is very good.

Before a well can be drilled with the primary objective of finding a commercial hydrocarbon accumulation, boreholes must be drilled to obtain stratigraphic, structural and geochemical information. Without such information, petroleum exploration wells could prove to be of very high risk and petroleum exploration wells are considerably more expensive than stratigraphic boreholes.

The biggest risk in exploring for oil and gas in onshore Tasmania appear to lie in the ability to acquire meaningful seismic data which will define the structural configuration of the subsurface.

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GLOSSARY OF GEOLOGICAL TERMS

Aeromagnetic Survey:	Magnetic observations made from a specially equipped aircraft. Provides information on subsurface configuration.
Anticline:	A fold in layered rocks in which the strata slopes down and away from the axis.
Back Reef:	Depositional environment between a reef and the shoreline.
Basement:	Non prospective rocks underlying a sedimentary basin.
Basin:	A segment of the earth's crust which has downwarped and in which sediments have accumulated.
Bioherm:	A mound-like mass built exclusively or mainly by sedimentary organisms such as corals, etc. Often contain important hydrocarbon accumulations.
Carbonates:	Sedimentary rocks composed mainly of calcium carbonate (e.g. limestone and dolomite).
Cambrian:	The oldest geological period of the Palaeozoic Era corresponding to approximately 500 - 570 million years ago.
Closure:	An upwardly confined, three dimensional configuration of strata; generally implies capable of hosting an accumulation of oil and/or gas.
Conglomerate:	Rounded, water-worn fragments of rock or pebbles cemented together by another mineral substance which may be of siliceous or argillaceous (clay rock) nature.
Conodont:	Microscopic phosphatic tooth-like structures from probable vertebrate which ranged from Cambrian to Jurassic time.
Core:	A cylindrical sample of rock obtained when drilling a bore hole, through the use of a hollow drilling bit.

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Cretaceous:	Geological period corresponding to approximately 65 - 135 million years ago.
Devonian:	Geological period corresponding to approximately 345 - 395 million years ago.
Dolerite:	An igneous rock also known as diabase.
Dolomitization:	The process whereby limestone becomes dolomite by the substitution of magnesium carbonate for a portion of the original calcium carbonate, thereby becoming porous.
Evaporites:	Sediments deposited from an aqueous solution through evaporation (e.g. sodium chloride and gypsum).
Exinite:	Organic constituents comprising plant spores and cuticular matter considered to be capable of forming oil.
Exploration Well:	A well drilled to discover whether a previously untested trap contains oil or gas - often called a wildcat well.
Facies:	The aspect of belonging to a geological unit of sedimentation including mineral composition, type of bedding, fossil content, etc.
Fault:	A break in a body or layers of rock across which there has been some vertical or lateral displacement.
Fluvial:	Pertaining to a river.
Fold:	The bending of strata, usually as the result of compression.
Formation:	The basic unit for the naming of rock units in stratigraphy.
Graben:	An elongate downthrown block between parallel faults; antonym is horst.
Graptolite:	Extinct colonial organism.
Gravity Survey:	Airborne or ground survey over a grid, using instruments which measure variations in the magnitude of the earth's gravitational field.

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Mature Source Rocks:	Rock containing organic material and considered able to release liquid or gaseous hydrocarbons which have been generated from within.
Metamorphic:	Pertaining to rocks which have formed in the solid state in response to pronounced changes in pressure, temperature and chemical environments.
Migration:	The movement of hydrocarbons within sedimentary rocks.
Oil Seep:	A natural flow of oil to the earth's surface.
Ordovician:	The second geological period in the Palaeozoic Era, corresponding to approximately 435 - 500 million years ago.
Orogeny:	Profound deformation of rock bodies along restricted zones and within a limited time interval; essentially mountain building.
Outcrop:	That part of a rock unit occurring at the surface of the earth.
Overthrust:	In a position overlying a thrust fault plane.
Palaeozoic:	A geological era comprising the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian periods and corresponding to approximately 225 - 570 million years ago.
Permeability:	The degree to which fluids (such as gas and oil) can move through a reservoir rock - measured in darcies or millidarcies.
Permian:	Geological period corresponding to approximately 225 - 280 million years ago.
Phyllite:	A rock containing appreciable clay and which is intermediate in metamorphic grade between slate and schist.
Porosity:	A measure of the free pore space of voids in a reservoir rock compared with the total rock volume.

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Prospect:	A geological feature in which there is thought to be the potential for oil or gas accumulation.
Quartzite:	A granulose metamorphic rock consisting essentially of quartz.
Regressive:	Applies to sediments deposited during the relative lowering of sea level.
Reservoir:	A permeable sedimentary rock containing adequate pore space to provide storage room for fluids such as oil, gas and water.
Rock Eval Pyrolysis:	A standardised geochemical technique of pyrolysis used to indicate source rock potential.
Seal:	An impervious layer of rock over a reservoir which prevents escape of fluids from the reservoir.
Sedimentary Rocks:	Rocks formed by the accumulation on land or in water of mineral or skeletal particles.
Seismic:	A method of geophysical prospecting involving the generation and recording of reflected sound waves to determine the structure and depth of sedimentary layers.
Shows:	The detectable presence of hydrocarbons observed during the drilling of a well - not necessarily indicative of a commercial accumulation.
Sill:	An intrusive body of igneous rock of approximately uniform thickness and relatively thin with respect to lateral extent which has been emplaced parallel to the bedding of host rocks.
Static (Seismic):	Interferences with acoustic and seismic waves.
Stratigraphic Well:	A borehole drilled solely to obtain subsurface information on sediments, structure, organic maturity, etc. Usually a small diameter borehole.
Syncline:	A structure in which strata are folded into a concave upwards, trough like form.

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Source Rock:	An organic rich sedimentary rock which is capable of generating hydrocarbons under optimum maturation conditions of temperature and time.
Stratigraphic Traps:	Type of trap where hydrocarbons are enclosed as a result of a change in rock from porous/permeable to non permeable.
Stratigraphy:	That part of geology dealing with the subdivision, composition, age and correlation of sedimentary rocks.
Tectonic:	Pertaining to structural movements of the earth's crust.
Tertiary:	Geological period corresponding to approximately 3 - 65 million years ago.
Thrust Fault:	A fracture characterized by a low angle of inclination which results in the emplacement of older strata above younger strata.
Total Organic Carbon (TOC):	A measure of the relative organic richness of a potential source rock.
Trap:	A body of reservoir rock, vertically and laterally sealed, the geometry of which allows it to retain hydrocarbons should they migrate into it.
Triassic:	Geological period corresponding to approximately 195 - 225 million years ago.
Turbidite:	Sediments deposited in deep water by the process of gravity sliding off the continental shelf.
Unconformity:	A surface of erosion or non deposition, usually the former, that separates younger rocks from older rocks.
Vitrinite Reflectance:	A technique of measuring degree of organic maturity.
Volcanogenic:	Produced by volcanic activity or derived from previously deposited volcanic products.

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QUALIFICATIONS

Questra Australia Pty Ltd (Questra) was formed in Adelaide, South Australia in 1969 and has operated since that time as independent consultants to the oil and gas industry.

Questra is a well known and respected petroleum consultancy group which specialises in oil and gas field evaluations (reserves, deliverability, development, economics). Much of Questra's work has been carried out for State Government Energy Groups and for lending institutions.

The geological report included in this Prospectus was prepared by G. E. Carne; a Director of Questra. Mr. Carne graduated from Queen's University in Kingston, Ontario, Canada in 1971 with a Bachelor of Science degree, receiving First Class Honours. He worked as a petroleum geologist for major and junior companies in Canada, Indonesia and Australia before becoming a consultant in 1984. He has had considerable experience in sedimentary basin analysis, in particular in frontier areas of Canada and Indonesia.

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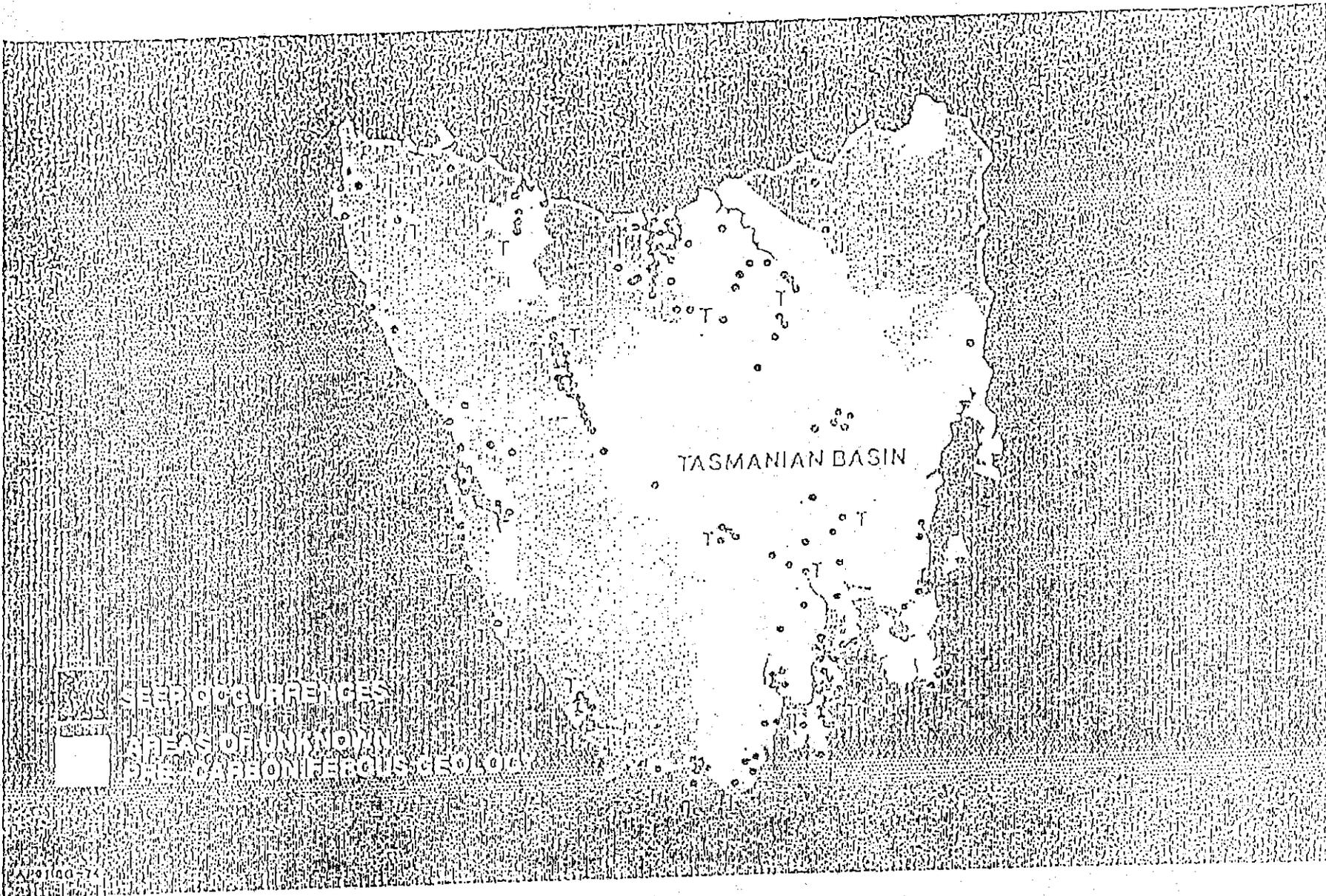
DISCLAIMER

Questa has relied on published documents which for the most part, originated from Condor Oil, and on discussions with senior professionals involved in the "oil search" in Tasmania, to formulate the ideas and conclusions contained in the above geological report. Questa has no first hand experience with the geology of the State of Tasmania. We have relied on geochemical, petrophysical and geophysical analysis carried out by others, to form the basis of our report. Questa have no reason to doubt the expertise, the motives or the credibility of those concerned and accept the data used in the report as being factual.

Gerry Carne, the primary author of the Geological Report, has made three trips to Tasmania during the course of preparing this Prospectus, holding discussions with key government and industry professionals and officers and carrying out a brief but enlightening geological reconnaissance of certain parts of the State.

Drafts of this geological report were critically reviewed by Mr. Peter Baillie, Petroleum Geologist with the Tasmanian Department of Mines, by Dr. J. K. Volkman, a Chemical Oceanographer and Geochemist with CSIRO, by Dr. D. E. Leaman, a consultant Geophysicist based in Tasmania and by Mr. M. R. Bendall, a Geologist and a Director of Condor Oil. Errors in factual content contained in draft versions of this report and pointed out by the above professionals, have been corrected.

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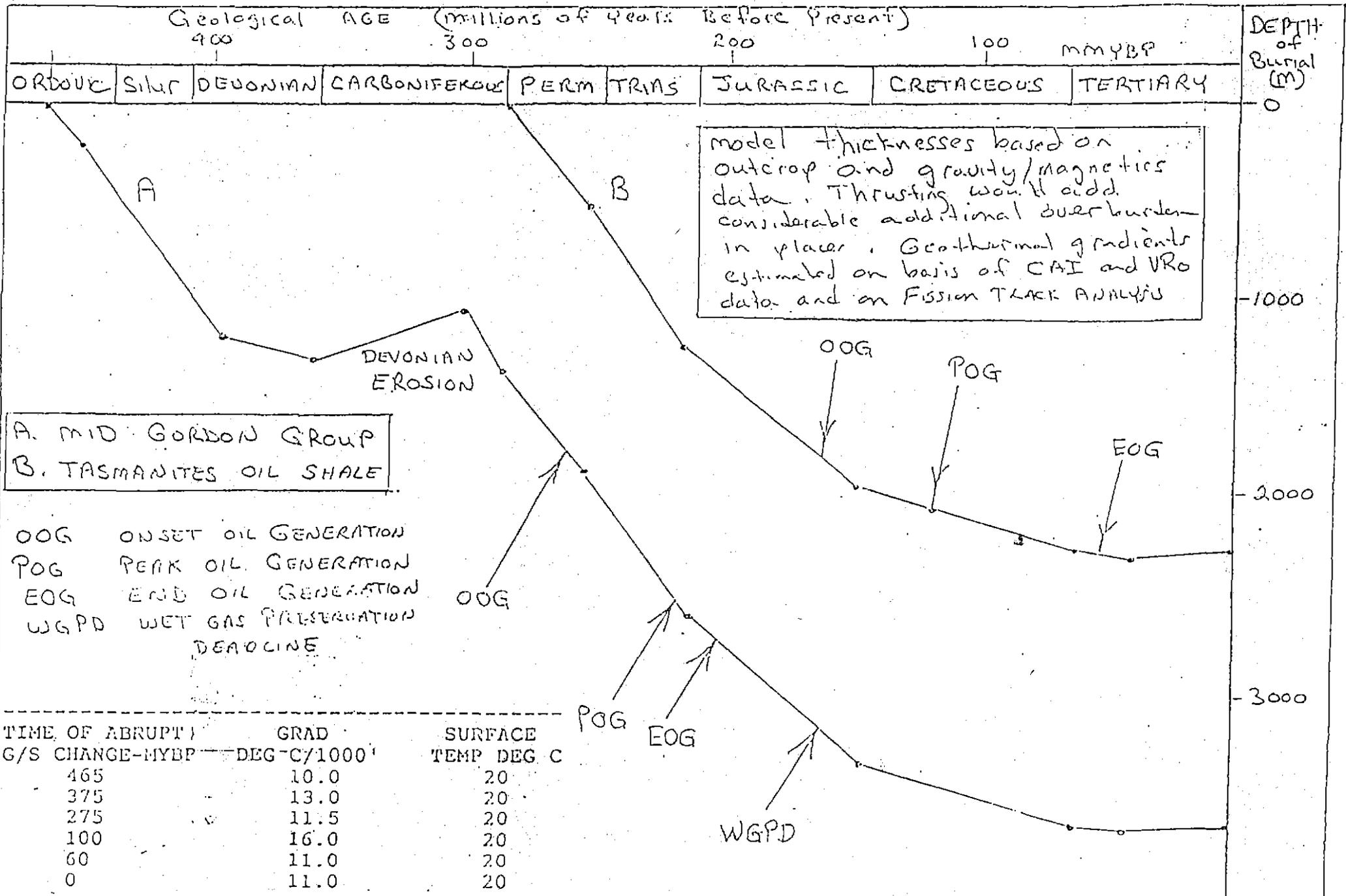
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Appendix

