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CONGA OIL PTY LTD

# PERMIAN PETROLEUM POTENTIAL - ONSHORE TASMANIA
# AND 1992 DRILLING PROPOSALS

Six monthly report December 1991 to Dept of Resources and Energy.

# PERMIAN PETROLEUM POTENTIAL - ONSHORE TASMANIA

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## ABSTRACT

All oil source rocks within the Tasmania Basin are within the oil window and every rock evaluation on the source rocks so far completed confirms generated and in place hydrocarbons. Reservoir rocks of the same porosities as the Cooper Basin exist and similarities to the Spraberry oil field west Texas indicate the possibility of major oil finds in Tasmania within the previously overlooked Permian age rocks.

# PERMIAN PETROLEUM POTENTIAL- ONSHORE TASMANIA AND 1992 DRILLING PROPOSAL

## 1 INTRODUCTION :-

The petroleum potential of the Tasmanian Gordon limestone [ Ordovician carbonates and shales ] has been extensively covered in Bendall et al(1990). Recent evidence gathered by Conga oil however, proves that the previously overlooked younger Permian rocks which unconformably overlie the Lower Paleozoic rocks have generated and reservoired oil and gas. The results of work completed on the Permian rocks within the Tasmania basin confirms a Cretaceous heating event[ 100 million years ago] as does recent zircon and apatite fission track data ( Hills pers comm ) therefore further supporting the validity of the Ordovician oil play concept. Thermal maturation trends in the Permian basin will also provide valuable guides for the optimum drill sites for oil in the older rocks.

The Tasmania basin is of Permo-Triassic age and the rocks contained within it are known as the Parmeener supergroup. It covers almost half of the state,its location is described by the yellow colouring in diagram 1. The distribution of the upper and lower units of the Tasmanian Basin Permian sequence are displayed in diagrams 2 & 3. Although many seeps had been reported in the basin and display a distribution implying they are related to structuring no mature source rocks of Permian spore colour alteration and geochemistry confirmed them to have generated and reservoired hydrocarbons.

## 2 REGIONAL GEOLOGY:

In the late Carboniferous-Permian ,a sequence of glacioterrestrial and glaciomarine predominatly siliciclastics (lower Parmeener Supergroup ,Diagram 1 )were deposited unconformably on the older rocks and were succeded conformably by Triassic terrestrial sandstones of the upper Parmeener supergroup (Diagram 2). 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 Jurrasic 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 Paleozoic paleomagnetism and anneal the fission tracks within apatite present in the state.North to northwesterly-trending horsts and grabens were were produced in the general extensional environment in the Late Cretaceous to Early Tertiary and the grabens were filled with up to 1 Km of mainly terrestrial sediments. Many Tertiary volcanic centres are present onshore [ Bendall et al 1990 ].

It is obvious that the shale itself although up to 30% porosity in places (Leaman pers com) and 8.7% interstitial oil as recovered from the oil shale at Latrobe (ref 1), could not hold the volume of oil and gas produced at over 10% generation from the shale.

Effective porosities of 8 to 18% (Sharples 1990) of the overlying sandstones (the Liffy ,Risdon and Triassic ) are therefore important as they represent possible reservoir rocks. Migration of oil and gas into these reservoirs from the Tasmanites source in the middle to upper oil window would have generally filled them to spill (Mulready pers com) and therefore direct comparisons to the Cooper basin flows can be made.The porosity of the sandstone reservoirs in the Cooper basin ranges from 5 to 12% corresponding to production rates of 100 to 600 barrels per day . The major differences between the Cooper Basin and the Tasmania Basin are the depth of reserviors although the shallower Tasmania basin may have flows assisted by gas drives or over pressuring , due to the rapid denudation in the late Cretaceous, pumping will probably have to be employed to achieve the same flow rates from the Tasmanian sandstones.

Seven bore holes within the Tasmanian Basin have recorded mature hydrocarbons (oil); in Gleasons bore (Ross) , Johnstones well and Mines Department holes (Bruny island) , Styx River(Maydena) , Ross #2 ,Tunbridge and the Douglas River holes. The Douglas River and Ross #2 core bled live oil , tar spots were present in the Ross #2 , upon cutting (E.W.Domack pers com) and the

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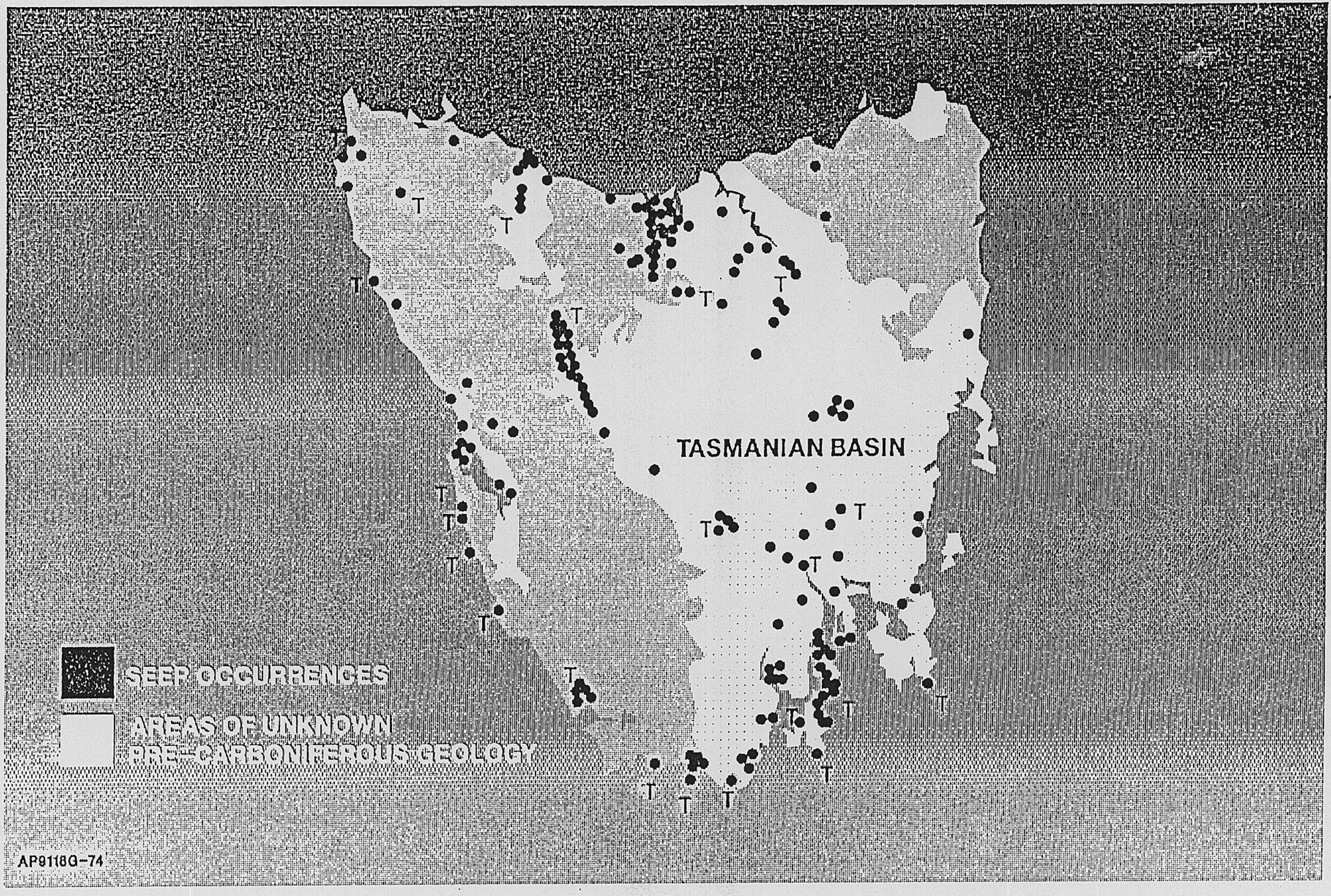