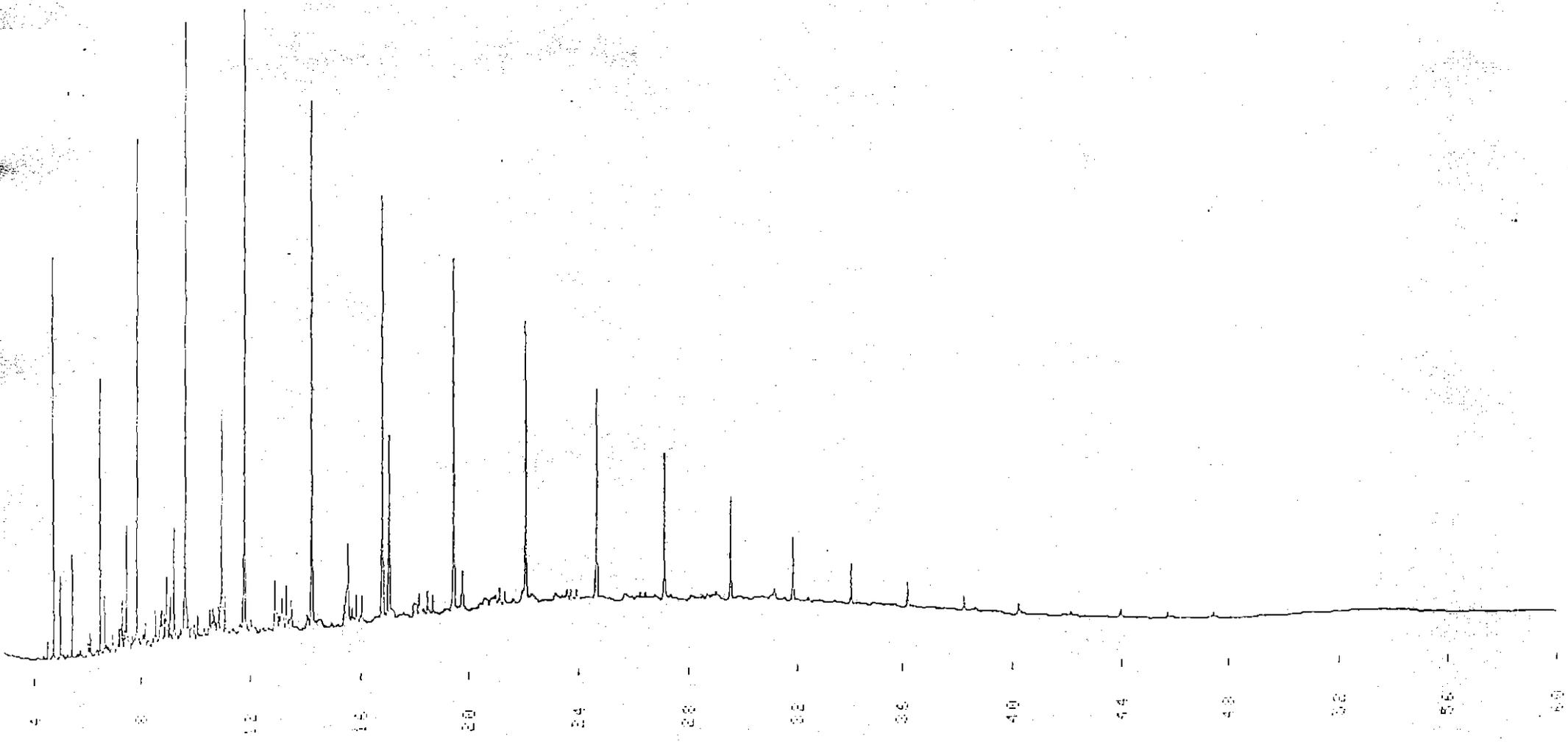
1. Maturation model.
2. GCMS graph (per CSIRO Hobart).

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Burial History and maturation model of idealized TASMANIAN SEDIMENTARY

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REPORT 93-CONDOR-1

HYDROCARBONS AND GAS IN WATER SAMPLES FROM THE BICHENO
BOREHOLE: COMPARISON WITH TASMANITE OIL SHALE

Prepared by: A.T. Revill and J.K. Volkman
CSIRO Division of Oceanography

Prepared for: Condor Oil Investments Pty. Ltd., Tasmania
Trading as Condor Oil Investments Unit Trust No. 1

Attention: Mr. Malcolm Bendall

March 4, 1993



INTRODUCTION

In 1978, a fully-cored diamond borehole was drilled near Douglas River north of Bicheno in Eastern Tasmania (Fig. 1) as part of a study related to coal exploration in the region (Leaman and Richardson, 1981). The borehole had a diameter of 45 mm and penetrated to a depth of 533.8 m terminating in the Siluro-Devonian Mathinna beds (Calver *et al.*, 1984).

The top 100 m of the core consisted of Triassic sediments and coal seams. Below this, Permian Upper Marine, Lower Freshwater and Lower Marine Sequences were penetrated. At 321 m, a black shale rich in fossil remains of the alga *Tasmanites punctatus* was encountered (Fig. 2).

A sample of the *tasmanite* oil shale was obtained from the core store of the Tasmanian Department of Minerals and Energy and subjected to Rock-Eval and organic geochemical analysis to assess its petroleum source potential and thermal maturity. A summary of the results are provided here.

In January, 1993 Mr Malcolm Bendall revisited the drill site and opened the hole which had become covered with soil and plant debris. He noted that water and gas were escaping from the hole and samples of these were obtained for analysis. An oily sheen was noted on the water and the gas could be ignited. The presence of gas had previously been noted by the drilling operator and Dr David Leaman when the borehole was first completed. The hole was full of water at the time and drilling had stopped so it was not clear at what depth the gas was entering the hole (D. Leaman, pers. comm.).

SAMPLES

This report presents the results from the analysis of three water samples and one gas sample from the borehole north of Bicheno, Tasmania. These data are compared with extracts from the *Tasmanites* band from the borehole, and with other samples from on-shore Tasmania.

One water sample (CSIRO sample No. 93-004) was provided by Mr. Malcolm Bendall in a 300 mL "Coke" bottle which also contained abundant remains of plant material. Two subsequent samples (CSIRO sample Nos. 93-005 and 93-006) each of 4 litres, were collected by Dr. John Volkman and Dr. Andrew Revill of CSIRO directly from the borehole into pre-cleaned winchesters on 22nd January 1993. The first sample appeared to contain a "waxy" scum whilst the two larger samples exhibited a surface sheen. The gas sample was collected by Mr. Malcolm Bendall on the same date.

ANALYSIS

Sample 93-004 in the "Coke" bottle was topped-up with pure Milli-Q water and allowed to settle. The waxy scum was then removed along with some water (ca. 6 mL) by pasteur pipette into a centrifuge tube, shaken with hexane (2 mL), centrifuged (5 minutes @ 1800 rpm) and the solvent removed. This process was repeated and the solvent layers combined and reduced under a stream of nitrogen to ca. 1 mL. The total extract was then analysed by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS).

Sample 93-005 (the first 4 L sample) was analysed in a similar way to 93-004 except that a mix of hexane/chloroform (4:1) was used as the solvent system. Analysis of sample 93-006 (repeat 4 L sample) involved extraction of subsequent aliquots of the water (ca. 800 mL) with chloroform (2 x 40 mL). The combined solvent fractions were reduced by rotary evaporation (Buchi, 25 °C), transferred to a vial and further reduced under nitrogen. These samples were analysed by GC and GC-MS.

The gas sample was transported by hand to Dr. Roger Summons at AGSO, Canberra by an agent of Mr. Malcolm Bendall for analysis of composition and isotopic values.

RESULTS

Hydrocarbons in the Tasmanite oil shale from the Bicheno Borehole core.

Rock-Eval analysis of the *Tasmanite* oil shale from the Bicheno bore hole core showed that it contained abundant organic matter (17%), which was hydrogen-rich (HI index of 868). This is typical of kerogen derived from oil-prone algal organic matter (Table 1). *Tasmanite* oil shales from Oonah and Latrobe in the north of Tasmania tend to have higher organic matter contents, but they are less thermally mature.

The shale has excellent potential for generating hydrocarbons (S₂ of 147.5 kg/tonne), and based on the T_{max} value it is within the early stage of the oil window.

Table 1. Rock-Eval parameters for *Tasmanite* oil shale from Bicheno Borehole

T_{max} (°C)	S1 (kg/Tonne)	S2 (kg/Tonne)	S3 (kg/Tonne)	S_2/S_3	TOC (% whole sample)	Hl	OI	%CO ₃
446	6.28	147.5	0.15	983.5	17	868	1	10.7

Free hydrocarbons were also abundant in the oil shale (S1 of 6.28 kg/tonne). These were extracted and shown to have a high proportion of aliphatic hydrocarbons (63%; Table 2). The extractable organic matter figure of 290 mg per 50 g extracted (i.e. 5.8 kg/tonne) is only slightly less than the S1 Rock-Eval value presumably due to loss of some lighter hydrocarbons during the extraction step.

Table 2. Composition of solvent extract of *Tasmanite* oil shale from Bicheno Borehole

Amount Extracted (g)	EOM (mg)	Aliphatics (%)	Aromatics (%)	Polars (%)
50	290	63	27	10

EOM: extractable organic matter

The hydrocarbons were analysed by gas chromatography which revealed a distribution of *n*-alkanes showing no odd or even chain-length preference and maximizing at *n*-C₁₃ (Fig. 3), which is typical of the distributions of thermally-mature hydrocarbons found in most crude oils.

Analysis of water samples by gas chromatography

GC analysis of the total extract from sample 93-004 yielded an *n*-alkane distribution superimposed on an unresolved complex mixture (UCM) combined with a prominent group of apparently non-hydrocarbon compounds (Fig. 4a). This latter group of compounds was thought to be contamination, possibly from the sealant used prior to taking the water sample (as reported by Mr. Malcolm Bendall). With this in mind, the sample was passed through an activated silica gel column which removed these compounds (Fig. 4b). This distribution is similar to that from a weathered "light" crude oil, but this may also indicate a refined product such as "heavy" diesel i.e. the lack of compounds below C₁₁ and a maximum at *n*-C₁₅ (Fig. 4).

However, the knowledge that this sample had been contaminated introduced doubt as to the authenticity of the hydrocarbon distribution necessitating re-sampling at a later date to allow sufficient water washing of the source of the contamination.

Analysis of the two bulk samples (93-005 and 93-006) yielded hydrocarbon distributions (Fig. 5) dominated by broad UCMs with the resolved compounds corresponding mostly to isoprenoidal compounds. The overall distribution of hydrocarbons in these samples is consistent with that expected from heavily biodegraded crude oil. Note that these hydrocarbon distributions are in marked contrast to the *n*-alkane distribution in sample 93-004.

The total amount of extract was *ca.* 2-4 mg from 4 L of water. This figure was derived from the concentration required to obtain reasonable gas chromatograms, rather than by direct measurement, since the quantity was too small to determine with any accuracy by other means. This value is in contrast to typical oil production waters which have an oil content of *ca.* 30 mgL⁻¹

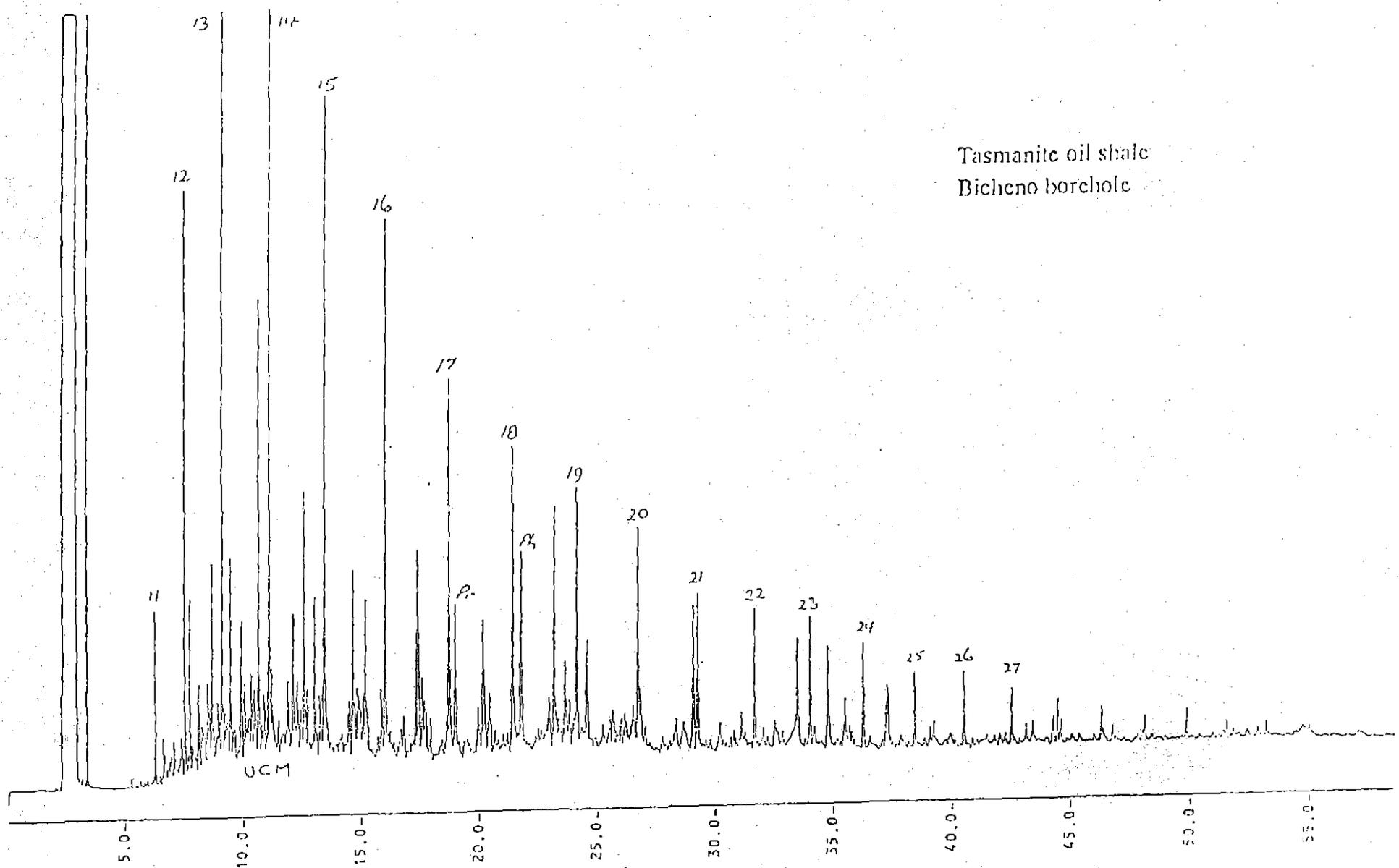


Figure 3. Aliphatic hydrocarbons from the tasmanite oil shale band in the Bicheno borehole core. Numerals refer to carbon number of n-alkanes; Pr: pristane; Ph: phytane; UCM: unresolved complex mixture.

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93-004

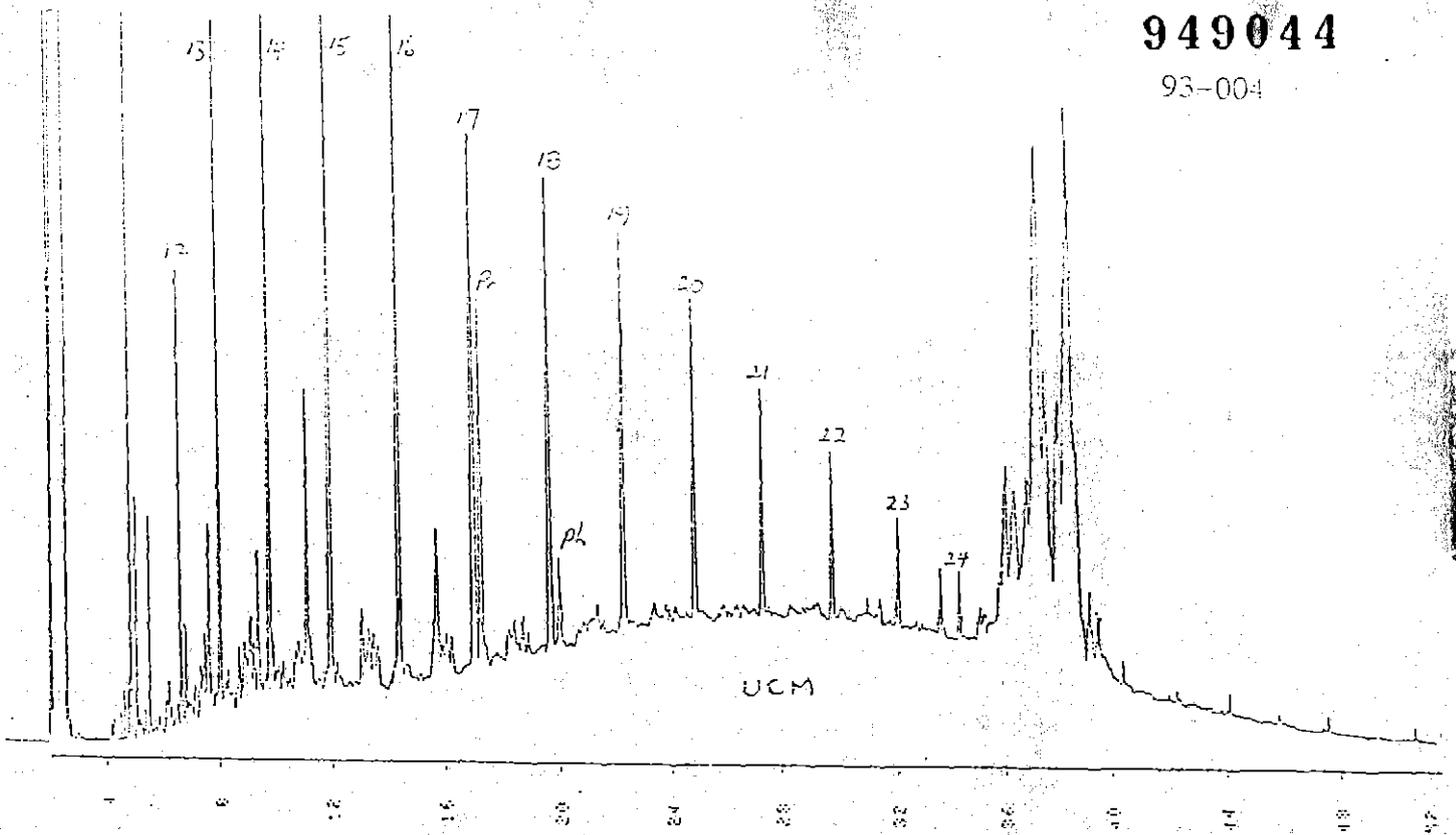


Figure 4. (a) Capillary gas chromatogram of total extract from water sample 93-004 before column chromatography. Numerals refer to carbon number of n-alkanes; Pr: pristane; Ph: phytane; UCM: unresolved complex mixture.