DIAGRAM 1-Tasmania basin plan

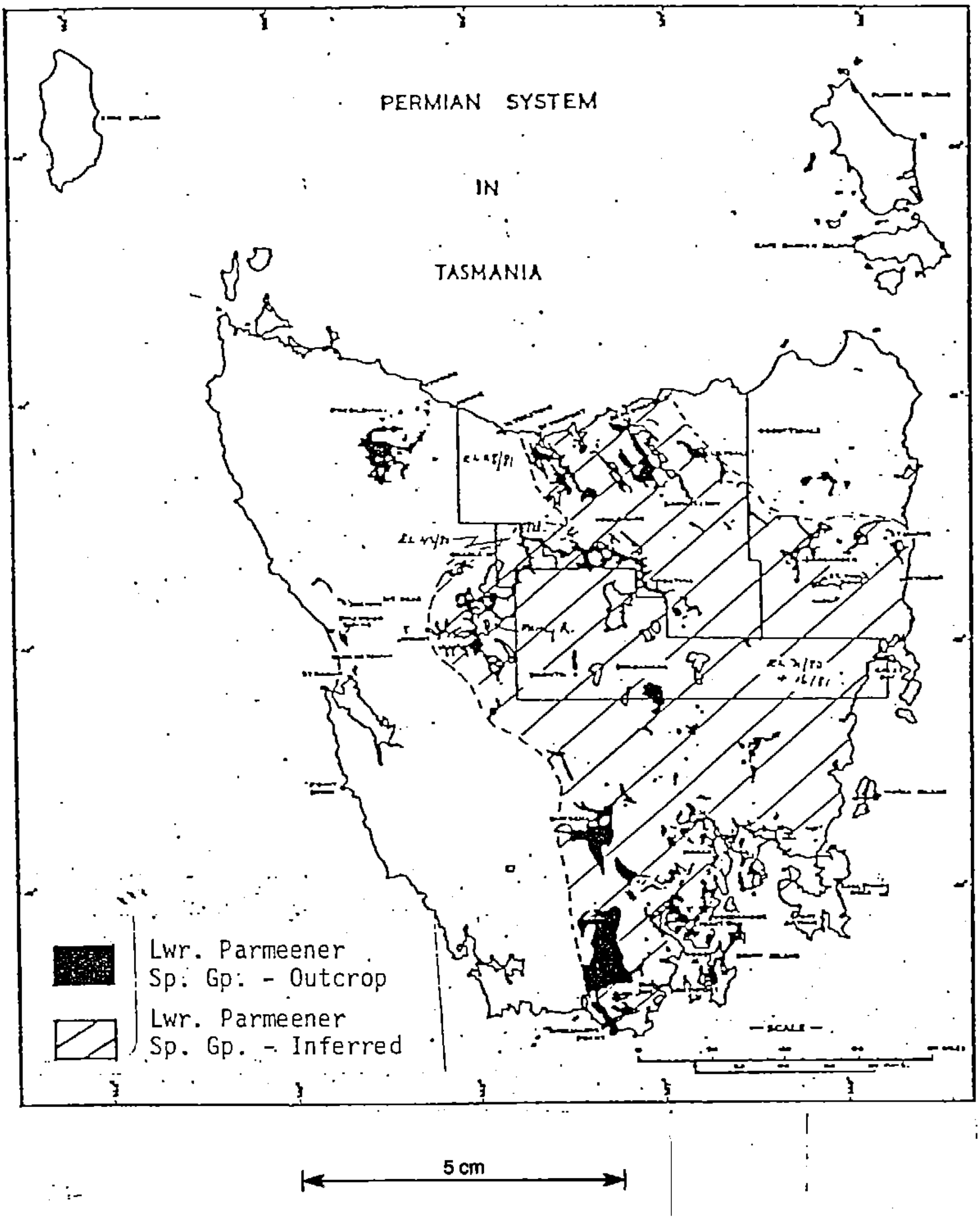

DIAGRAM 2-Permian system distribution lower

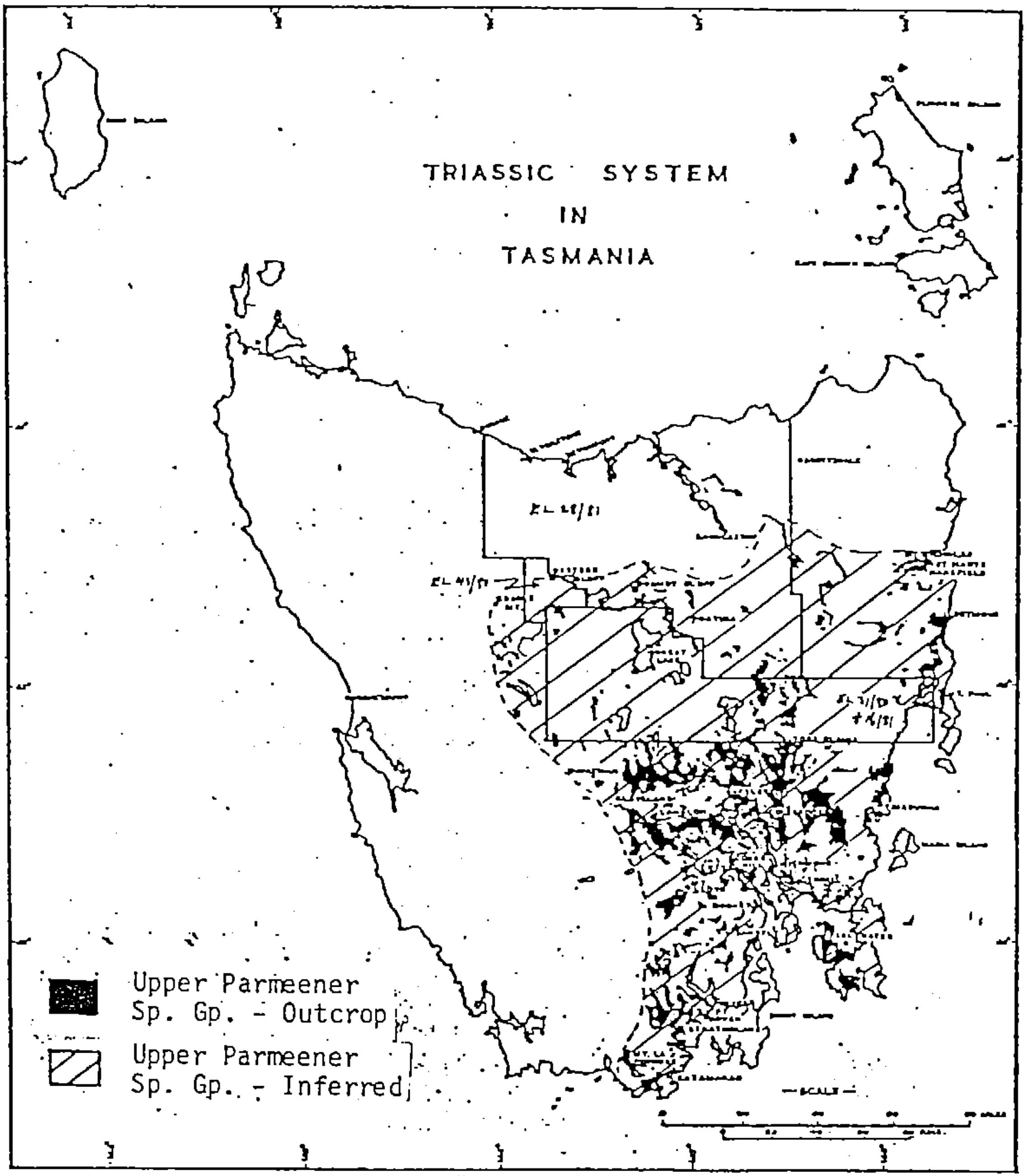

DIAGRAM 3-Permain system distribution upper

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age were thought to exist. The basin had been regarded as too shallow and therefore too cold to have produced oil and gas. A world class source rock ,the Lower Permian Tasmanites oil shale, had been mined from 1910 to 1932 recovering 248,114 gallons of oil by artificial distillation (Ref 1) but no natural generation of oil from the rock was thought to have occurred.

Recent results (Refs 1,2,3,4,5,6,7) have proved that the Tasmania Basin is in the oil window, grading from .7 vitrinite reflectance [ lower oil window ] at the edge of the basin to 1.35 vitrinite reflectance [ upper oil window ] at the centre of the basin. This means that the source rocks in the basin have generated oil and wet/ dry gas in proportion to the degree of heating that they have received which in turn is a function of depth of burial and crustal heat flow . Diagram 4 displays this range of petroleum generation outlining the different ratios of oil to gas at different temperatures. The heating range in the Tasmanian basin is indicated, the lower oil window producing 10-20 gallons per cubic metre oil (Ref 2) and the upper limit producing up to 100 gallons per cubic metre oil and 2700 cubic feet of gas per cubic metre. From distillation results (ref 1) the shale produces 3.8 gallons per cubic metre of oil per % Total Organic Carbon [ T.O.C ]. In the Douglas River drill hole the T.O.C maximum was 30% (Ref 3), giving a total potential generating capacity of 114 gallons per cubic metre, as it is only in the lower middle oil window it has generated less than this.