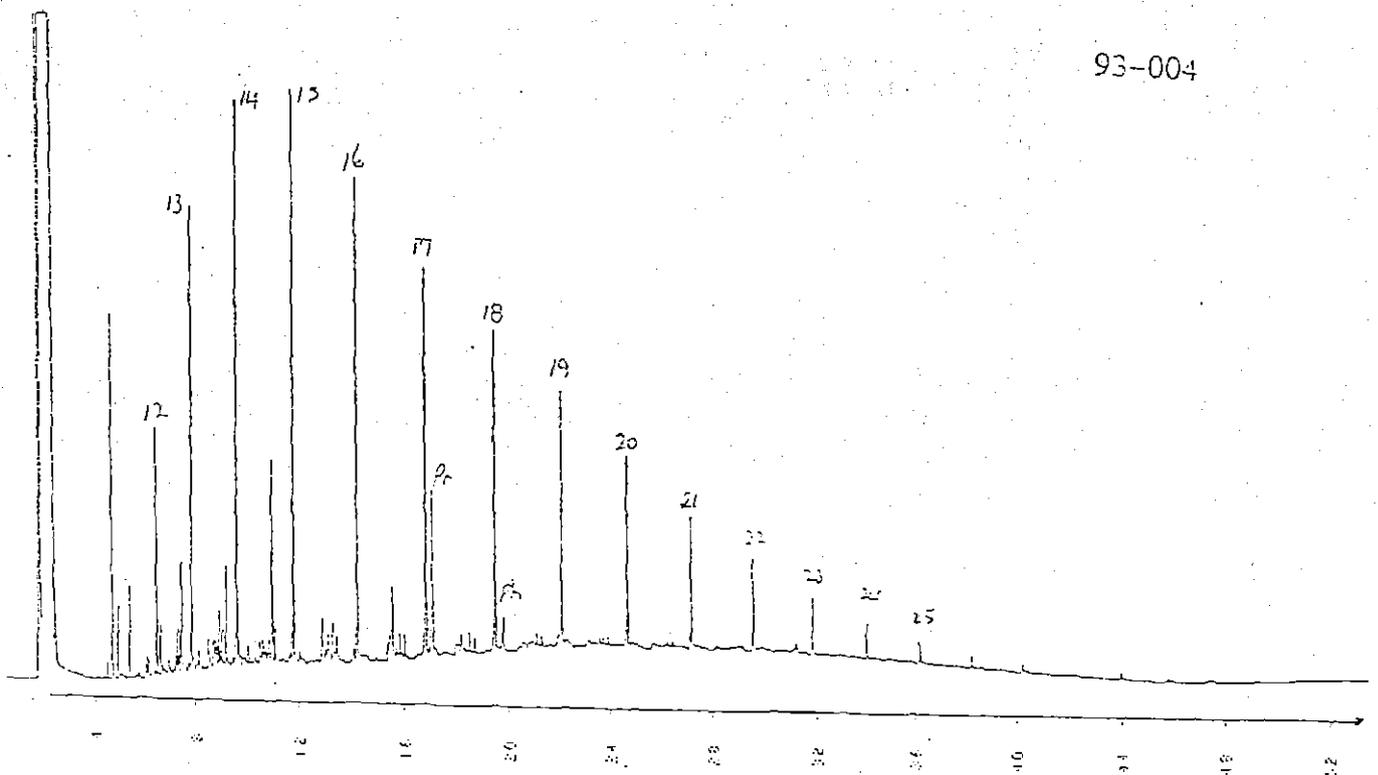


Figure 4. (b) Capillary gas chromatogram of total extract from water sample 93-004 after column chromatography to remove contaminants.

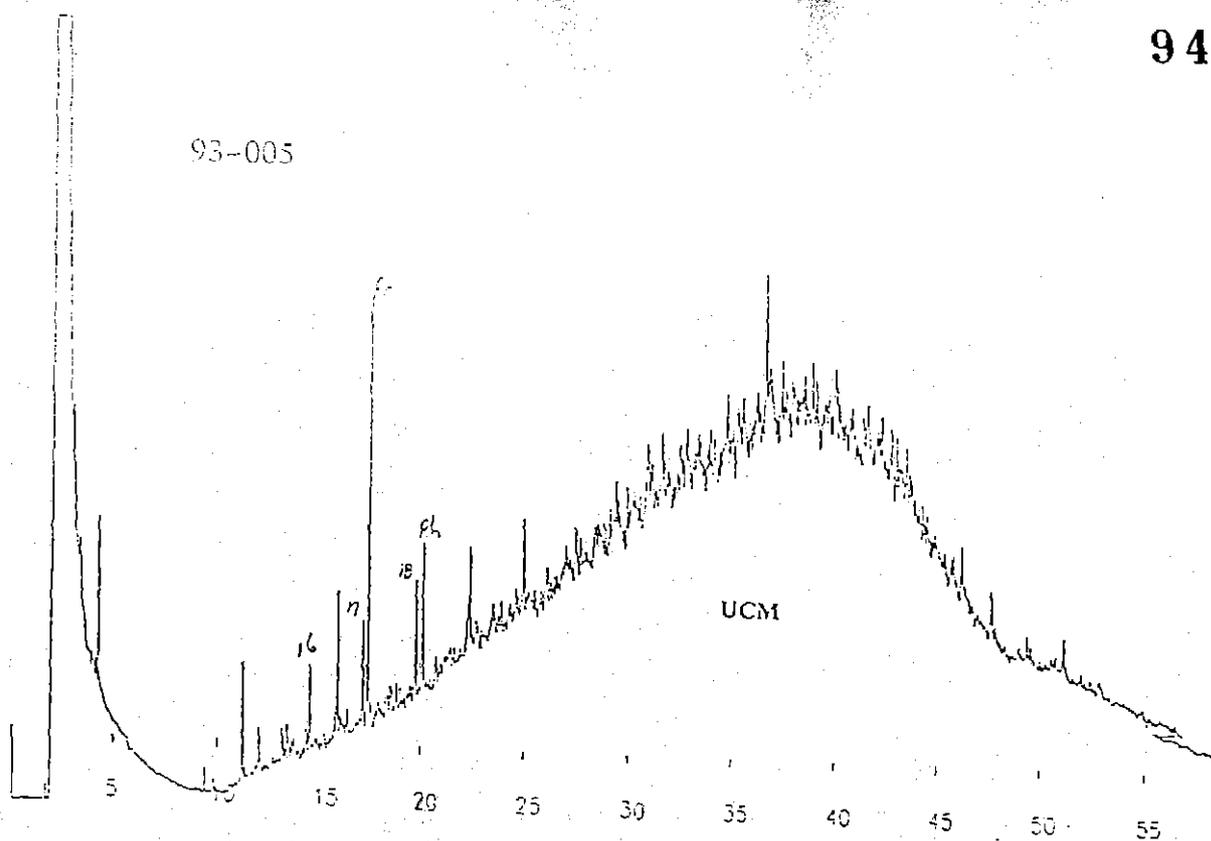


Figure 5 (a). Gas chromatogram of total aliphatic hydrocarbons in water sample 93-005. Pr: pristane; Ph: phytane; UCM: unresolved complex mixture.

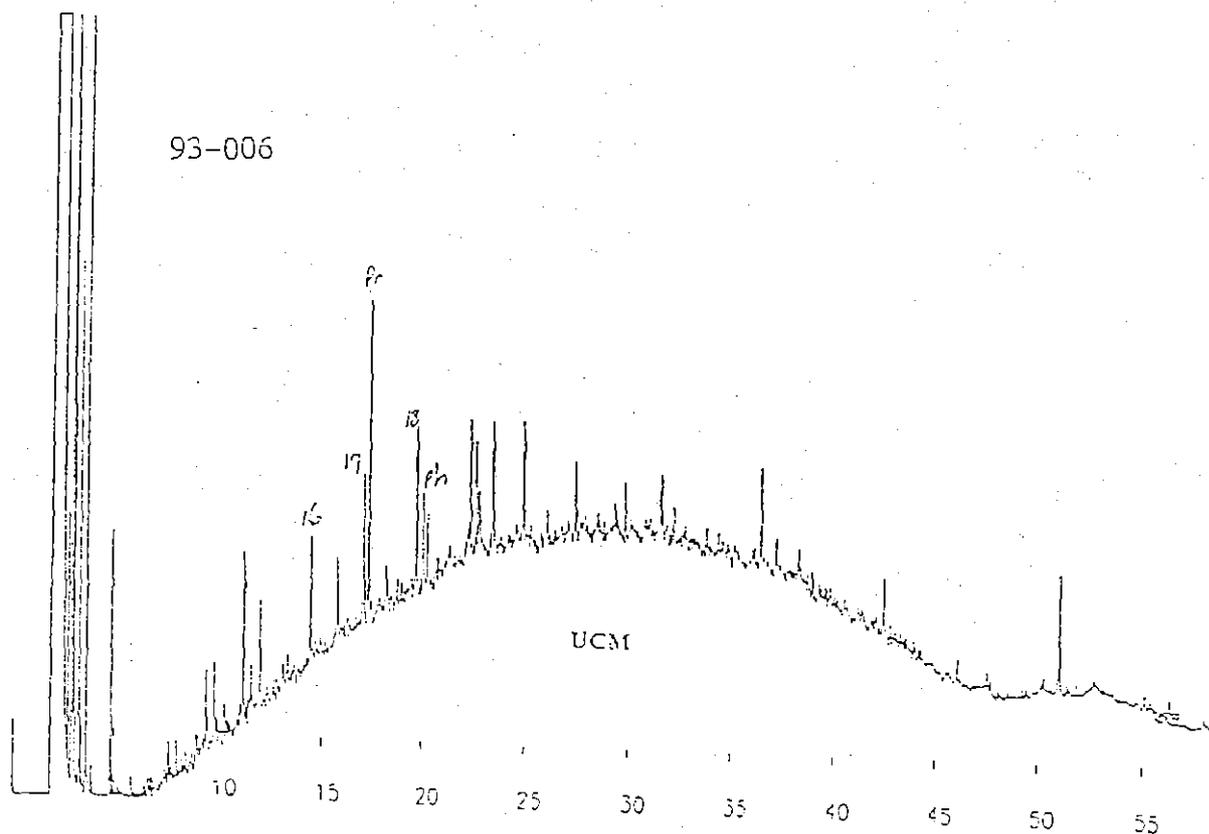


Figure 5 (b). Gas chromatogram of total aliphatic hydrocarbons in water sample 93-006. Pr: pristane; Ph: phytane; UCM: unresolved complex mixture.

Biomarker analysis of water samples

Analysis of hydrocarbon biomarkers can often yield information about the source and maturity of an oil. Figure 6 shows the m/z 191 mass fragmentogram for biomarkers from the three samples. Figure 7 is included to show the distributions of these compounds in a previously analysed Permian sample from Poatina and the Bicheno core *Tasmanites* sample. All samples exhibit similar compound classes (tricyclic and hopane derived compounds), but in varying relative amounts which is taken to suggest at least two and possibly more sources for the hydrocarbons in the samples. All the distributions suggest a thermally mature oil as the source of the hopanes.

Tricyclic compounds

Tricyclic alkanes are more abundant than hopanes in sample 93-004 (based on peak areas in the m/z 191 mass fragmentograms), approximately equal in abundance in 93-006 and relatively minor constituents in 93-005 (Fig. 6). However, the relative proportions of individual compounds within the tricyclic alkane distribution is relatively constant in the 3 samples. In each case the C_{23} compound is dominant which is in contrast to the *Tasmanites* sample analysed from the original core, in which the C_{21} , C_{23} and C_{24} compounds dominated (Fig. 7). However, this distribution is similar to that seen in the Permian mudstone from Poatina (Fig. 7; Volkman and Holdsworth, 1989).

Hopanes

The hopane distributions in each sample again remain relatively constant, irrespective of the amount present compared with the tricyclic compounds (Fig. 6). Of interest in these distributions is the relative amounts of the C_{29} and C_{30} compounds. In each case the peak due to C_{29} is greater than C_{30} which is in stark contrast to the distributions observed in samples from either the Bicheno core or the Permian mudstone from Poatina (Fig. 7). This ratio is consistent with that observed in oils from carbonate source rocks (such as those from the Middle East) and is similar, though not identical, to that seen in samples of Ordovician limestone from Tasmania (Volkman, 1988).

There is slight evidence for the presence of methyl hopanes (m/z 205, Fig. 8) in the samples, but this is inconclusive. These compounds have previously been found in Ordovician limestones from Tasmania and overseas (Volkman, 1988). However, examination of the m/z 205 mass fragmentogram suggested the presence of an unusual compound eluting after the C_{31} hopanes (Fig. 8). This compound was also detected in the m/z 218 mass fragmentogram and the mass spectrum suggests an "oleanane" type of compound. These types of structures have only been detected from the Cretaceous onwards corresponding to the evolution of the higher plants and are taken to be indicative of this type of organic matter. The absence of this compound in sample 93-004 is taken to be indicative of a functional group within the compound since this sample was passed through a silica gel column which would remove compounds with any degree of polarity. The mass spectrum is similar to that of a compound with a keto group, which suggests an immature source.