DIAGRAM 4-Chart of organic maturation range

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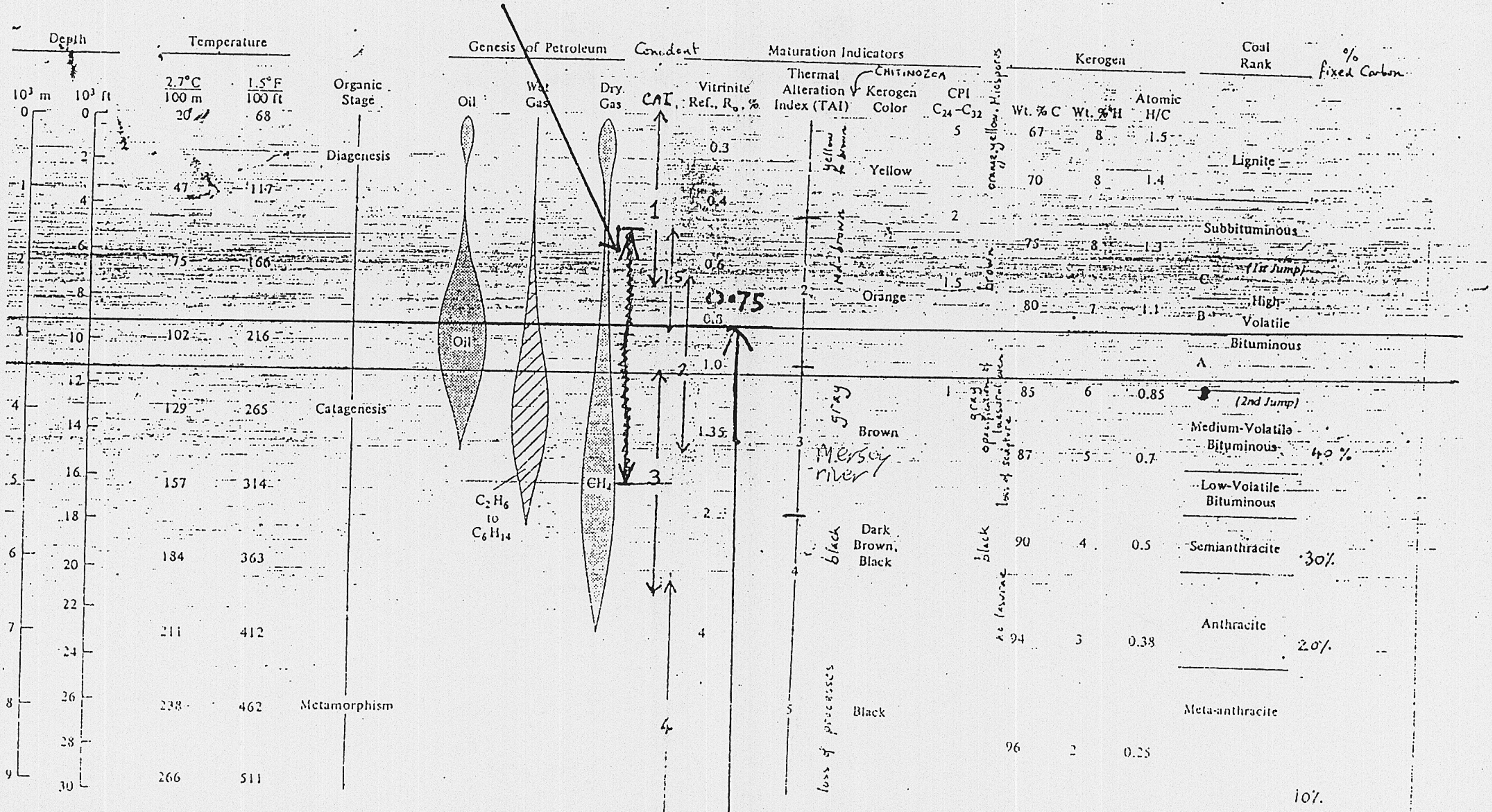
range indicated by Model.



result of sample

Figure FROM HUNT, 1979.

Chart of organic maturation $R_o$ = reflectance with oil immersion objective; CPI = correlation preference index. Maturation data are for an Eocene mixed-kerogen type. [Maturation limits from Dow 1977a; Staplin 1969; Teichmüller 1974]. Conodonts (CAI) from Epstein et al 1977. Hiospores & Chitinozoans from Cramer; 1972.

charley Cer.

TOC [illegible]

## 3 GEOTHERMAL HISTORY

The type of kerogen will determine the amounts and temperatures at which either wet and dry gas or oil are generated. Minimum temperatures are required to generate hydrocarbons from kerogen (preserved organic matter from past living organisms) and at maximum temperatures hydrocarbons generated will be destroyed. Therefore the geothermal history of the basin is important in determining its hydrocarbon prospectivity. Previously the Tasmania basin was thought to be too cold to have generated hydrocarbons ,however maximum heating temperatures have been recorded by irreversible colour change of the source kerogen and indicate graded heating from the centre to the edge of the Tasmania basin. Supporting the kerogen data are geochemical results indicating mature hydrocarbons generated and in place within the pore spaces of Tasmania basin rocks. Those hydrocarbons also indicate by changes in their chemical composition the maximum temperatures obtained and their presence proves the Tasmania basin is a hydrocarbon provence. The different types of maturity meters are listed below along with results relevant to the Tasmania basin.

### 3.1 -Geochemical maturity

The aromatic fraction of the hydrocarbons extracted by the C.S.I.R.O from the rocks in the Permian basin can give an indication of thermal maturity , this measure is called the Methyl phenanthrene index ( M.P.I.). The M.P.I is calculated from the abundance of

Phenanthrene and methyl phenanthrene isomers according to Radke et al (1983) and can be used to give vitrinite reflectance equivalent values for the rocks. This usually gives a reasonable indication of the degree of thermal maturation to which the source rock has been subjected, but the values must be treated with some caution.

Permian , Quamby Formation rocks have been analysed and have returned the following results:-

| LOCATION | VIT REF EQU |
|---|---|
| -Preolenna | .60 |
| -Golden valley | .70 |
| -Poatina | .75 |
| -Douglas river | .60 |
| -Ross#2 | 1 .35 |
| -Tunbridge | 1 .35 |

## 3.2 -Vitrinite reflectance

Vitrinite reflectance data from around the state indicates a range of results from .7 to 1.35 , an anomaly with this data appears to be that the upper coals seem to have been heated more than the lower coals this anomaly may be due to the Jurassic dolerite intrusions.

## 3.3 - Thermal alteration index (T.A.I)

This index is based upon the fact that with increasing temperature spores irrevocably alter colour. Each colour indicates a temperature range from 1 to 5 (diagram 4 ) ranges 2 and 3 indicate the lower and upper temperatures for the generation window any colder and oil will not be generated or any warmer and generated oil will be destroyed. The range of indicated maximum heating based upon the T.A.I values for the Quamby Mudstone within the Tasmania basin is listed below in table 3. The results indicate all samples are within the oil window.

TABLE 3

| Location | T.A.I | observer |
|---|---|---|
| Mersy river(headwaters) | 3 | |
| Bronte | 3 | |
| Styx river | 2 | Summons,1981 |
| Quamby brook | 2 | |
| Poatina | 2 | -------------- |
| Tunbridge | 3 | |
| Ross #1&2 | 3 | Domack,1991 |
| Douglas river | 2 | |
| | | -------------- |
| Great mersy bend oil shale | 2 | Powell,1985 |
| Golden valley | 2 | |

### 3.3 -Modern geothermal gradients

#### (a)Heat flows

Units of W / M2 are used to measure surface heat flow (Q) this is related to thermal conductivity (\,in units of W/ M / C ) and the geothermal gradient( B,in units of C / M )by the expression Q = \ B. Tasmania currently has an abnormally high heat flow which is up to approximately twice the world average of 60 mW / M 2.The heat flow map of Tasmania (Lilley et al,1978) reported Q values ,in mW / M 2 ,for Tasmania as follows:-

| | |
|---|---|
| Storys creek ( Mathinna group sediments ) | 150 |
| Rosebery ( Cambrian schist ) | 120 |
| Central plateau ( Dolerite ) | 75 -100 |
| Glenorchy ( Parmeener Super group - C volc ) | 87 |

### (b)Geothermal gradients

Present geothermal gradients onshore Tasmania are 30-40 C / Km ( Summons,1981).The down hole results of the Tunbridge bore hole indicate 41 C / Km and Coles bay bore hole 30 C / Km both were logged by the B.M.R.. Shell logged the Douglas river hole ( B.P.B.Loggers ) giving a result of 30 C / Km.

## 4 COMMENTS ON OIL SOURCE ROCK KEROGEN

Kerogen is organic matter which occurs in three main forms , when it is subjected to the right geothermal history it produces oil and wet/dry gas , in proportion to the temperature and original kerogen type and abundance. All three types of kerogen occur in Tasmania and have all generated oil and gas.