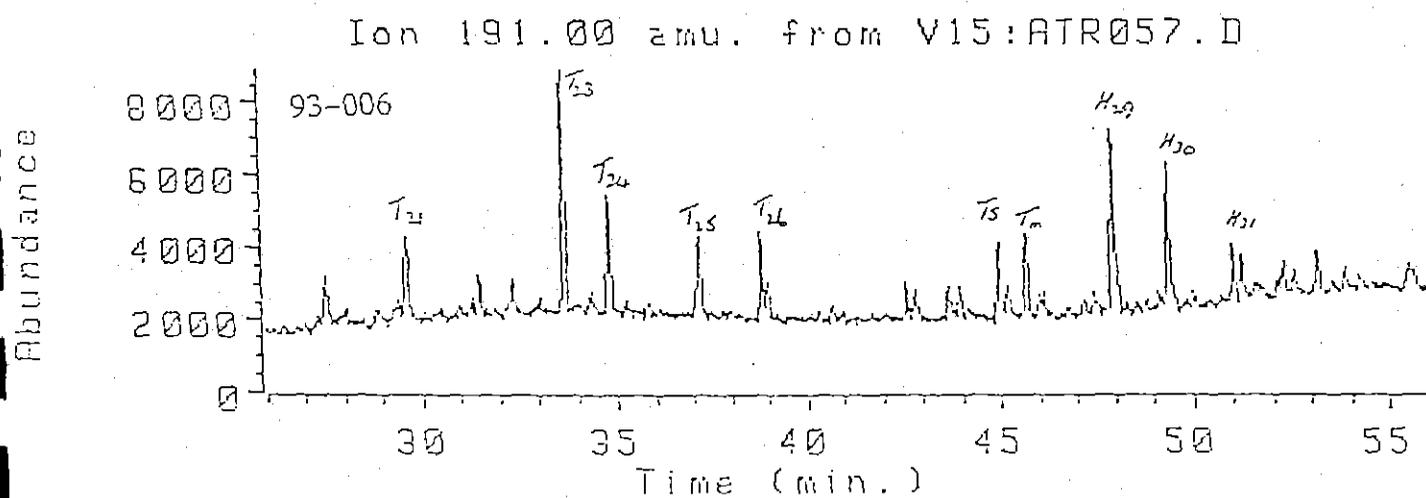
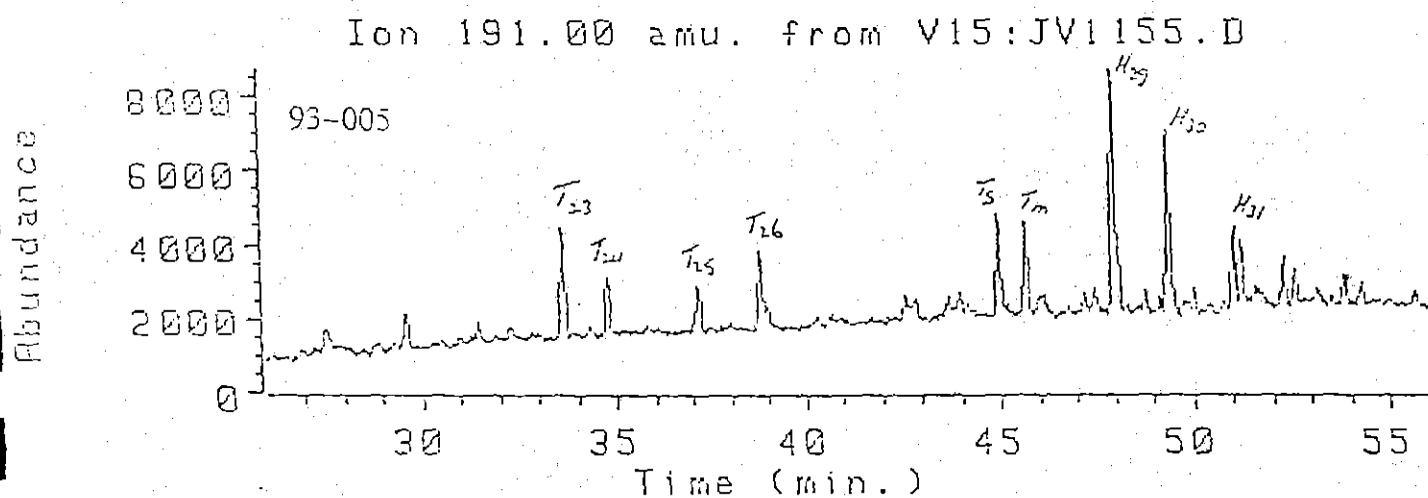
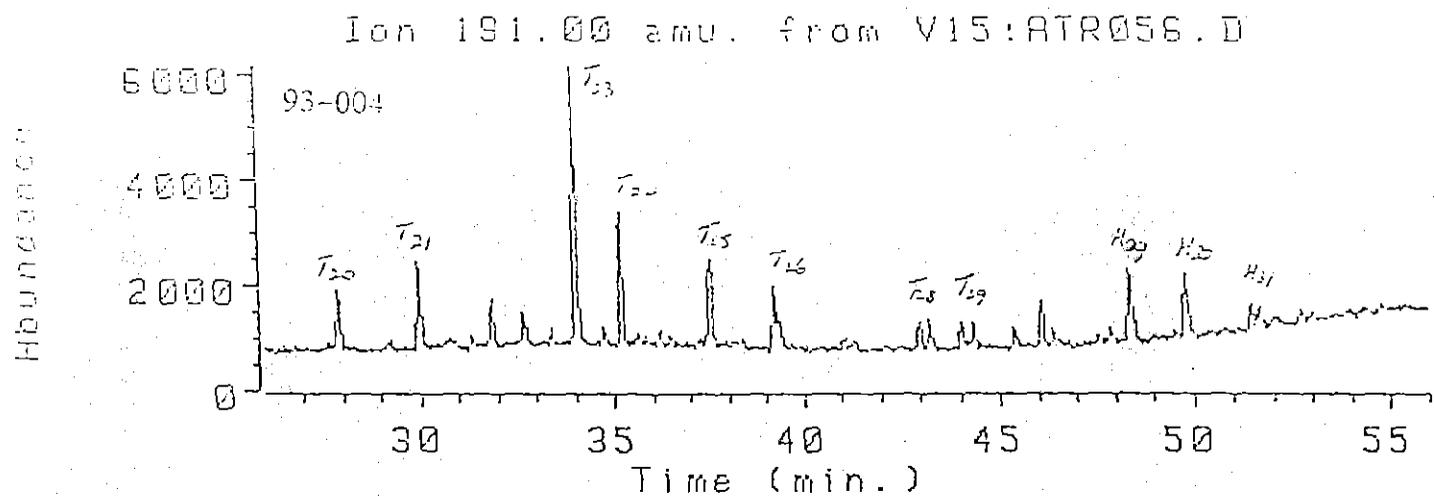


Figure 6. Mass chromatograms for m/z 191 showing the distribution of tricyclic alkanes and hopanes in each of the three water samples.

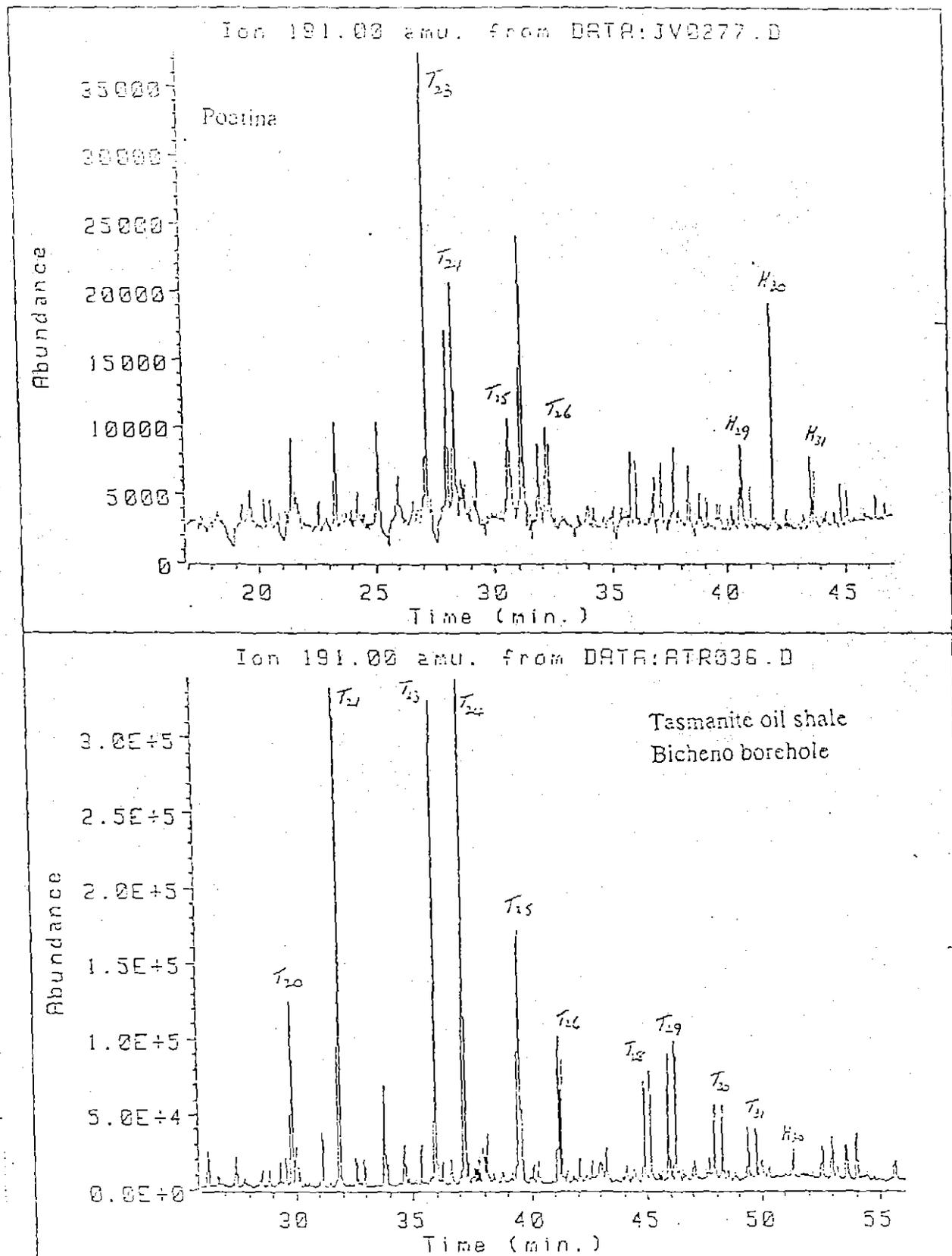


Figure 7. Mass chromatograms for m/z 191 showing the distribution of tricyclic alkanes and hopanes in a mudstone from Poatina (Volkman and Holdsworth, 1989); and the tasmanite oil shale from the Bicheno borehole.

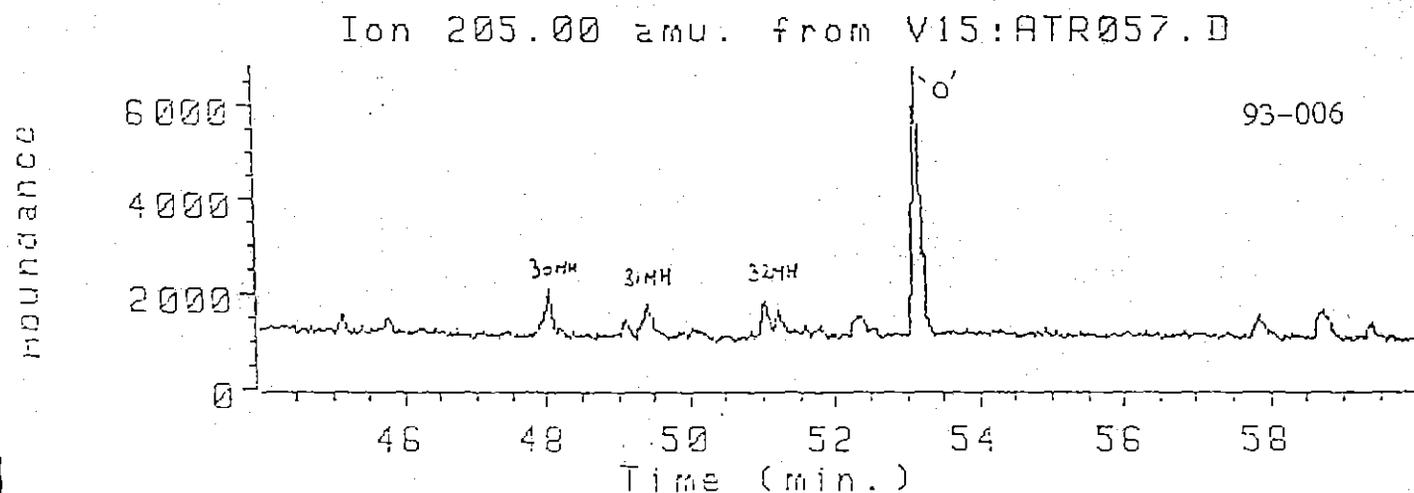
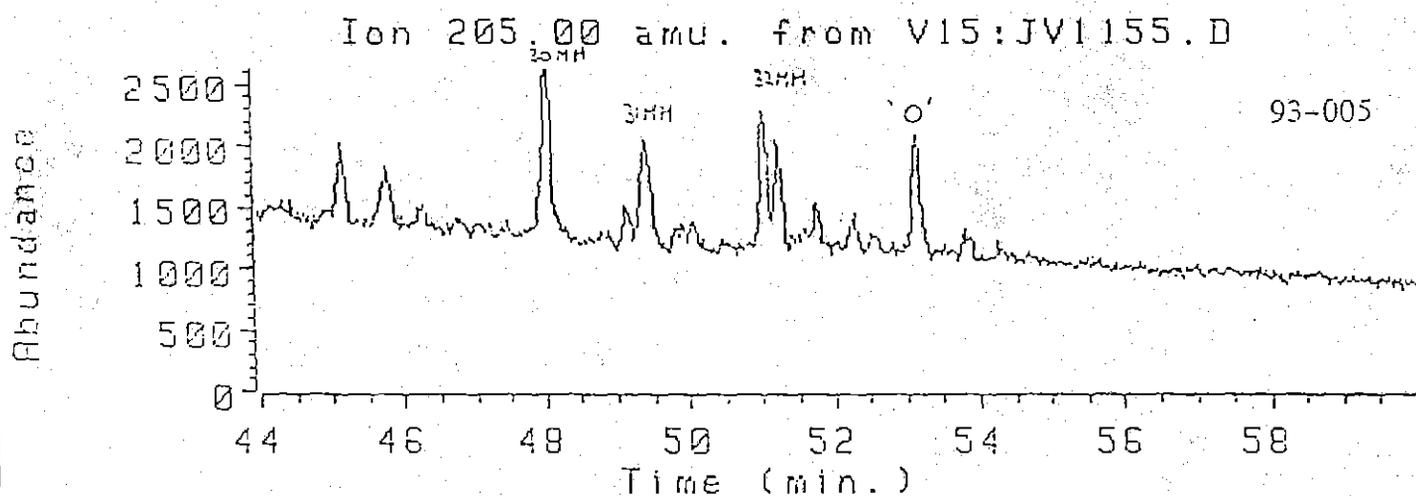
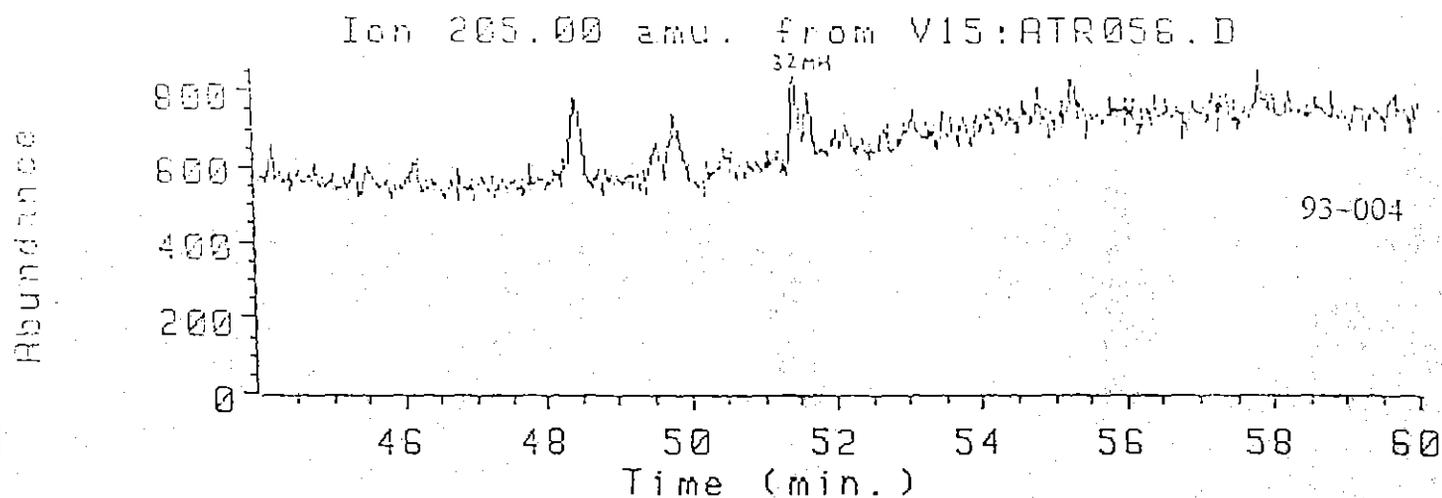


Figure 8. Mass chromatograms for m/z 205 showing the distribution of 2-methylhopanes in each of the three water samples. MH: methyl hopanes; O: unknown compound thought to be a functionalised oleanoid.

Biomarker analysis of Tasmanite band

Biomarker analysis showed that tricyclic alkanes dominated the cyclic hydrocarbons (Fig. 7), which appears to be a characteristic of *Tasmanites* oil shales from elsewhere in Tasmania (unpublished data). The major tricyclics have 21, 22 and 23 carbon atoms, and the distribution extends at least to C₃₅. This distribution is not identical with those isolated from the water samples.

Hopanes are relatively minor components in the m/z 191 mass chromatogram, but isomer distributions (not shown) are consistent with a moderately-mature hydrocarbon distribution. Steranes were identified from the m/z 217 mass chromatogram (Fig. 9). C₂₉ and C₂₇ components dominated, with much smaller amounts of C₂₈ steranes and only trace amounts of C₃₀ steranes. Diasteranes (rearranged steranes) are more abundant than regular steranes: high proportions are often associated with sediments containing clay minerals which catalyze the backbone rearrangement of the steroidal precursors. The 1:1 ratio of 20S to 20R C₂₉ α,α,α isomers and similar proportions of C₂₉ α,α,α to α,β,β isomers (Fig. 9) confirmed that the oil shale is within the early oil window. An equivalent vitrinite reflectance would be about 0.55–0.6 which is higher than that found for the tasmanite oil shales from Oonah and Latrobe.

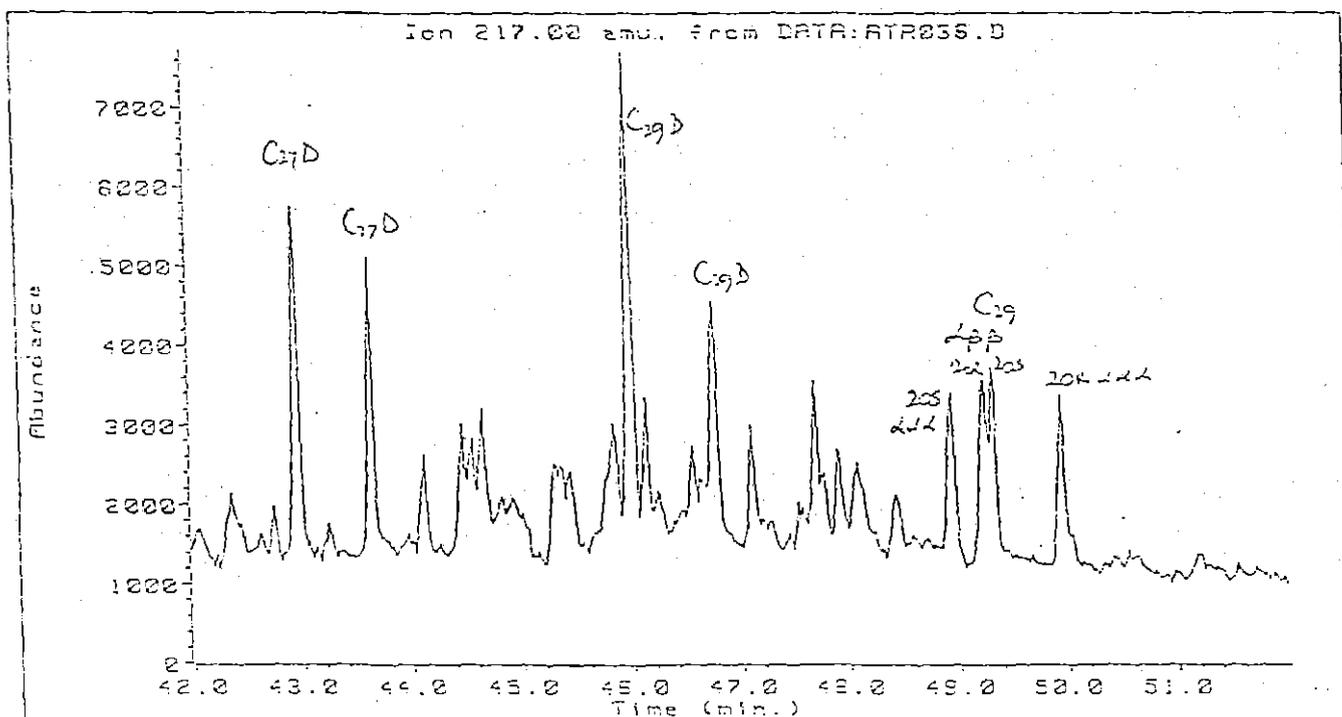


Figure 9. Mass chromatograms for m/z 217 showing the distribution of steranes in the tasmanite oil shale from the Bicheno borehole. Peaks labelled D are rearranged steranes (diasteranes).

Gas analysis

Results from the gas analysis are given in Table 3 below: Dr Summons' comments on these data are shown in Appendix 1.

Table 3. Analytical data for gas sample from Bicheno Borehole.

Component	Analytical Composition ^a (%)	Corrected Composition ^b (%)	Normalised Composition ^c (%)	$\delta^{13}\text{C}$ (‰PDB)
Oxygen	3.2	0	0	
Nitrogen	28.6	11.8	19	
Carbon dioxide	0.1	0.1	0.1	
Methane	68.1	68.1	81	-66.3

a Raw data

b Corrected data assuming oxygen content represents air contamination

c Data re-normalised after removing air contamination

The absence of any hydrocarbons higher than methane suggests a "dry" gas, *i.e.* a non-petrogenic source, though it is possible for this composition to occur due to high thermal maturation of the organic matter (Stahl, 1974).

The carbon isotope figure of -66.3‰ is consistent with a biogenic source for the methane (Fig. 10). Such values are typical of "shallow" dry gases and bacterially-formed marsh gas (Fig. 10). A few commercial gas deposits also exhibit such light carbon values, but gas associated with petroleum is typically much heavier (*i.e.* enriched in carbon-13 isotope).

Australian coal seam gas typically has $\delta^{13}\text{C}$ values of -45‰ to -75‰ (Fig. 11), but unfortunately we are not aware of any isotope analyses of coal seam gases from Tasmania to permit a direct comparison. It seems unlikely, however, that the gas is associated with coal. A methane gas seep at Marion Bay had a carbon isotope value of $\delta^{13}\text{C} = -45.5‰$ and a deuterium isotope value of $\delta^2\text{H} = -248$ SMOW (Baillie, 1990), from which it was concluded that the gas was biogenic.

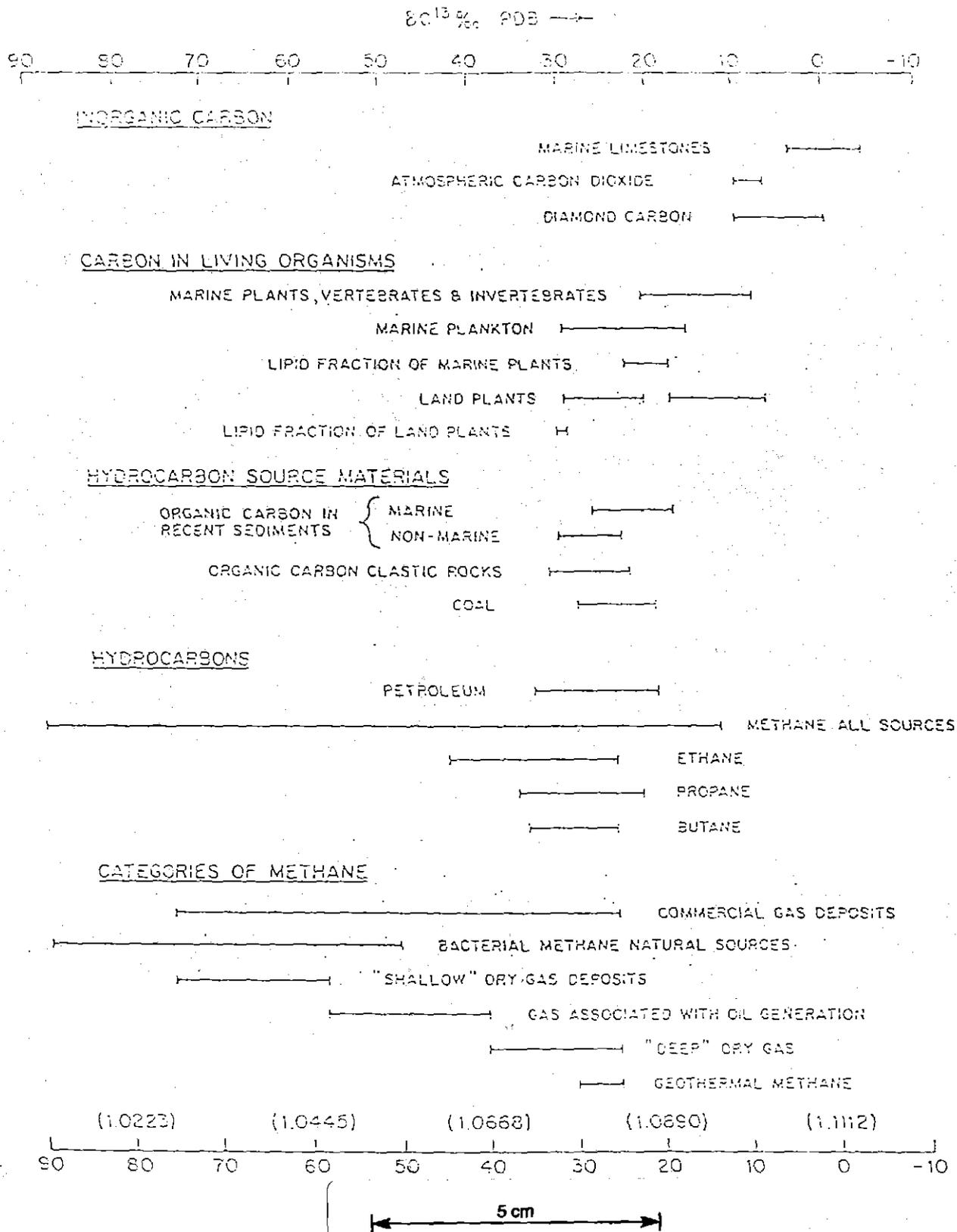


Figure 10. Examples of the range of $\delta^{13}C$ (‰ PDB) isotope values of a variety of geological materials and precursor organic matter (from Feux, 1977)

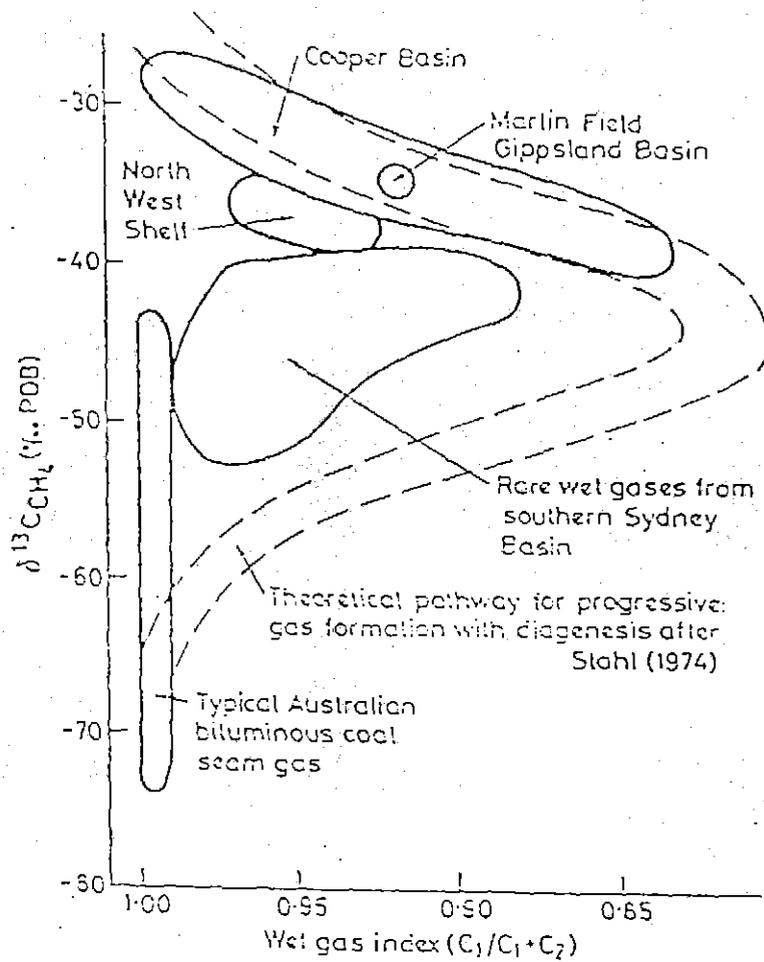


Figure 11. Isotope and chemical composition of Australian natural gas and coal seam gases (from Smith *et al.*, 1985).

CONCLUSIONS

- (i) The small quantities of hydrocarbons found in the water samples from the Bicheno borehole do not provide any evidence for substantial accumulations of oil in sediments through which the water has travelled.
- (ii) At least two types of thermally mature hydrocarbon distributions appear to be present in the water samples. One is likely to be of Permian origin based on the high proportion of tricyclic alkanes, but the molecular distribution of the tricyclic alkanes does not match that found in the tasmanite oil shale from the borehole. The second distribution has features commonly associated with carbonate-derived hydrocarbons. Although the amounts are very small, the presence of these hydrocarbons does indicate that sediments penetrated by the drill are within the oil window.
- (iii) The tasmanite oil shale in the core is very rich in oil-prone organic matter and it is within the early stage of the oil window. Rock-Eval and organic geochemical data confirm that it is an excellent petroleum source rock.
- (iv) The methane is not associated with petroleum formation, and it is unlikely to be derived from coal seams. Rather, the isotope data suggest that it is of biogenic (bacterial) origin.
- (v) Further work is required to determine the origins of the hydrocarbons and methane. Further geochemical analyses of core samples from the Bicheno borehole would provide biomarker fingerprints for comparison with the hydrocarbons in the water samples. The borehole should be pumped out and preferably redrilled to determine at which depth the gas is entering the hole.

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APPENDIX

REPORT OF A GAS SAMPLE FROM DOUGLAS RIVER,
TASMANIA

Requested by: Dr J.K. Volkman

Report by: Dr R.E. Summons

GAS ANALYSIS

The sample was delivered by Mr Bendall on January 27, 1992. The gas (ca. 1 litre) was confined above a layer of water (ca. 1 litre) in an inverted preserving jar sealed with a rubber flange. The seal was submerged under water in an ice cream container. The jar was opened under water, keeping the jar upright and in its inverted position, while several 25ml aliquots of gas were removed with a gas-tight syringe.

This gas was submitted for a compositional analysis using a Carle GC-gas analyser. The traces for the Douglas R. gas, a standard gas and the compositional analysis results are attached. The main components were methane (68.1%), nitrogen (28.6%), oxygen (3.2%) and there was a trace (0.1% CO₂). The presence of oxygen in this gas indicates a minor air component and the analysis can be corrected for this air to give a composition of:

methane	81%
nitrogen	19%

The gas was combusted and the resultant CO₂ was analysed for its ¹³C content. Results and those of normalising standards are attached. The $\delta^{13}\text{C}$ average of duplicate samples was -66.29‰ PDB. This information, combined with the compositional data showing no wet gas components, indicates that the gas is biogenic. It does not appear likely that the gas is associated with a petroleum deposit.

OTHER HYDROCARBONS

Mr Bendall reported that immediately after collection the interface between water and gas contained a layer resembling floating liquid hydrocarbons. No such layer was obvious to my eye at the time of receipt. However, we did carry out an extraction of the water in the jar in order to detect any hydrocarbons present as soluble material or adhering to the walls of the jar. We did notice after this procedure was carried out that the sides and lid of the jar contained a film of brownish insoluble

deposit resembling emulsified iron oxides. Perhaps this film was floating at the time of collection and then either sank or became dispersed on the glass walls during transport.

We extracted the water using 150 ml CHCl_3 containing 15ug of 3-methylheneicosane and an internal standard. Total EOM was 0.9mg (=0.9ppm) and from this we obtained saturated hydrocarbons (0.2mg) and a combined polar+ aromatics fraction (0.6mg). Chromatograms of these materials are attached.

It is likely that the major high MW peaks in the EOM are plasticisers. The saturates chromatogram shows a suite of n-alkanes, pristane and phytane showing that traces of petroleum-related hydrocarbons are present. However, the gravimetric analysis and the relative height of the internal standard peak give a coherent result for the very low abundance of these compounds. We have often analysed bore water samples containing dispersed petroleum hydrocarbons and find levels 1-2 orders of magnitude above the 0.2 ppm found here.

GC-MS ANALYSIS OF SATURATES

The saturated hydrocarbons were analysed by GC-MS and these data have been sent under a separate cover. The biomarkers are present in low abundance compared to the internal standard for 100ng deuterated 3-methylcholestane. However, several distinctive features are evident which may prove of use in identifying the hydrocarbon source (assuming they are indigenous and not contamination). These is a sterane isomer distribution with relatively high abundances of $\alpha\beta\beta$ steranes compared to other isomers and the presence of 30-norhopanes and 2 α -methyl hopanes. Biodegradation does not appear to be extensive since there do not appear to be peaks for 25-norhopanes.

Robert Summers
15/2/93

RECENT DEVELOPMENTS IN EXPLORATION FOR OIL IN TASMANIA

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ABSTRACT

Recent work on oil seeps, organic geochemistry, geophysics, structural geology and palaeontology suggests that there is considerable potential for onshore petroleum in Tasmania.

Archival research has shown that hydrocarbon seeps were commonly reported in the first half of this century and that wildcats produced gas (at Port Sorell in the north) and oil (at Johnson's Well on Bruny Island, in the south). Almost all of the 270 historical hydrocarbon occurrences lie on lineaments revealed independently by gravity and magnetic surveys. The thermal maturity of conodonts from Ordovician and Siluro-Devonian carbonates suggests that much of the pre-Upper Carboniferous beneath the Tabberabberan unconformity is within the oil and gas windows.

Organic geochemistry reveals a very close similarity between hydrocarbons from Ordovician limestones, those from the drill site at Bruny Island and with tar samples from the Tasmanian coast, but little similarity with the Permian Tasmanite Oil Shale, or with the Gippsland crudes and biogenic-ocean-rich South Australian bitumens. The predominance of C_{25} steranes in Tasmanian bitumens suggests a widespread algal source and the abundant diasteranes imply a clay or silt-rich source that extends across much of Tasmania.