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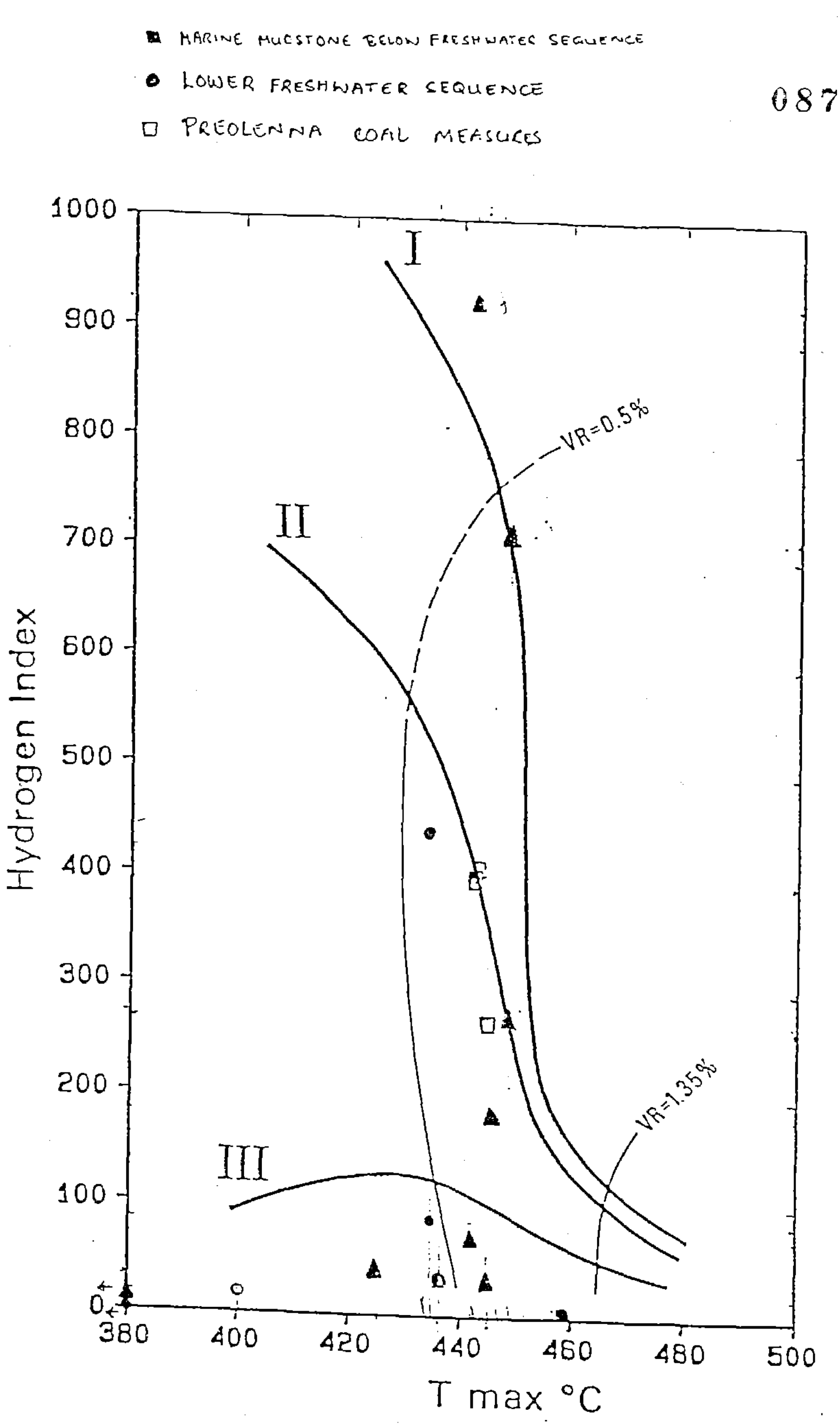

DIAGRAM 5-rock eval results

DIAGRAM 6-rock eval results

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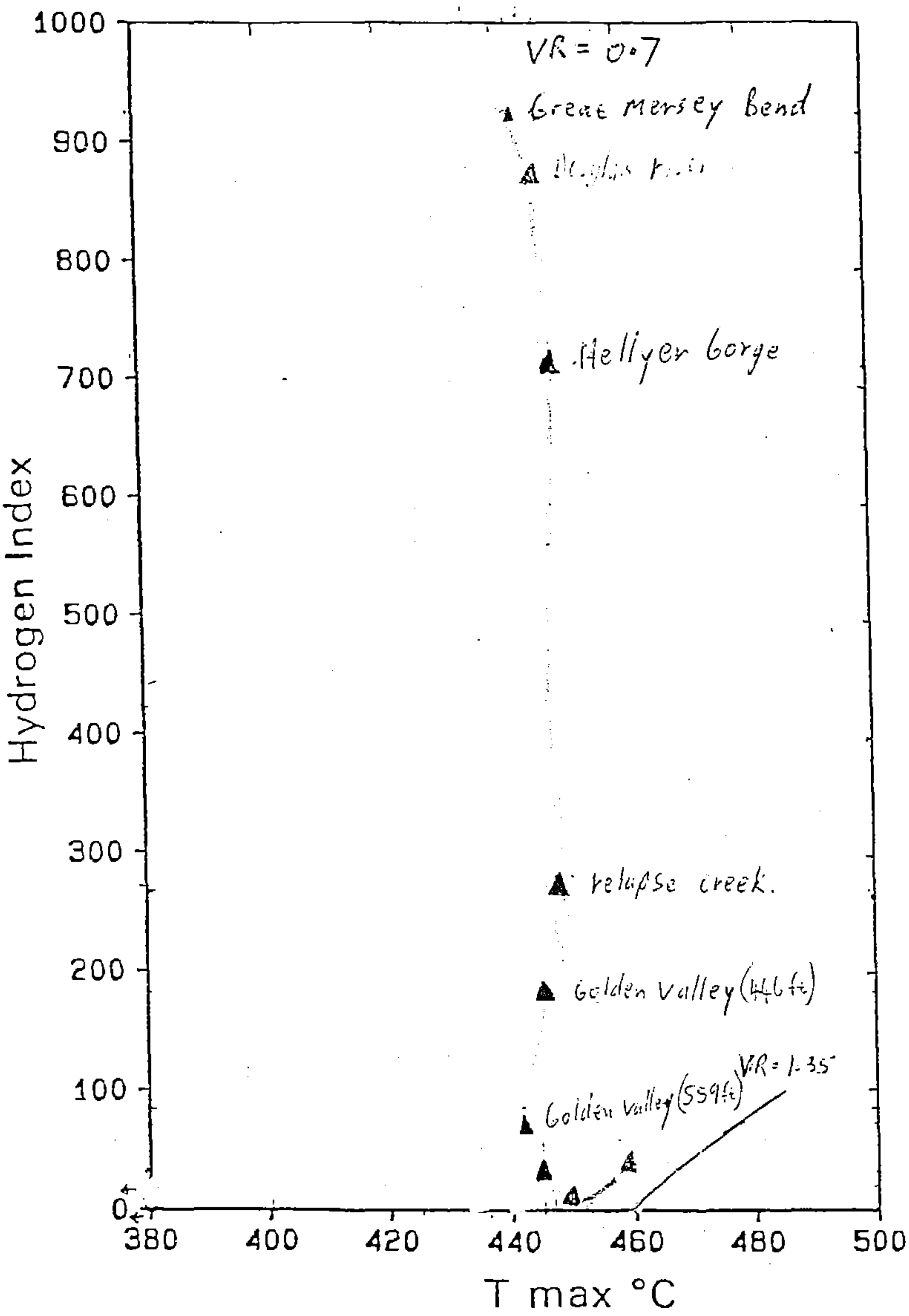

## 4.1-Tasmanites type 1 kerogen

Diagrams 5 & 6 show Rock evaluation results for the Tasmanites oil shale, samples 84cp8 (great mersy bend oil shale) and 84cp9 (Hellyer gorge), displaying excellent source rock characteristics including 65 - 100% exinite. The results reveal the Tasmanites is Type 1 oil prone kerogen with hydrogen indices in the range 700 to 950 and T max values of 442 C and 449 C. Because of the high concentrations of carbon and hydrogen naturally occurring in the rock the productionof hydrocarbons can occur at low vitrinite reflectance values. The B.M.R.(1991) have determined that the generation of hydrocarbons can occur at .4 vitrinite reflectance implying the generation of hydrocarbons starting at depth burials of just over 1 Km. The Santa Barbra oil field in California has similar diatomaceous kerogen in Miocene rocks and has oil production at similar low vitrinite reflectance values (Domack.E.W pers com).

## 4.2 -Preolenna coal type 2 & 3 kerogen

From diagrams 5 & 6 it is clear that this source is types 2 & 3 kerogen based upon the low hydrogen indices and T max values confirming it is an oil prone terrestrial kerogen. This source is similar to other non marine (fresh water) oils found elsewhere in Australia for example,the Cooper basin. Diagram 6 plots the maceral composition of the coals showing 39% to 88% inertinite confirming their source rock potential.

## 5 OIL SOURCE ROCKS

The potential oil generating capacity of the source rock kerogen types is covered in chapter 4 ,the actual oil generated by that kerogen by empirical measurement is the focus of this chapter.

### 5.1-Tasmanites S1 & S2

It is apparent (James,C.E.(1935)) that about 20% of the total oil recoverable from the kerogen is recovered at under 200 C, implying it to be already generated interstitial oil.

The standard rock eval S 1 measurement is taken to represent hydrocarbons present intersticially in the rock , either generated and in place or migrated into the rock , is taken as hydrocarbons expelled by rapid heating up to 200 C. The S 2 measurement is thus hydrocarbons generated from the source kerogen then recovered from 200 C to 480 C. S1 and S2 results for Tasmanites oil shale determined by Powell.T.1985 ( appendix 2 ) and James.C.E.1932 are listed in table 4 along with recent results from Rodger Summons (B.M.R. pers com). These show S1 results of 15 Kg per tonne or 16 litres per tonne (8 gallons per cubic metre) of interstitial hydrocarbons present in the Tasmanites band at the Great Mersey bend .

TABLE 4 Rock eval and organic carbon data

| ROCK TYPE (LOCATION) | ORG | S1 | S2 | ltrs oil per |
|---|---|---|---|---|
| | C% | Kg per tonne | | cubic M |
| Tasmanites oil shale | | | | |
| ( Great mersey bend ) | 25.65 | 15.02 | 236.80 | 32.30 |
| ( Douglas river )* | 30.00 | 5.80 | | 12.00 |
| | 17.00 | 6.28 | 147.53 | 14.00 |
| ( Tunbridge bore #2 ) | 2.8 | 0.56 | 0.92 | |
| ( Ross bore #2 ) | 1.19 | 0.15 | 0.09 | |
| Preolenna coal measures | | | | |
| ( Relapse creek ) | 25.43 | 10.10 | 102.4 | 21.72 |

* calculated from E.O.M on IATRA C.S.I.R.O

[Oleary .T 1991.]

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James.C.E,(1932) calculates that after deduction of 6% of the dry weight of the shale from the kerogen percentage, the shale produces approximately 1.9 gallons per ton per percent kerogen. At normal T.O.Cs for the Tasmanites (24 to 33%) a quick calculation for oil production from the kerogen per 1 percent is 1.5 gallons per tonne oil. This calculation when applied to the Tasmanites horizon at the Douglas River hole means , at

30% T.O.C ,it has potential to generate by end of oil window over 2 barrels (90 gallons or 409 litres) of oil per cubic metre plus over 2,700 cubic feet of gas. However table 3 indicates that the shale at Douglas river is in the lower oil window and table 4 indicates that it actually has generated and reservoired 14 litres per cubic metre of oil at .6 vitrinite reflectance and some gas was seen escaping the drill hole in an unknown proportion (Leaman pers comm).

### 5.2-Quamby

In the Ross #2 bore hole Domack (1991) identified a section above the Tasmanites horizon which recorded a T.O.C of 16% . No other data is availiable at this stage but the discovery of another source rock within the Quamby Mudstone is interesting as it may have a distinctive chemical signature of its own and will now receive some attention.

### 5.3-Proelenna coal S1 & S2

Table 4 shows the S1 results for the coal measures at .49 vitrinite reflectance , it indicates 10.10 Kg per tonne generated and in place hydrocarbons and 102 Kg per tonne of available S2 if heated through the oil window . Recent GC-MS results (volkman 1991) confirm extractable hydrocarbons in the coal measures to be mature and to have similar geochemical biomarkers to tar occurrences at Bridgewater and South Bruny Island and a show of liquid oil at Tunnack.

## 6 OIL RESERVOIR ROCKS

### 6.1-Quamby mudstone(Tasmanites)

Porosities of up to 30% (Leaman pers comm) have been recorded in this horizon. Domack (pers comm) concluded from thin section data that there was porosity in the rock and because of flattening of the Tasmanites spores there was lateral permeability. Gas flowing from the Douglas River hole supports some lateral permeability in the horizon as does elevated temperature in the Tasmanites horizon in the Tunbridge bore hole. Fractures observed in numerous outcrops, including Poatina and the Styx River and in B.H.Ps bore hole at Styx River suggest a possibility of fracture enhanced permeability. Comparisons can be made between the Spraberry formation (Texas) and the Quamby formation as they are similar rocks that have been fractured on a basin wide scale due to extensional crustal forces (Wilkinson.M.(1953)) and both sources are within the oil window. Mac Forster who commissioned the report by Summons,(1981) also travelled to Texas to review the similarities of the two rock types. He reported them to be identical in hand specimum and fracturing characteristics.

### 6.2-Liffey Sandstone (Preolenna)

The Liffey Sandstone is the first sandstone horizon in the lower Permian above the Tasmanites oil shale and most importantly is associated with the Preolenna Coal Measures (chpt 4.2). The effective porosity range of this sandstone, as measured by Amdel 1981 was 10.66 - 11.99 percent .At Preolenna a tar probably sourced from an Ordovician shale is present as a fossil reservoir and indicates good permeability for the sandstone.

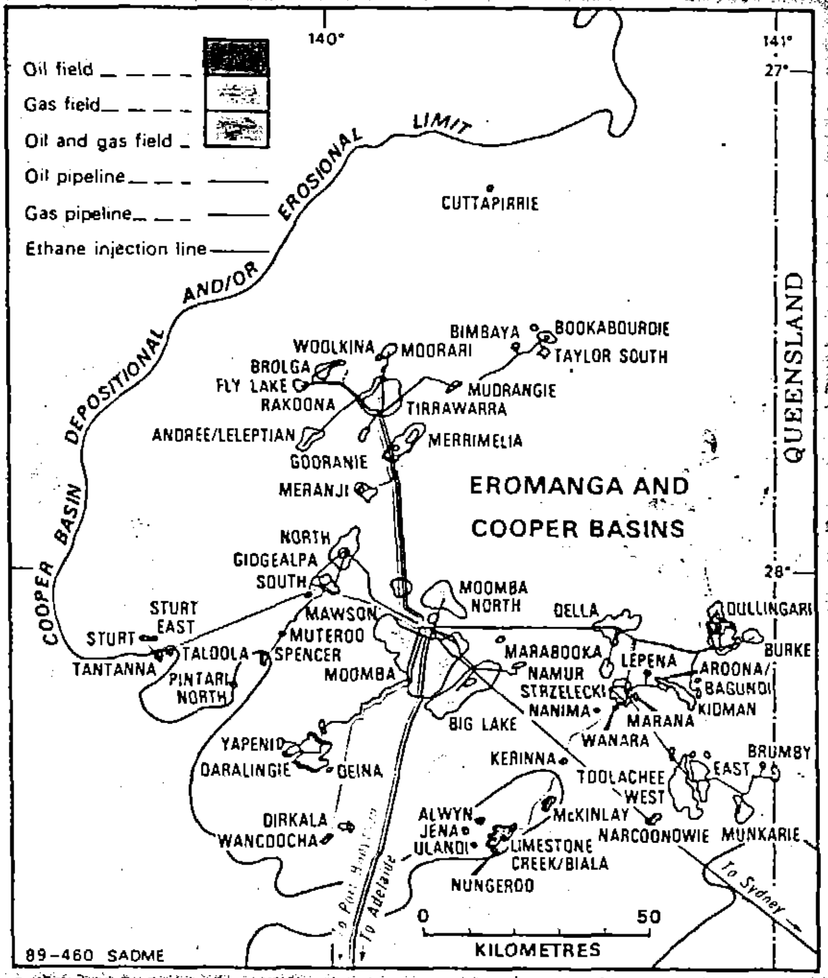
### 6.3-Risdon sandstone

Although no porosity data is availiable Prof.Sam Carey (pers comm) recalls he always got his students to smell the hydrocarbons present in the rocks outcropping at Risdon, a suburb of Hobart.