Recent geophysical and structural work suggests that a thin skinned interpretation of Tasmania's structure is reasonable. Most sightings of hydrocarbons are associated with either faults or fractures which have post-Jurassic displacements or with intersections of major high angle faults with thrusts. The delineation of reservoirs within the thrust sheets is a priority.

INTRODUCTION

Onshore Tasmania has been considered unprospective for hydrocarbons for over 50 years. This view has resulted from misunderstandings or ignorance about the nature and origin of the many occurrences of hydrocarbons previously recorded. Oil shales of Permian age have long been known in Tasmania and some production (by retorting) has been derived from them.

The numerous records of seepage or tar sightings from the period 1850-1955 were generally ascribed to an oil shale source. The absence of serious exploration in recent times has led to general ignorance of the existence of these records. Modern maps of Australian basins refer to the 'Tasmanian Basin' when considering Tasmania. This is taken to mean the Late Carboniferous-Triassic deposition presumed to overlie economic basement (Fig. 1).

Consequently, if it is assumed that any hydrocarbons present were derived from Permian oil shale then no reliable seals or traps of any magnitude are likely to exist, due to disruption of the post-Carboniferous sequences by faulting and intrusion and an absence of closed structures. An unprospective environment is a valid conclusion based on these assumptions.

Many pre-war observers did not have this view since many seepage sites are far removed from Permian rocks and several occur in Precambrian quartzite (Port Davey) or Precambrian granite (King Island) (Figs 2 & 3). Many are directly associated with or occur near Ordovician carbonates. They could not, therefore, offer a credible explanation for these occurrences.

The lack of exploration activity since 1959 may be contrasted with that of the previous 50 years when many companies were floated. All were based on effusive oil or tar seepages. Some accumulations were large sufficient to fill the hold of a coastal cargo vessel (from Port Davey). Few drilling proposals were converted into action but several attempts were made to drill at Port Sorell and Bruny Island. The maximum depth of any such hole was about 400 m but gas was recorded in one well at Port Sorell and oil was recovered in small quantities from another at Bruny Island.

This paper presents information assembled during the last 10 years, and especially the last three years. It suggests that the faith of the early explorers was justified and that the perceptions of the last 50 years have been wrong. Hydrocarbon occurrences have been verified, are widespread and are associated with seismic activity. The chemistry of the seep hydrocarbons is not consistent with Permian oil shale derivation but is indicative of lower

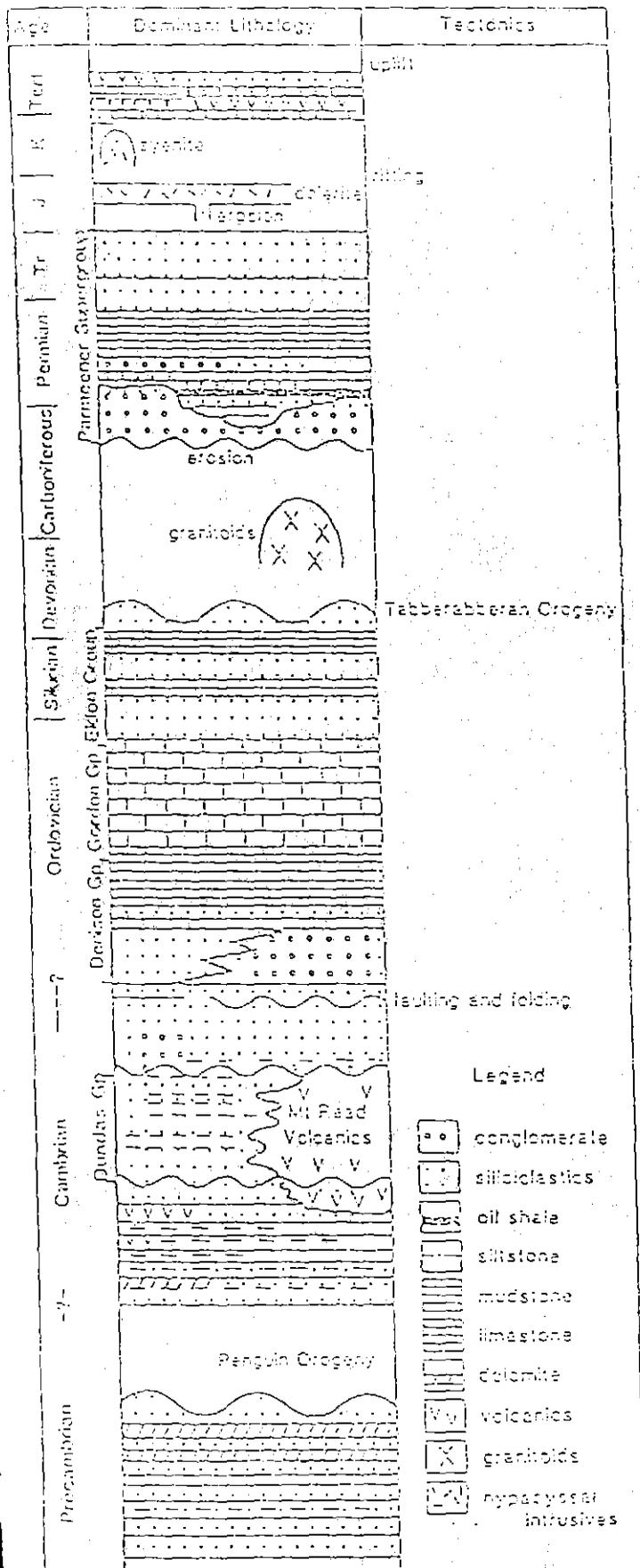


Figure 1. Highly generalised geological column for Tasmania.

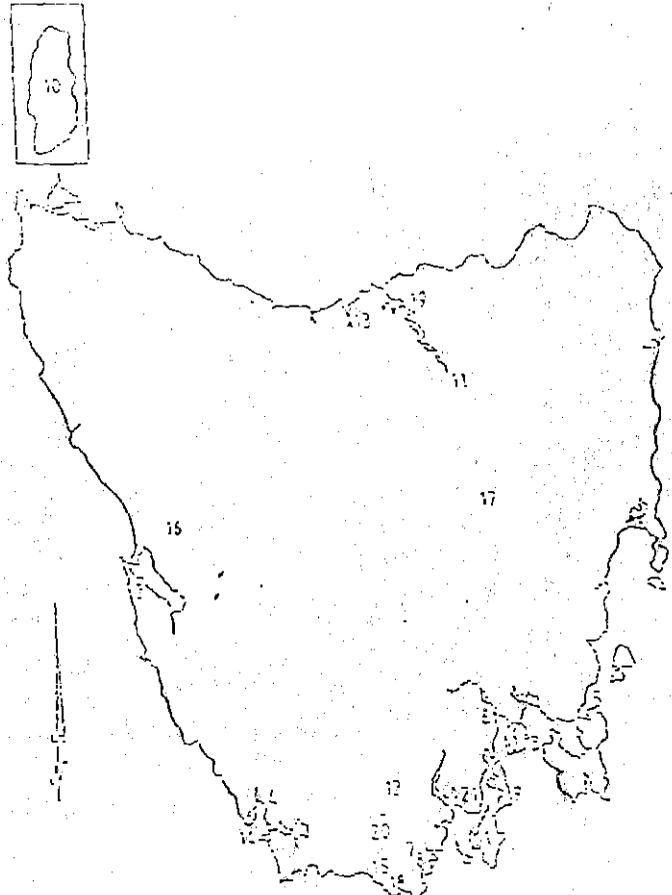


Figure 2. Locality map. 1-Briny Island, 2-Cape Sorell, 3-Clifton Beach, 4-Deep Creek, 5-Dunally, 6-Hobart, 7-Hastings, 8-Ida Bay, 9-Johnson's Well, 10-King Island, 11-Launceston, 12-Picton River, 13-Port Sorell, 14-Port Davey, 15-Precipitous Bluff, 16-Queenstown, 17-Ross, 18-Surprise Bay, 19-Tamar River, 20-Vanishing Falls, 21-Woodbridge.

Palaeozoic source rocks. This knowledge, when coupled with a revised structural view of Tasmania, transforms prospectivity assessments.

GEOLOGICAL HISTORY

A full and recent account of the geology of Tasmania may be found in Burnett and Martin (1959). The oldest rocks in Tasmania (Fig. 1) are Proterozoic quartzites, phyllites and dolomites which crop out extensively in the central and northwestern parts of the island. After the Penguin Orogeny at 700 Ma these were unconformably overlain by shallow marine quartz sandstones and dolomites and then by marine turbidites, mudstones and basalts in the late Proterozoic or early Cambrian. A mineral-rich island arc (Mt Read Volcanics)-back arc basin (Dundas Group) complex formed in the middle to late Cambrian and was unconformably overlain by turbidites and volcanoclastics in the latest Cambrian. These mainly marine sediments were successively overlain in the Ordovician by fanglomer-

crates (Owen Conglomerate and correlates), by shallow marine sandstones (Moina Sandstone and correlates), by subtidal siltstones and mudstones (Florentine Valley Mudstone and correlates) and by a thick succession of tropical carbonates (Gordon Group). The Gordon Group carbonates are up to 1.5 km thick in central Tasmania and are dominantly micritic. Dolomitisation is common. In the south there is a transition southwards from shallow marine conditions near Vanishing Falls, to platform margin build-ups at Precipitous Bluff, to deep (> 200 m) water carbonate turbidite-graptolitic shale environments at Surprise Bay (Burrett et al., 1981, 1983, 1984). The Gordon Group carbonates were conformably overlain by the dominantly marine siliciclastics of the Late Ordovician-Early Devonian Eldon Group. In the eastern third of the state, Ordovician-Devonian sediments consist of graptolitic basinal turbidites (Mathinna Beds).

The Tabberabberan Orogeny in the Early Devonian created a fold-thrust belt producing approximately north-south trending folds in most areas but with east-west trending folds in the north-west of the state. Numerous and extensive granitoids were intruded between 395 and 380 Ma. Regional metamorphism gave rise to the pattern of conodont CAI (Colour Alteration Index) isograds shown in Figure 3, with heating of the lower Palaeozoics to 300°C in the west and north-west and much lower temperatures (150°C) in central and southern Tasmania (Burrett, in press). In the Late Carboniferous-Pennsylvanian, a sequence of glaci-terrestrial and glaci-marine predominantly siliciclastics (lower Parmeener Supergroup) were deposited unconformably on the older rocks and were succeeded conformably by Triassic terrestrial sandstones of the upper Parmeener Supergroup. Coals are present in both divisions of the Parmeener and the famous Tasmanite Oil Shale occurs just above the basal tillite of the supergroup.

Extensive, thick (often 500 m) sills of dolerite fed by narrow feeder dykes were intruded in the Middle Jurassic and presently outcrop over about half of the state. Although the dolerite is voluminous, metamorphism appears to be restricted to the immediate vicinity of the sheets. Minor local syenites were intruded in the Cretaceous but regional heating was sufficient to reset the Palaeozoic palaeomagnetism. North to northwesterly-trending horsts and graben were produced in a general extensional environment in the Late Cretaceous to Early Tertiary and the graben were filled with up to 1 km of mainly terrestrial sediments. Many Tertiary volcanic centres are present on-shore.

SEEP DISTRIBUTION AND ORGANIC GEOCHEMISTRY

SEEPS

The distribution pattern and historical background of seeps are summarized by Bendall (1990). The distinctive NW/SE, NE/SW seep trends (Fig. 3) transect all rock types, strongly suggesting that deep crustal lineaments are still active. Seepages have been mainly reported directly after major quakes. The records of oil shows from archival research include reports from 53 drill holes, 127 oil leases and

120 other signs of either tar, oil or gas. The discovery of samples of some of the tars in Launceston's museum, along with archived photographs, confirms the validity of the old records. Geochemical confirmation of hydrocarbons around the 1929 Bruny Island drill hole, current gas seeps at that site and wet gas recently found at Dunalley are all on lineaments and suggest the validity of other unconfirmed sightings on those lineaments. Many companies were formed to exploit the potential that the seeps indicated (Bendall, 1990). Of these companies only two produced shows of hydrocarbons both of which were confirmed by government geologists, as were many of the historical reports of tars and seeps.

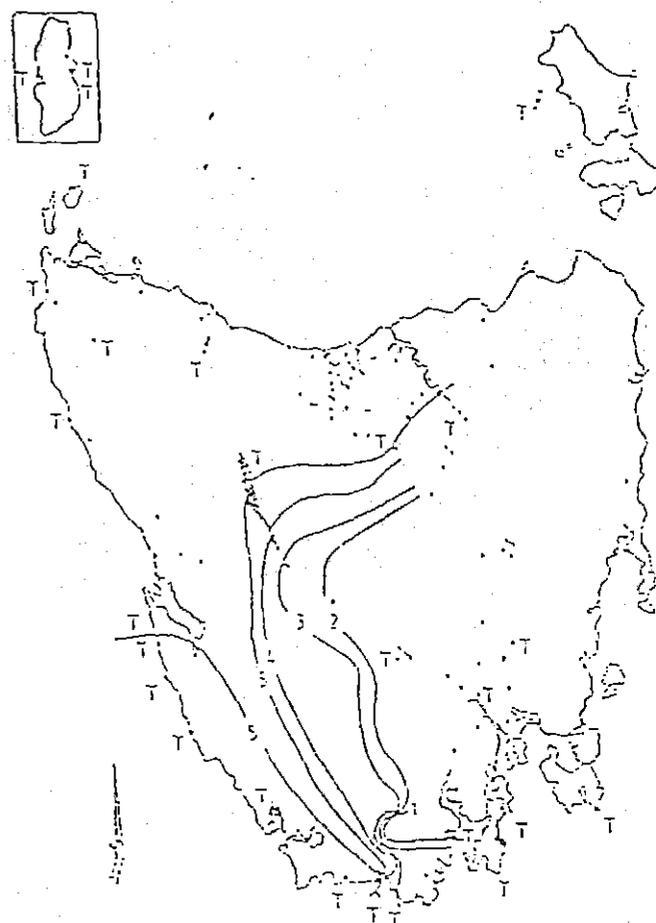


Figure 3. Seep distribution in Tasmania from Bendall (1990). T = tars. Contour lines are isograds based on conodont Colour Alteration Indices (CAI) from Burrett (in press). CAI 5 = 300°C and CAI 1 = 150°C.

ORGANIC GEOCHEMISTRY

Methods

Sediment from the site of the 1928 drilling at Johnson's Well on Bruny Island was extracted using hexane with ultrasonication. Solvents of greater polarity were not used due to the high concentrations of naturally occurring polar lipids. The limestone sample from Ida Bay in southern Tas-

maria was crushed and then a portion was extracted using chloroform-methanol with ultrasonication. The bitumen from Port Davey in western Tasmania was extracted directly with chloroform, which dissolved the entire sample. Portions of each extract were analysed by layered thin-layer chromatography-flame ionisation detection (Wellman et al., 1988) to determine the total hydrocarbons.

Saturated and aromatic hydrocarbons were isolated by applying a portion of the extract to a column of silicic acid capped with activated alumina. Aliphatic hydrocarbons were eluted with hexane and a second fraction containing aromatic hydrocarbons was obtained by eluting with toluene-hexane. Resins and asphaltenes were eluted with chloroform and methanol.

Each hydrocarbon fraction was analysed by capillary gas chromatography on a non-polar methyl silicone fused silica capillary column to determine the distribution of straight-chain and isoprenoid alkanes. These fractions were then analysed by gas chromatography-mass spectrometry (GC-MS) in selected ion monitoring mode (SIM) (Wellman et al., 1988). Ion chromatograms for ions m/z 217 and 218 (steranes), m/z 259 (diasteranes), m/z 251 (methyl steranes), m/z 191 (hopanes and other triterpanes), m/z 177 (demethylated hopanes), m/z 205 (methyl hopanes) plus some molecular ions were acquired.

Results

Geochemical analyses of two soil samples from Johnson's Well were undertaken. These revealed small amounts of hydrocarbons (about 400 ng/g) which were dominated by n-alkanes of plant origin, plus the common petroleum constituents pristane and phytane (ratio 2:1). GC-MS fingerprinting conclusively demonstrates the presence of trace amounts of petroleum hydrocarbon biomarkers including steranes and diasteranes (Fig. 4) and hopanes (Fig. 5). Trace amounts of petroleum-derived hydrocarbons were also detected in a few water and sediment samples from elsewhere on the island, but the amounts were generally too low for detailed fingerprinting studies. The low concentrations of petroleum-derived hydrocarbons at Johnson's Well indicated that petroleum seeps are no longer active at this site but provided some evidence for their former presence.

A limited organic geochemical study of the hydrocarbons in Ordovician limestones from Ida Bay in southern Tasmania and Queenstown in the west was undertaken. One sample from Queenstown was of interest as it appeared to contain flecks of asphaltic material. These rocks contained low amounts of 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. Although sediments from the Queenstown area have much higher conodont CAIs (Fig. 3), which suggest a higher thermal maturity, the biomarker maturity parameters in samples from the two regions are remarkably similar.