## 7 RESERVOIR POTENTIAL CALCULATIONS

To get the oil potential of the Permian Tasmania basin in perspective it is useful to compare some effective porosity and maturity data to known currently producing oil fields . Two useful comparisons are the Cooper basin ( S.Aust ) for production from similar sources (freshwater coals) and sandstone reservoirs with similar effective porosities and the Spraberry field (Texas) as it has source rocks with similar physical characteristics and has undergone the

DIAGRAM 7-Cooper basin plan



*Producing oil and gas fields*

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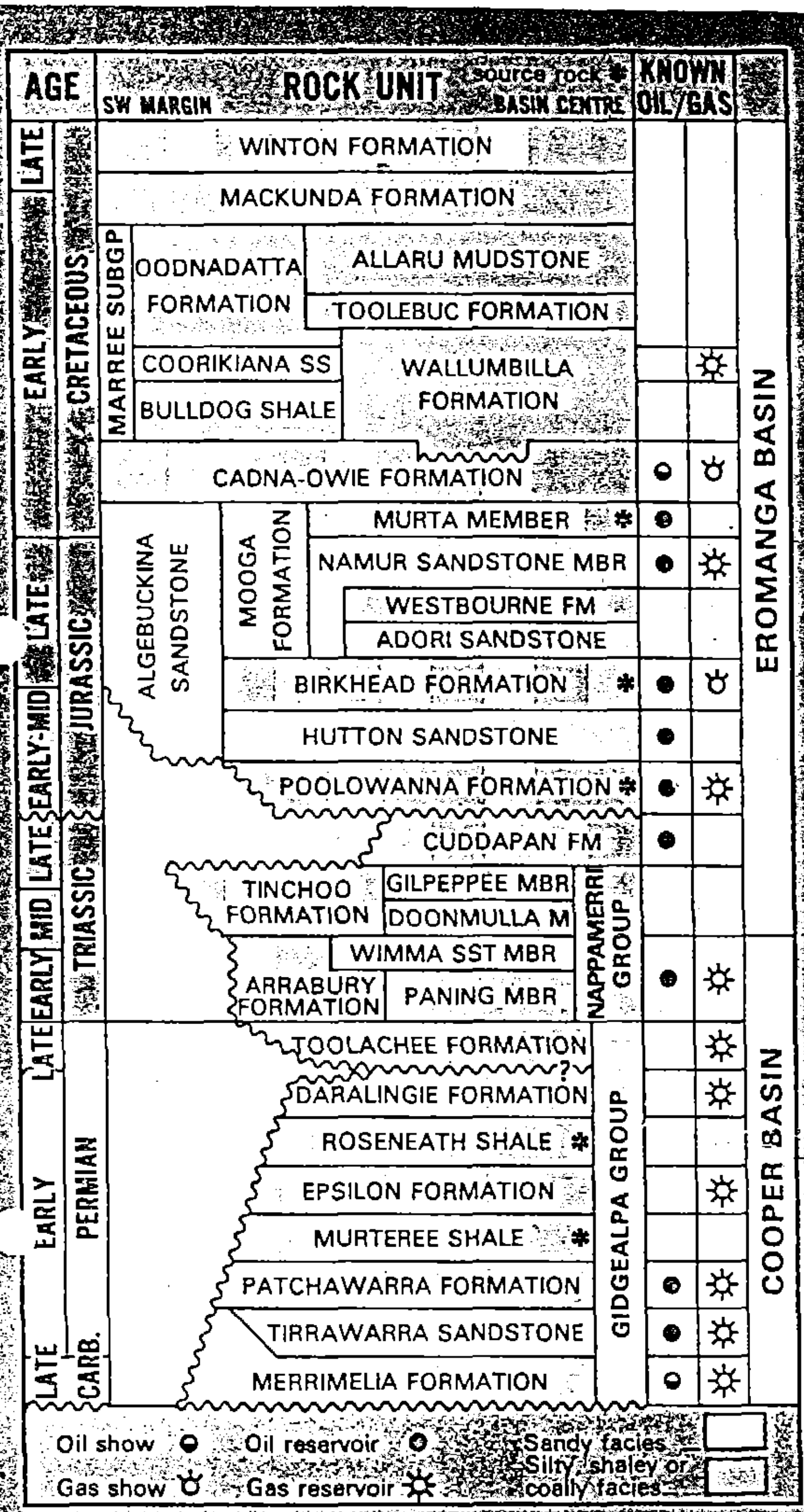
DIAGRAM 8-Geological summary of the Cooper Basin



*Stratigraphy*

same expansional brittle fracturing as the Tasmania Basin Quamby group which includes the Tasmanites oil shale .

## 7.1 Permo-Triassic Cooper basin comparison

The Cooper basin freshwater fluvial sandstone reservoirs porosities range from 5 to 12% corresponding to Production rates of 100 to 600 Barrels per day. Diagram 8 shows the size of the Permo-Triassic Cooper Basin within South Australia and the known gas/oil fields. Diagram 9 shows the geological summary for the Cooper basin , the major similarity to the Permo-Triassic Tasmanian basin are that both have vitrinite reflectance ranges from .7 to 1.35 and have fluvio-deltaic sequences comparable with the Preolenna coals and liffy sandstones.

## 7.2 Permian Spraberry formation (West Texas) comparison.

Wilkinson.M.(1953) describes the extent (150 miles long , 50 miles wide) and the geological setting of the oil production gained by drilling the Permian Spraberry formation. Being similar to the Tasmania basin Permian Quamby group it shares the characteristics of being brittle and when stressed creates a lattice of micro and macro fracturing allowing hydrocarbons generated in the rock to migrate latterally. As opposed to the Texas gushers sourced by the Ordovician Trentonian limestone (Tasmanian Gordon limestone equivalent ) Donkey pumps are generally used to help the flow of oil into the drill holes from the Spraberry formation and "fracking" techniques (over pressuring the hole and introducing sand to hold open the fractures) to improve oil flows are also generally used.

The production gained from the Spraberry field ( with a porosity average of 8.4% ) just 3 years after discovery was 2.744 million barrels in one month ( April 1953 ) (Wilkinson.M.(1953)) indicates the potential of the Quamby formation to be a satisfactory reservoir capable of producing large quantities of oil and gas. In the Spraberry formation the average per acre production ( Warn.g.f. 1953 ) was 2,000 to 10,000 barrels with 400 to 800 barrels per acre recovery, total primary recovery from the Spraberry formation is 5-10 percent of the oil surrounding the well. Optimum well spacing appears to be one per 16 acres.

## 8 PROPOSAL FOR PROSPECTIVITY ASSESMENT

Holes previously drilled have had shows of oil and gas , geochemical analysis has proven that oil to be mature and implied sources related to both Permian and Ordovician rocks. It is proposed to drill small diameter stratigraphic wells and assess the source rock potential to determine if the rocks have the potential to source commercial oil fields. Because of the availability of infrastructure and markets even small fields or flows may be economic (Mulready 1987). The three drill locations below have been suggested out of six possible locations

(Johnstoneswell,Rosswest,DouglasRiver,Sorrell,Hamilton, Southport ) however further seismic work will have to be undertaken to confirm these proposed locations.The three sites below have been proposed because of their importance to verify the implied stratigraphic sequences, below hydrocarbons seen in drilling and in the core or surrounding rock.

## 8.1 Johnstones well Bruny island

In 1929 the then Director of Mines, Macintosh Reid, confirmed oil and gas seeping into Johnstones well on North Bruny Island. The Tasmanian oil company was subsequently established in late 1929 and took 6 months to drill a hole to the depth of 30 metres. The hole drilled through a mudstone sealing rock into a sandstone reservoir rock which flowed oil and gas. The oil was collected in containers until they were all filled .No further action was taken until the mud around the hole was analysed in 1987 and found to have oil traces with an Ordovician type of signature. This confirmed the validity of the previous observations along with a show of oil in a Mines Department drill hole on the southern end of the Bruny island neck in 1990 . That oil in loose sand at a depth of thirty metres showed iatra scan results implying a distribution of aliphatics to aromatics similar to oils which on subsequent G.C.M.S analysis proved to be related to an Ordovician source.

It is intended to drill a stratigraphic hole with thru the Permian rocks on Don Hazells property Murray field 50 metres east of the original bore hole.

The hole will be continued thru the Permian (700 metres) to determine the nature of the underlying rock , and the maturity of the Quamby mudstone (Tasmanites) horizon. The cost of the hole will be 700 metres at $80.00 per metre giving a total cost ,with $30,000 incidentals of $90,000 dollars.

## 8.2 Douglas river drill hole

In 1980 Dr David Leaman supervised the drilling of a diamond drill hole beside the Douglas River bridge as part of the Mines Department coal assesment program. That hole was continued past the coal measures to the pre Permian Mathinna beds. The hole flowed gas in the Quamby mudstone (Leaman pers comm) and Clive Calver et al (1984) reported two seams of the Tasminites oil shale between 320 and 321.5 metres . It was not until Domack 1988 that free oil was identified in the core and T.A.I indices measured indicated that it was in the lower oil window. In 1991 the core was cut and given to Dr John Volkman [ C.S.I.R.O Hobart ] for analysis by G.C.M.S and iatrascan to determine the composition, origin and thermal maturity of the oil. His results confirmed the oil to be mature at a vitrinite reflectance equivalant of .6 and consisting of 62.6% aliphatic hydrocarbons, 26.9% aromatic hydrocarbons and 10.5% polar material from a total extractable organic matter (E.O.M) of .58% or approximatly 12.6 litres per cubic metre ( 3 gallons per cubic metre E.O.M ) B.M.R rock evaluation results concluded similar concentrations of oil.

It is intended to drill to the Tasmanites horizon at 322 metres to test the source horizon going 30% T.O.C with a HQ diametre hole and recover core samples of rock for analysis . If the rocks contain sufficiently high abundance of hydrocarbons it would justify a production assessment hole . That hole would then be completed and fracted to enhance the recovery and a donkey pump installed . A flow of 100 barrels per day could reasonably be expected ( see chpt 7.2 ) and would bring a gross income of $730,000 per annum for the oil plus whatever the value of gas which was also recovered and stored.

The cost of the drilling would be 330 metres times $80 per metre plus $30,000 incidentals giving a total of $56,400.

### 8.3 Ross #2 drill hole

IN 1985 the Ross #2 bore hole was drilled ( 480 metres ) in the Permian to the pre-Permian by the Department of Mines under the supervision of Steve Forsythe. Tasmanites was not identified in the hole until Domack 1988 did T.O.C and thin section work proving its existence at a depth of 410 metres. Domacks student Donald Campbell has confirmed in writing that the core bled oil upon cutting and that there was visible tar in thin sections cut from the horizon. Some core was cut for analysis from near the Tasmanites horizon and analysed by John Volkman at the C.S.I.R.O using iatrascan and G.C.M.S techniques. The iatrascan results showed the oil to be 81.1% Aliphatics, 3.3% aromatics and 15.6% polars. The G.C.M.S results showed no distinctive biomarkers just a large unresolved complex mixture ( U.C.M ) identical to that observed in the Quamby mudstone at Styx river. This U.C.M consists of a very complex mixture of branched and cyclic alkanes that cannot be resolved into individual components , even by the high resolution capillary colmns used . Small amounts of U.C.M , were also observed in the mature oil in the Quamby mudstone at Poatina .

It is intended to drill 20 kilometres to the West of that hole to test the depth and thermal maturity of the Tasminites horizon at 500 metres at a cost of $80 per metre plus $30,000 incidentals totalling $70,000 for the hole.

## 9 SEISMIC RESULTS

### 9.1 Onshore

Richardson(1987) outlines the location and field specifications of a seismic survey carried out on Don Hazells property at Murray Field, North Bruny island. Diagram 10 shows a copy of those results indicating very poor reflections due to the interferance of high velocity dolerite sills and dykes at or near the surface. Previous attempts to identify reflectors beneath the Permian cover by David Leaman at Leslie vale and at clifton beach did indicate reflectors at depth and further follow up work in those areas as well as other parts of the state is required.

## 9.2 Offshore

In 1988 the B.M.R undertook a joint project with Conga Oil collecting 260 kilometres of marine seismic around Bruny Island and Storm Bay. Upon processing the data was revealed to be of poor quality and because of the lack of down hole shots no accurate velocity data was available to set realistic velocity ranges for correct migration of the data. Shell Australia joined the research in 1990 and acquired the data from the B.M.R and restacked the data clarifying it considerably,but again lack of down hole velocity data and appropriate velocity assumptions has hampered processing ( Leaman pers comm ). One problem is that Australian processors seem unable to accept the abnormally high velocities of the Permian rocks of 4,000 metres per second and dolerite near surface velocities of 6,000 metres per second . A contribution by the Tasmanian Department of Resources and Energy to help cover, with short lines,the six proposed drill sites and then down hole shots to correctly record the seismic velocity of the Permian and Ordovician rocks once the holes were drilled would be enormously benificial to the state and to Conga oil.

## 10 ACKNOWLEDGEMENTS

Thanks is given to David Gravestock,David Leaman and Rod Hargreaves for their help in presenting this report.

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# APPENDIX 1 - Bendall et al 1990

# 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 botryococcane-rich South Australian bitumens. The predominance of $C_{27}$ 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 1880–1935 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 1939 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

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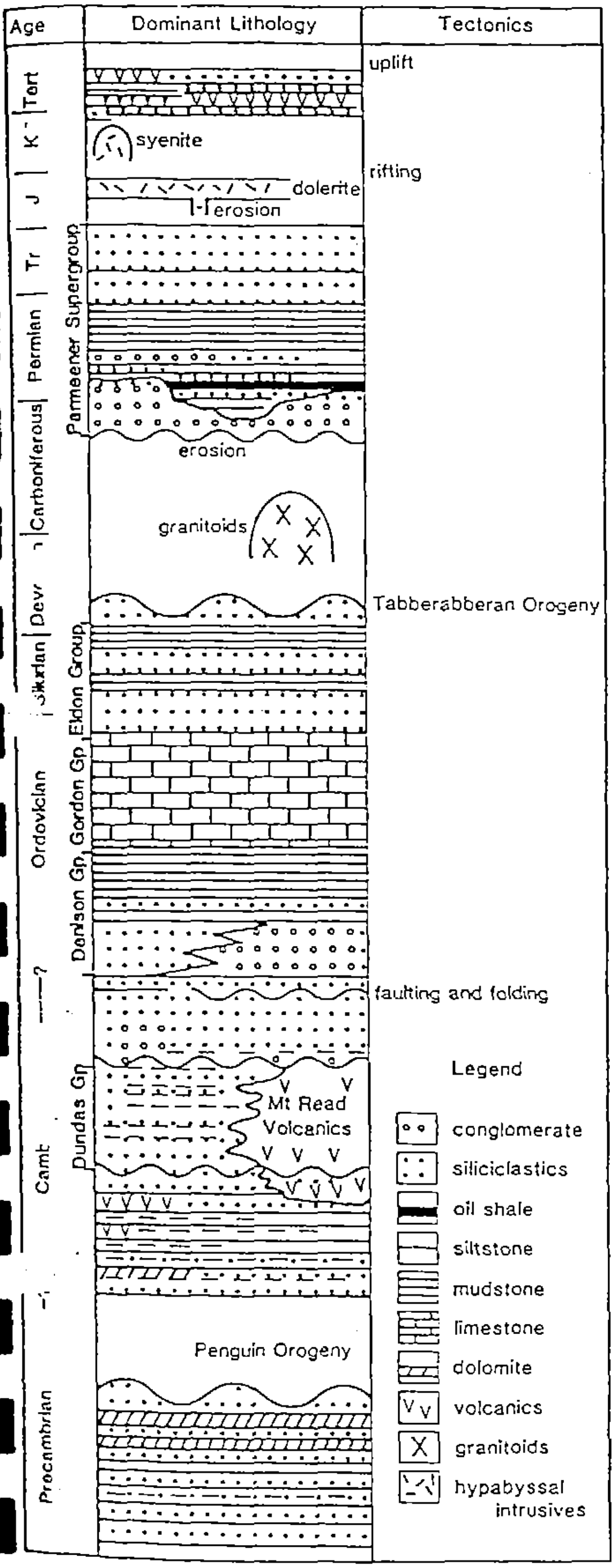

Figure 1. Highly generalised geological column for Tasmania.

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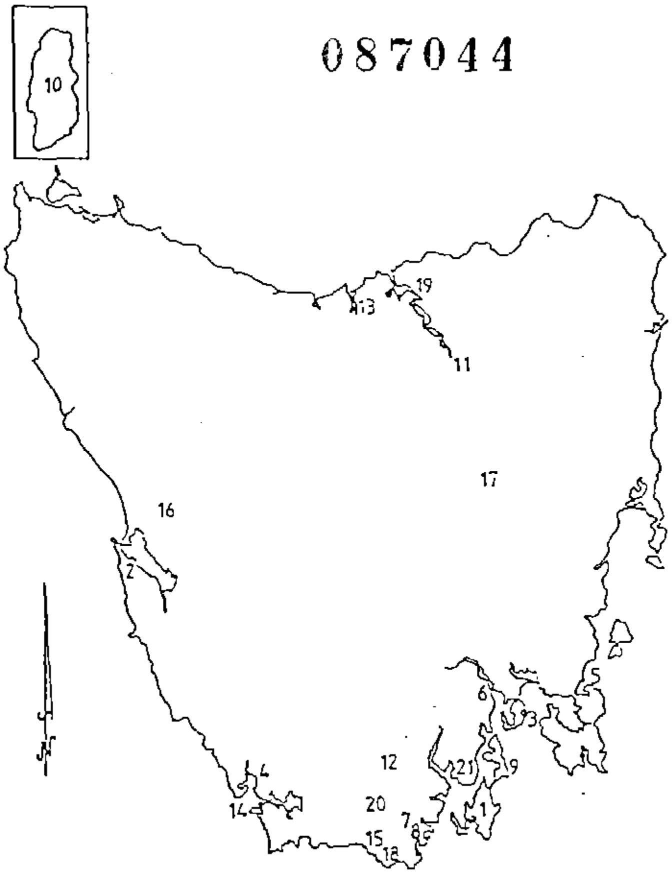

Figure 2. Locality map. 1=Bruny Island, 2=Cape Sorell, 3=Clifton Beach, 4=Deep Creek, 5=Dunalley, 6=Hobart, 7=Hastings, 8=Ida Bay, 9=Johnson's Well, 10=King Island, 11=Launceston, 12=Picton River, 13=Port Sorell, 14=Port Davey, 15=Precipitous Bluff, 16=Queenstown, 17=Ross, 18=Surprise Bay, 19=Tamar River, 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 Burrett and Martin (1989). 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 750 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 fanglomerates (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 buildups 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 320 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-Permian, a sequence of glaciterrestrial and glacimarine 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 onshore.