The sterane distributions in the limestones show many similarities to those in the Johnson's Well soil sample. In particular, the ratios of C_{27} : C_{28} : C_{29} steranes, which is a useful source input parameter (Mackenzie, 1984), are almost

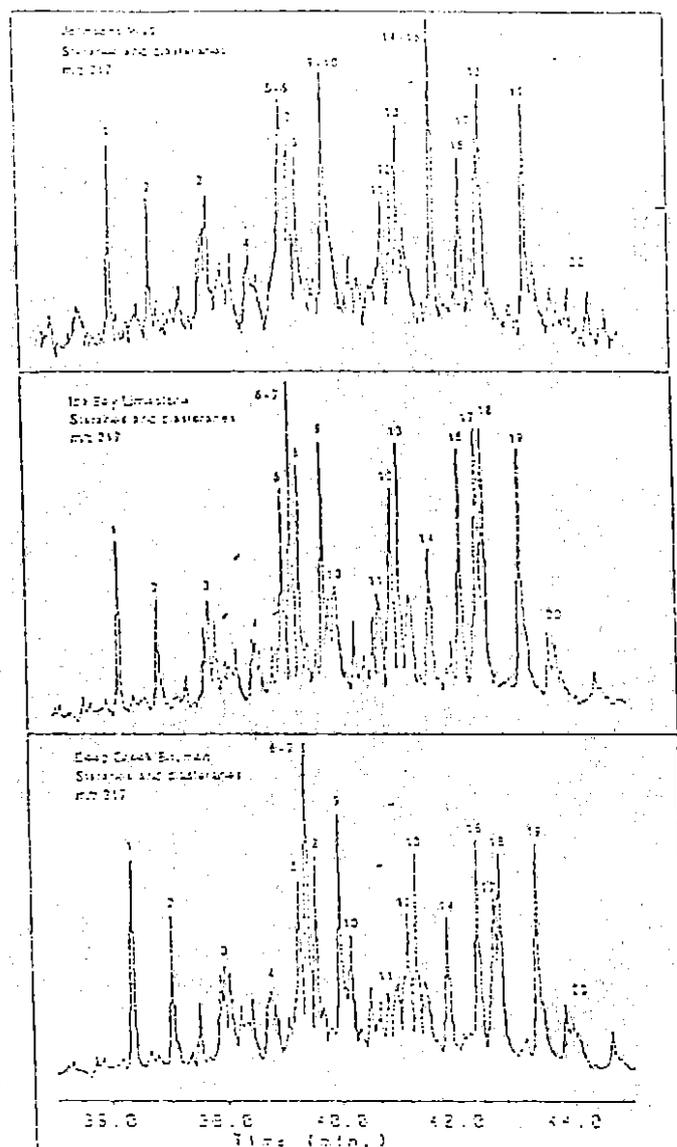


Figure 4. Mass fragmentograms for m/z 217 showing distributions of C_{27} - C_{30} steranes and diasteranes in (a) soil from Johnson's Well on Bruny Island, (b) Ordovician carbonate from Ida Bay and (c) tar from the mouth of Deep Creek near Port Davey on the west coast of Tasmania. Compound identifications are from peaks in m/z 217 mass fragmentograms.

Peak	Steranes and Diasteranes
1	C_{27} (20S)-13 β (H),17 α (H)-diasterane
2	C_{27} (20R)-13 β (H),17 α (H)-diasterane
3	C_{27} (20S)-13 β (H),17 α (H)-diasterane
4	C_{27} (20S)-13 β (H),17 α (H)-diasterane
5	C_{27} (20S)-3 α (H),14 α (H),17 α (H)-cholestane
6	C_{27} (20S)-13 β (H),17 α (H)-diasterane
7	C_{27} (20R)-3 α (H),14 β (H),17 β (H)-cholestane
8	(20S)-3 α (H),14 β (H),17 β (H)-cholestane
9	C_{27} (20R)-3 α (H),14 α (H),17 α (H)-cholestane
10	C_{28} (20R)-13 β (H),17 α (H)-diasterane
11	C_{29} (20S)-3 α (H),14 α (H),17 α (H)-24-methylcholestane
12	C_{29} (20R)-3 α (H),14 β (H),17 β (H)-24-methylcholestane
13	C_{29} (20S)-3 α (H),14 β (H),17 β (H)-24-methylcholestane

14	C ₂₁	(20S)-3 α (H),14 α (H),17 α (H)-24-methylcholestan-3-one
15	C ₂₁	Unknown
16	C ₂₁	(20S)-3 α (H),14 α (H),17 α (H)-24-ethylcholestan-3-one
17	C ₂₁	(20R)-3 α (H),14 β (H),17 α (H)-24-ethylcholestan-3-one
18	C ₂₁	(20S)-3 α (H),14 β (H),17 β (H)-24-ethylcholestan-3-one
19	C ₂₁	(20R)-3 α (H),14 α (H),17 β (H)-24-ethylcholestan-3-one
20	C ₂₁	24-propylcholestan-3-one

Peak	Hopane
1	C ₂₇ 13 α (H)-22,29,30-trisnorhopane (Ti)
2	C ₂₇ 13 α (H)-22,29,30-trisnorhopane (Tm)
3	C ₂₇ 17 β (H)-22,29,30-trisnorhopane
4	C ₂₇ 13 α (H),21 β (H)-29,30-dinorhopane
5	C ₂₇ 17 α (H)-21 β (H)-30-norhopane
6	C ₂₇ 17 β (H),21 α (H)-30-norhopane
7	C ₂₇ 17 α (H),21 β (H)-hopane
8	C ₂₇ 17 β (H),21 β (H)-30-norhopane
9	C ₂₇ 17 β (H),21 α (H)-homohopane
10	C ₂₇ (22S)-17 α (H),21 β (H)-homohopane
11	C ₂₇ (22R)-17 α (H),21 β (H)-homohopane
12	C ₂₇ (22R+S)-17 β (H),21 α (H)-homohopane
13	C ₂₇ 17 β (H),21 β (H)-hopane
14	C ₂₇ (22S)-17 α (H),21 β (H)-bishomohopane
15	C ₂₇ (22R)-17 α (H),21 β (H)-bishomohopane
16	C ₂₇ (22S)-17 α (H),21 β (H)-trisnorhopane
17	C ₂₇ (20R)-17 α (H),21 β (H)-trisnorhopane
18	C ₂₇ (22R)-17 β (H),21 β (H)-homohopane
19	C ₂₇ (22S)-17 α (H),21 β (H)-tetraakisnorhopane
20	C ₂₇ (22R)-17 α (H),21 β (H)-tetraakisnorhopane
21	C ₂₇ (22S)-17 α (H),21 β (H)-pentaakisnorhopane
22	C ₂₇ (20R)-17 α (H),21 β (H)-pentaakisnorhopane
23	C ₂₇ (22S)-17 α (H),21 β (H)-hexakisnorhopane

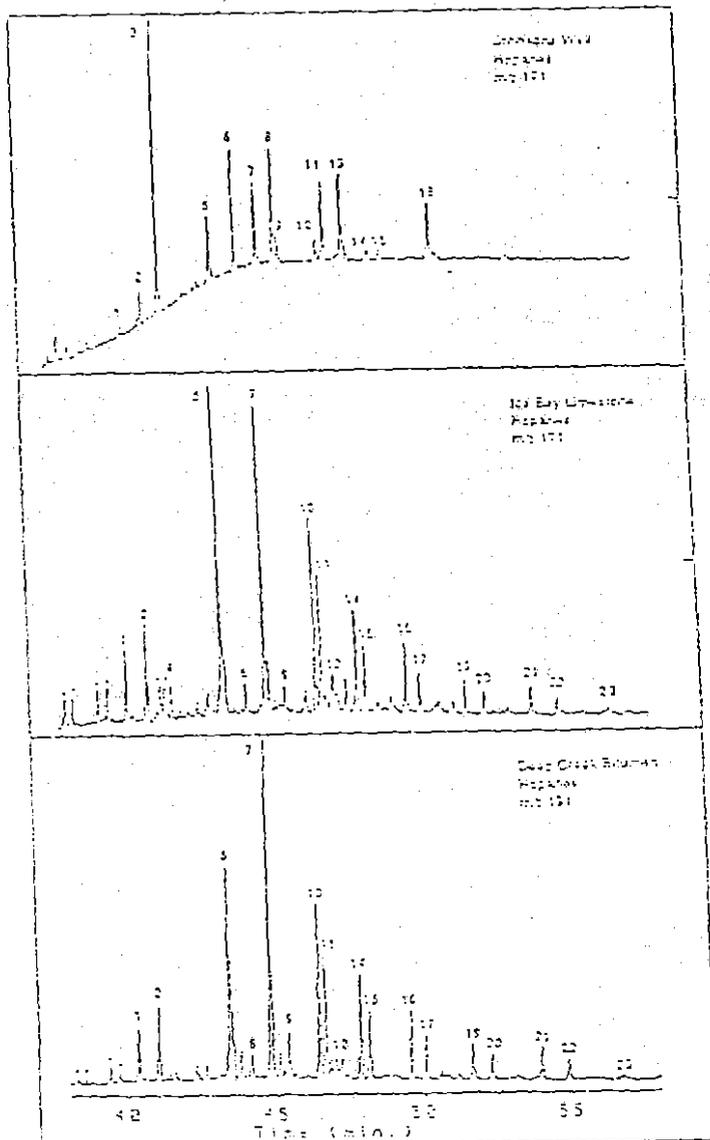


Figure 5. Mass fragmentograms for m/z 191 showing distributions of C₂₇-C₃₃ hopanes in (a) soil from Johnson's Well on Bruny Island, (b) Ordovician carbonate from Ida Bay and (c) tar from the mouth of Deep Creek on the west coast of Tasmania. Tricyclic alkanes are denoted by *. The baseline rise in mass fragmentogram (a) is due to a contribution of the m/z 191 ion from column bleed. Identifications of peaks in hopane (m/z 191) and methyl hopane (m/z 205) mass fragmentograms:

identical. Similar ratios have been found in carbonate-derived oil from the Middle East, and from Ordovician sediments from mainland Australia (Hoffmann et al., 1987). However, this ratio is very different from those found in oils presently recovered from the Gippsland Basin which show a strong predominance of C₂₇ steranes. The presence of similar amounts and proportions of rearranged steranes (diasteranes) is also of interest since these compounds are usually of very low abundance in pure carbonates.

In 1990, 15 samples of bitumens collected early this century from coastal sites were obtained from Tasmanian museums for geochemical analysis. Many of these samples are mentioned in an early report on petroleum exploration in Tasmania (Twelvevees, 1917). All the samples are black, shiny asphaltic bitumens which show a characteristic conchoidal fracture and an aromatic odour when broken. They contain no inorganic matter and dissolve completely in chloroform.

Aliphatic hydrocarbons represented 13.2-15.0 per cent of the total extract of the bitumens, aromatic hydrocarbons 3.5-6.7 per cent, with the remainder consisting of polar resins and asphaltenes. The distributions of aliphatic hydrocarbons in each bitumen are similar to those of mature crude oils except that volatile hydrocarbons (<n-C₁₂) are absent. The n-alkanes extend at least to n-C₃₃ with no odd or even predominance. Higher molecular weight components are not abundant indicating that the bitumens are not derived from a waxy crude like that from the Gippsland Basin. The major n-alkane is either n-C₁₈ or n-C₁₅. Pristane and phytane are the most conspicuous branched constituents in all samples. Longer-chain isoprenoids are

comparatively minor components and botryococcane, which occurs in some bitumens found on South Australian beaches (McHardy et al., 1986), was not detected. The pristane/phytane ratios of most samples fall in the range 1.80-1.83. All of the chromatograms show a small 'unrelated complex mixture' (UCM or 'hump') throughout the chain-length range typical of crude oils. The aliphatic hydrocarbon distributions give the overall impression of a non-waxy, weathered heavy crude oil.

GC-MS fingerprinting shows that the sterane distributions in all of the bitumens are remarkably similar. The Port Davey (Deep Creek) sample is typical (Figs 4 and 5). Although C_{27} steranes (peaks 5, 7, 8 and 9) predominate, they are only slightly more abundant than the C_{28} steranes and C_{29} steranes. This feature is also found in hydrocarbons isolated from the Ordovician limestone samples and the soil from Johnson's Well (Fig. 4). The bitumens also contain significant amounts of diasteranes. Mass fragmentograms for m/z 251 show that small amounts of methyl steranes are present in all the bitumens, but individual compounds were not identified.

The distributions of hopanes were characterised from mass fragmentograms of the major fragment ion m/z 191 (Fig. 4). Comparable data for the hopanes isolated from the Johnson's Well and Ida Bay samples are also shown. The major hopane peak in the bitumens is C_{30} , with C_{29} next most abundant. Moretanes are present in low abundance (peaks 6, 9 and 12), and the ratios of 22S to 22R epimers in the extended hopanes (i.e. $>C_{30}$, e.g. peaks 10 and 11) are typical of a mature oil. These isomers isomerise to an equilibrium mixture before the onset of the oil window. The ratio of the two C_{30} hopanes Ts (peak 1) and Tm (peak 2) is a sensitive indicator of thermal maturity. Ts was less abundant than Tm in all samples implying that all bitumens were generated at closely similar thermal maturities at an equivalent vitrinite reflectance of about 0.6-0.7.

Although the sterane distributions from Johnson's Well, the Ida Bay limestone and various bitumen samples are all very similar, the hopane distributions show significant differences. The hopanes in the limestone contain significantly more C_{29} hopane due to the presence of a series of 29-norhopanes which are not present in detectable amounts in the bitumens. The bitumen hopane distributions are more typical of those found in shales. The carbonates also contain a series of C_{25} - C_{28} 2-methylhopanes, whose mass spectra have a characteristic base peak at m/z 205. These compounds are trace constituents of the bitumens, implying that the bitumens are unlikely to be derived from a carbonate source rock. C_{17} demethylated hopanes were not detected in any of the samples using m/z 177 mass fragmentograms. These compounds are commonly associated with highly biodegraded residues of crude oil (Volkman et al., 1983), which suggests that the bitumens are not simply tar residues from exposed reservoirs.

The hopane distributions in the Johnson's Well sample do not, at first sight, appear to be at all related to either the Ida Bay carbonates or to the bitumen samples. This is due to a predominance of hopanes from microorganisms in the soil. Several of these hopanes have 17 β (H),21 β (H) stereochemistry (peaks 8, 15 and 18) which is typical of biologi-

cally produced hopanoids. This complication must always be considered when attempting to fingerprint petroleum-derived hydrocarbons in soil or in geologically young sediments (Volkman et al., 1983). However, hopanes of obvious petroleum origin such as Ts, Tm and extended hopanes were present. 2-Methylhopanes were not detected, which rules out Ordovician carbonates as the source.

The remarkable similarity between all the sterane distributions implies that the hydrocarbons in the bitumens are probably derived from the same type of organic matter which contributed to the carbonates. The predominance of C_{27} steranes is not found in oils generated from higher plants or from coaly matter, but is more typical of algal matter. The presence of abundant diasteranes implies a depositional environment in which the sediments contain a high content of silt or clay. The absence of methylhopanes argues against a shallow carbonate depositional environment.

The very low abundance of tricyclic alkanes in the bitumens indicates that the Tasmanite Oil Shale, in which these compounds are the predominant biomarkers (Denwer, 1986; Simoneit, 1986), was not the source of these hydrocarbons. Also, the oil shales show a much higher predominance of C_{27} steranes and a very different diasterane/sterane ratio (Denwer, 1986). Moreover, the maturity of the hydrocarbons in the bitumens is significantly greater than that found in Tasmanite Oil Shale.

Organic geochemical studies show a very close similarity between hydrocarbons from Ordovician Gordon limestone, those from Johnson's Well on Bruny Island and with tars collected from the Tasmanian coast. Little similarity is observed between the aforementioned hydrocarbons and lower Permian Tasmanite Oil Shale, the waxy Gippsland crudes or botryococcane-rich South Australian bitumens. The preponderance of C_{27} steranes suggests a widespread algal source and the abundant diasteranes imply a clay or silt-rich source that extends over most of Tasmania.

GEOPHYSICS AND STRUCTURE

Any suggestions that the historic and modern hydrocarbon occurrences might be derived from lower Paleozoic source rocks and that reservoir potential might exist in the rocks beneath the unconformity at the base of the Upper Carboniferous-Triassic Parmeener Supergroup pose problems for conventional models of Tasmanian geology. The pre-Parmeener rocks are concealed across more than half of Tasmania and the proposed source and reservoir rocks are never the dominant materials exposed elsewhere. Much of Tasmania consists of exposed Cambrian and Precambrian in the west and the Ordovician-Devonian turbidites in the northeast — all intruded by Devonian granitoids — and these have been inferred to occur at shallow depth beneath the unconformity. The few drill holes to have penetrated pre-Parmeener basement have proven Precambrian gneisses, Ordovician-Devonian turbidites or Cambrian volcanics. No hole is deeper than about 1000 m and all have been drilled for stratigraphic evaluation of the lower Parmeener. Yet the seepages are widespread and apparently associated with thrusts and lineaments.

Conga Oil began exploration on Bruny Island in sou-

them Tasmania. No pre-Parmeener rocks are exposed for more than 30 km in any direction, although drilling had proven Precambrian rocks at 999 m at nearby Woodbridge and Cambrian volcanics at 600 m beneath the northern suburbs of Hobart. Appreciation of the significance of the 1929 Johnson's Well drilling and depended first on imaging beneath the Jurassic dolerite, stripping off the Parmeener cover and finally assessing of the likely composition and distribution of material beneath the unconformity.

GRAVITY AND MAGNETIC SURVEYS

Gravity and magnetic methods have a long and proven record for structural assessment (e.g. Leaman and Richardson, 1981) in this complex surface environment and have formed the basis for all of our deep appraisal.

Because of their cost effectiveness and their ability to reveal shallow structures and constrain the geometry of dolerite bodies, gravity and magnetic surveys were extended from the area of the Bruny Island hydrocarbon occurrence to central Tasmania in 1987.

The gravity coverage has taken the form of an infilling of the state gravity data base such that the nominal station spacing is now about 2.5 km. All stations were fully corrected, including 32 km radius terrain corrections and were reduced using a crustal reference density of 2.67 t/m³. The aeromagnetic surveys were flown at elevations of 1000 and 1600 m for the southern and northern areas respectively with line spacings of 2.5 and 5 km. All specifications have been directed at resolution of primary structures and relationships at depths of 1000–3000 m below meter or sensor. The coupling of these two potential field methods is essential to the resolution of any concealed structures with the minimum of ambiguity.

Details of the southern survey and its interpretation have been discussed by Leaman (1990). Interpretation of the northern survey remains incomplete although it is now known that structural styles inferred in the southern survey and which are comparable with those exposed in western Tasmania, persist across the island toward Bass Strait.

The surveys have revealed the presence of deep Cambrian troughs containing thick piles of mafic and intermediate volcanics. These troughs are commonly limited by major structures containing ultramañes. Interfaces within presumed Precambrian basement rock are also implied at depths which range from the sub-Parmeener unconformity to perhaps four kilometres. Other Palaeozoic rocks overlap both Cambrian and Precambrian rocks and may be up to two kilometres thick in southern Tasmania. The presumed Ordovician and Silurian rocks can be traced to outcrops of the Gordon Group in the region west of Hastings of the Pieter River. Figure 6 shows the geology as might be seen if the Parmeener and dolerite cover were stripped away.

STRUCTURE

The gravity and magnetic analyses have provided several geological revelations. The 'Tamar Lineament', a fundamental crustal structure extending NNW-SSE across the island from the Tamar River to the southeast as proposed by Williams (1979), is not supported by either data set.

Magnetic trends are acute to the supposed structure. The granites of eastern Tasmania are present as giant bodies elongated N-S and their western margin cuts across all types of basement geology (Leaman and Richardson, 1990). The granites of western and central Tasmania are relatively isolated but are sometimes large bodies (Leaman and Richardson, 1989).

Many structural and stratigraphic patterns are repeated. The important and recognisable units include the ultramañes of Early-Middle Cambrian age and thick dolomitic successions of latest Precambrian age. At least three major repetitions can be identified beneath the Parmeener. Similar repetitions have now been implied in western Tasmania where the same rocks are exposed. All parts of the lower Palaeozoic succession are involved.

Although relatively small-scale thrusting has been recognised and mapped for many years, large scale movements involving basement or large portions of the Palaeozoic succession have rarely been accepted or proven. Leaman et al. (1979) reported the first such demonstration based on gravity data and this has now been confirmed by mapping and structural review. Other instances have been recognised since acquisition of much new data in western Tasmania as part of the Mt Read Volcanics Project (1988–). Examples of large-scale basement and, occasionally, crustal involvement in thrust stacks have been given by Leaman (1986, 1987, 1988). Such overthrust structures at Cape Sorell have now been established by drilling. Structures are complex; in western Tasmania the westward trending Devonian thrusts have disturbed pre-existing west-facing early Cambrian thrusts. Current interpretations suggest that little of the pre-Devonian geology of Tasmania, as presently exposed, is autochthonous.

SEISMIC SURVEYS

Very little seismic data is available for onshore Tasmania; however, a survey of Bruny Island was undertaken by Conoco Oil in 1987. Data records have been generally poor. This was initially ascribed to local terrain and high velocity surface problems. Jurassic dolerite produces irregular high velocity intrusion forms which couple with topographic effects to impose complex static corrections. The dolerite also reflects much energy from its upper surfaces and apparent reflector shadows appear beneath. The base of a dolerite sheet is not generally revealed even though the velocity contrasts are large. Processing problems associated with such difficult data are presently being assessed. Offshore surveys in southern Tasmania by Amoco in 1969 and by the Bureau of Mineral Resources in 1986, exhibit seismic character very similar to land based surveys.

Both onshore and offshore surveys have recorded events, fragmentally, at times of 1–3 seconds. At Bruny Island, an event could be traced the length of the 7 km traverse at about two seconds. The implied depth of 3–4 km is consistent with the potential field inference of a major density contrast at this level.

Although most records appear bland for times in excess of 500 to 900 ms — the time depth of the base Parmeener unconformity in most cases — it has been possible to obtain excellent records to two-way times of 11 seconds (to mantle levels) at rare localities. One example was reported

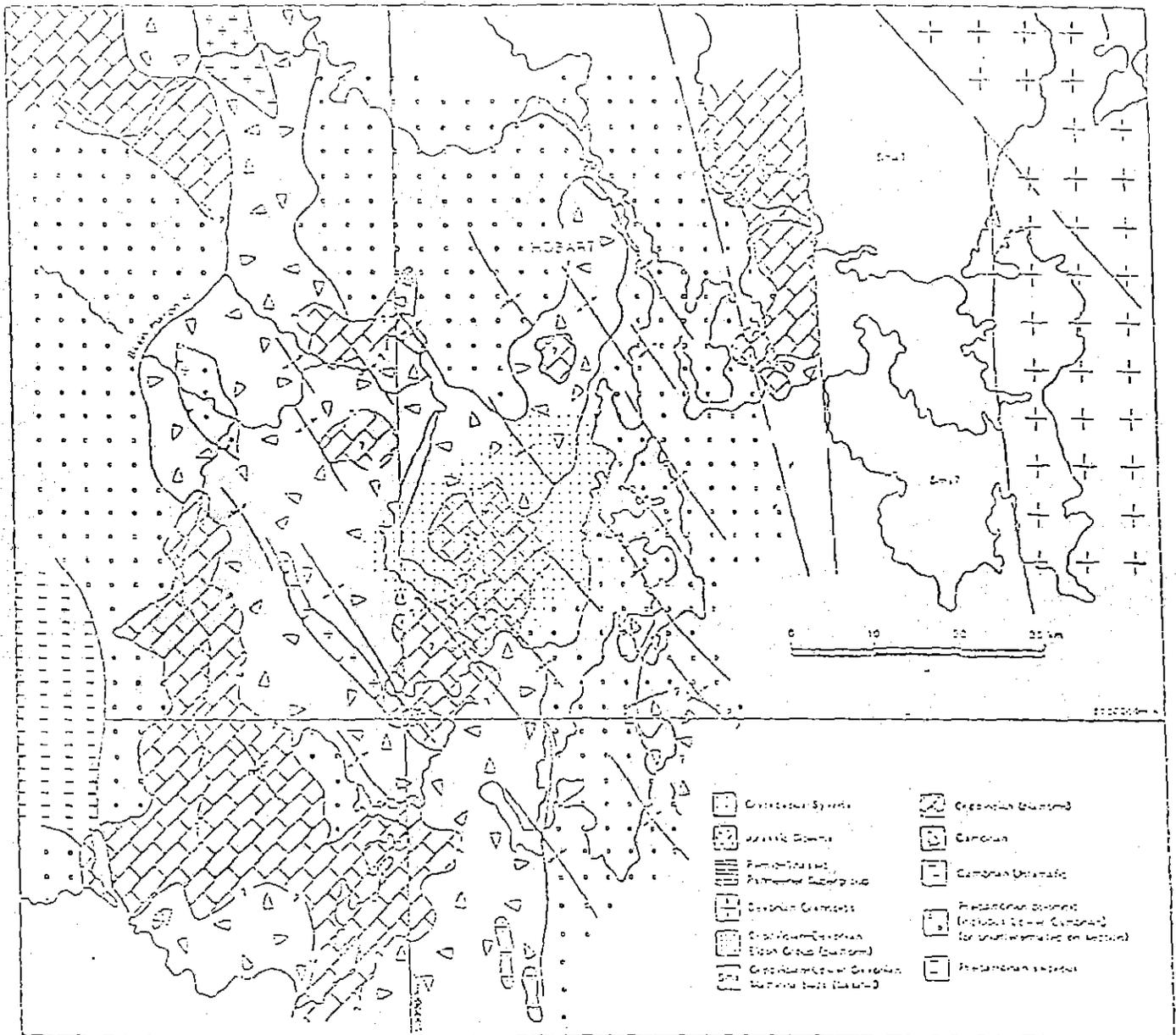


Figure 6. Pre-Permian geological map of southeast Tasmania based on magnetic and gravity interpretations supplemented by sparse drillhole data.



near Clifton Beach south of Hobart (Leaman, 1978). Results of this type suggest that seismic methods are viable when the entire Palaeozoic section is present but that the bulk of the geology beneath the unconformity, for most of the areas sampled, is not strongly stratified and is, therefore, either Cambrian or Precambrian.

LINEAMENTS

The gravity and magnetic data sets define some spectacular lineaments (Fig. 7). An initial outline of these and their relationship to major tectonic elements is provided by Leaman & Richardson (1990).

DISCUSSION AND NEW PLAY CONCEPTS

INTEGRATION

Recent work has shown that the hydrocarbon sightings of the past century are likely to be reliable and that the hydrocarbons have been generated from lower Palaeozoic sources rather than from Permian oil shales. The sightings are reasonably systematic and the patterns are both statewide and correlate well with structural lineaments identified in gravity and magnetic data.

Comparison of sighting patterns and seismic activity in the Tasmanian region suggests that hydrocarbons, as oil or

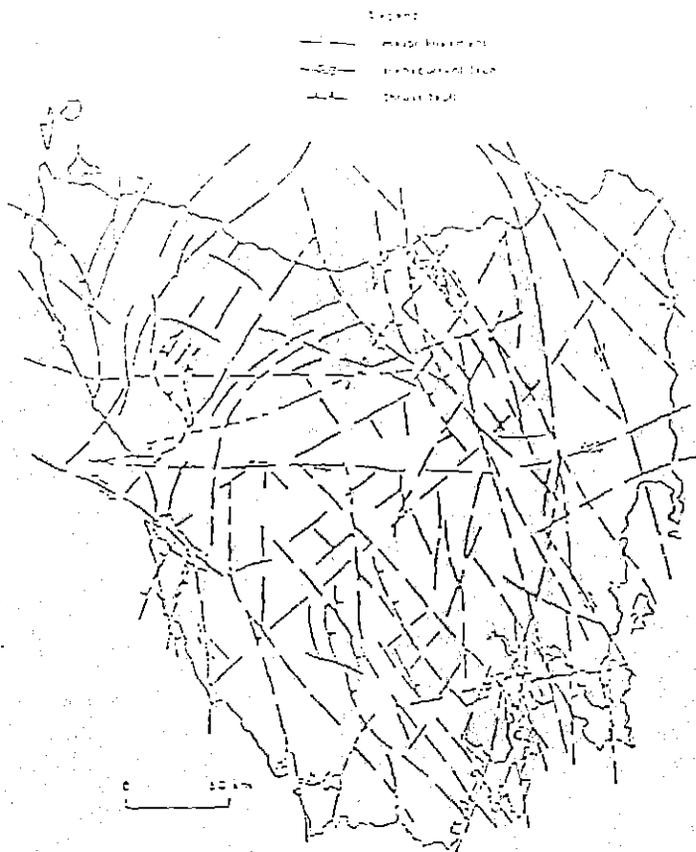


Figure 7. Major crustal lineations based mainly on magnetic and gravity surveys.

tars, are generally observed in the period immediately following intense activity or occasional large earthquakes. A relatively quiescent period since 1957 has decreased release volumes and consequent reports.

Most sightings are associated with either faults or fractures which have post-Jurassic displacements or with intersections of major high angle faults with thrusts.

The evidence suggests that hydrocarbons have been, and perhaps still are being generated and that the reservoir systems are either tight or well sealed. The thrust surfaces or the base Parmeener unconformity may act as sealing surfaces since the materials directly above them are either homogeneous quartzite and dolomitic siltstones or dense mudstones respectively. All possible source rocks have yet to be analysed but hydrocarbons in southern Tasmania have been generated from the Gordon Group. The similarities and differences between seep analyses suggest hydrocarbon generation from at least three other lower Palaeozoic sources.

Reservoir conditions exist within the Ordovician carbonates where they were karstified after folding in the Early Devonian, before being overlain unconformably by Upper Carboniferous siltites. Primary porosities of 15 per cent have been measured in Gordon Group carbonates and larger secondary porosities have been reported. Porosities of about 20 per cent are known in some Early Ordovician siliciclastics.

PLAY CONCEPTS

Many possible play concepts may be envisaged. Simple closed structures involving Ordovician and Silurian source and reservoir rocks may occur at the Parmeener unconformity where medium to long closures (1 to 4 km) are known or beneath the major thrust surfaces. The lower Palaeozoic may occur as a thin residual beneath the unconformity generally but may locally exceed 4 km in thickness where full sequences have been preserved. The pre-Parmeener erosional unconformity cuts Gordon Group limestones at several localities and palaeokarst reservoirs may be expected beneath Parmeener seals. Facies variations within the Gordon Group may also provide stratigraphic trap conditions. Many variations are possible and the most likely target category cannot be defined at the present time, however Figure 8 summarises some relationships and possible plays.

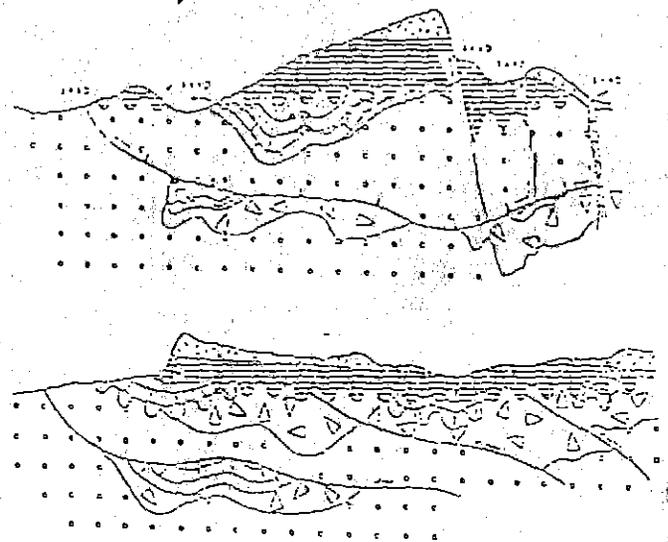


Figure 8. Schematic cross-sections showing possible play concepts in Tasmania. (Stratigraphy is denoted by some symbols as in Figure 5.)

The principal exploration problems at present relate to the location and identification of target successions and possible structures within them. The gravity and magnetic data which have been extensively used to date have been able to define regional structural elements, infer the presence of target successions and suggest fold elements, but are limited in ultimate resolution. Information recovered from these sources is sufficient to set viable stratigraphic targets — essential given the paucity of drilling control available — but not adequate for wildcard hydrocarbon prospects.

Specific prospect definition will not be possible until more seismic data is available and the processing requirements assessed and refined. Seismic surveys can be specific since the potential field data have already defined general target locations. This is considered the most cost-effective approach to the difficult problems presented by exploration in onshore Tasmania.

CONCLUSIONS

Recent appraisals of archived records, preserved tar samples, and structural reconstructions of Tasmania have shown that:

- Most hydrocarbons recovered over many decades have been derived from lower Palaeozoic rocks and not Permian oil shales.
- The potential source and reservoir sequence is largely concealed on an island-wide basis and the exposed rocks, whether of the Carboniferous-Triassic "Tasmania Basin" or the so-called Precambrian basement inliers, are irrelevant to prospectivity assessments.
- Tasmania must be seen as a typical fold-thrust province in terms of its hydrocarbon potential. Several major and minor thrusts are stacked. All Palaeozoic units are repeated and the entire overthrust system has been folded and intruded by granites. Precambrian basement inliers previously considered basement are blocks involved in the thrust stack. Devonian thrusting has been from east to west.
- Hydrocarbons have been produced in some quantity but are probably well sealed, as observations of seeps have only been made after intervals of intense seismic activity.

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