## SEEP DISTRIBUTION AND ORGANIC GEOCHEMISTRY

### SEEPS

The distribution pattern and historical background of seeps are summarised 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 35 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.

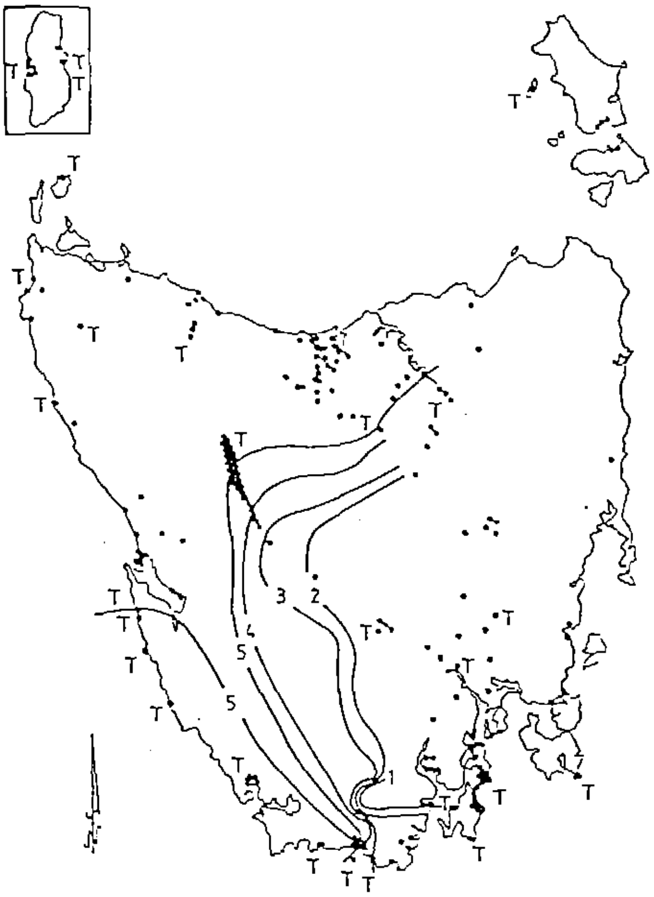

Figure 3. Seep distribution in Tasmania from Bendall (1990). T = tars. Contour lines are isograds based on conodont Colour Alteration Indices (CAI) from Burrett (in press). CAI 5=300°C and CAI 1=100°C.

## ORGANIC GEOCHEMISTRY

### Methods

Sediment from the site of the 1929 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 Tasmania 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 Iatroscan thin-layer chromatography-flame ionisation detection (Volkman et al., 1986) 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 -MS) in selected ion monitoring mode (SIM) (Volkman et al., 1988). Ion chromatograms for ions m/z 217 and 218 (steranes), m/z 259 (diasteranes), m/z 231 (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 $C_{27}$:$C_{23}$:$C_{29}$ steranes, which is a useful source input parameter (Mackenzie, 1984), are almost

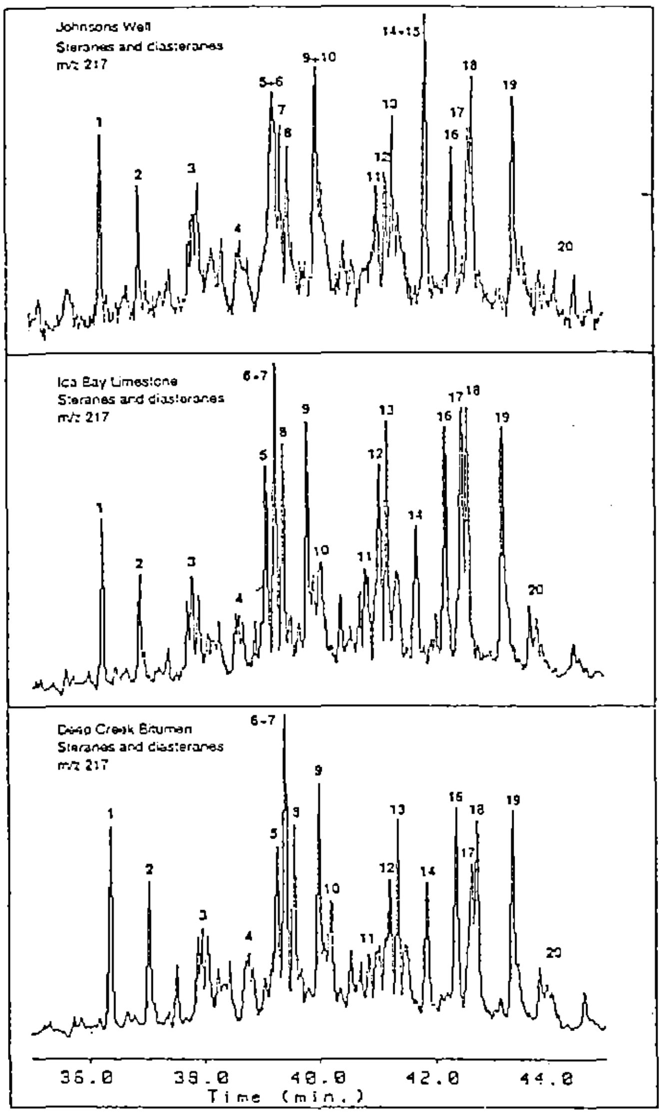

Figure 4. Mass fragmentograms for m/z 217 showing distributions of $C_{27}$–$C_{30}$ steranes and diasteranes in (a) soil from Johnson's Well on Bruny Island, (b) Ordovician carbonate from Ida Bay and (c) tar from the mouth of Deep Creek near Port Davey on the west coast of Tasmania. Compound identifications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

| Peak | | Steranes and Diasteranes |
|---|---|---|
| 1 | $C_{27}$ | (20S)-13β(H),17α(H)-diasterane |
| 2 | $C_{27}$ | (20R)-13β(H),17α(H)-diasterane |
| 3 | $C_{23}$ | (20S)-13β(H),17α(H)-diasterane |
| 4 | $C_{28}$ | (20R)-13β(H),17α(H)-diasterane |
| 5 | $C_{27}$ | (20S)-5α(H),14α(H),17α(H)-cholestane |
| 6 | $C_{29}$ | (20S)-13β(H),17α(H)-diasterane |
| 7 | $C_{27}$ | (20R)-5α(H),14β(H),17β(H)-cholestane |
| 8 | $C_{27}$ | (20S)-5α(H),14β(H),17β(H)-cholestane |
| 9 | $C_{27}$ | (20R)-5α(H),14α(H),17α(H)-cholestane |
| 10 | $C_{29}$ | (20R)-13β(H),17α(H)-diasterane |
| 11 | $C_{28}$ | (20S)-5α(H),14α(H),17α(H)-24-methylcholestane |
| 12 | $C_{28}$ | (20R)-5α(H),14β(H),17β(H)-24-methylcholestane |
| 13 | $C_{28}$ | (20S)-5α(H),14β(H),17β(H)-24-methylcholestane |

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| | | |
|---|---|---|
| 14 | $C_{28}$ | (20R)-5α(H),14α(H),17α(H)-24-methylcholestane |
| 15 | | Unknown |
| 16 | $C_{29}$ | (20S)-5α(H),14α(H),17α(H)-24-ethylcholestane |
| 17 | $C_{29}$ | (20R)-5α(H),14β(H),17β(H)-24-ethylcholestane |
| 18 | $C_{29}$ | (20S)-5α(H),14β(H),17β(H)-24-ethylcholestane |
| 19 | $C_{29}$ | (20R)-5α(H),14α(H),17α(H)-24-ethylcholestane |
| 20 | $C_{30}$ | 24-propylcholestanes |

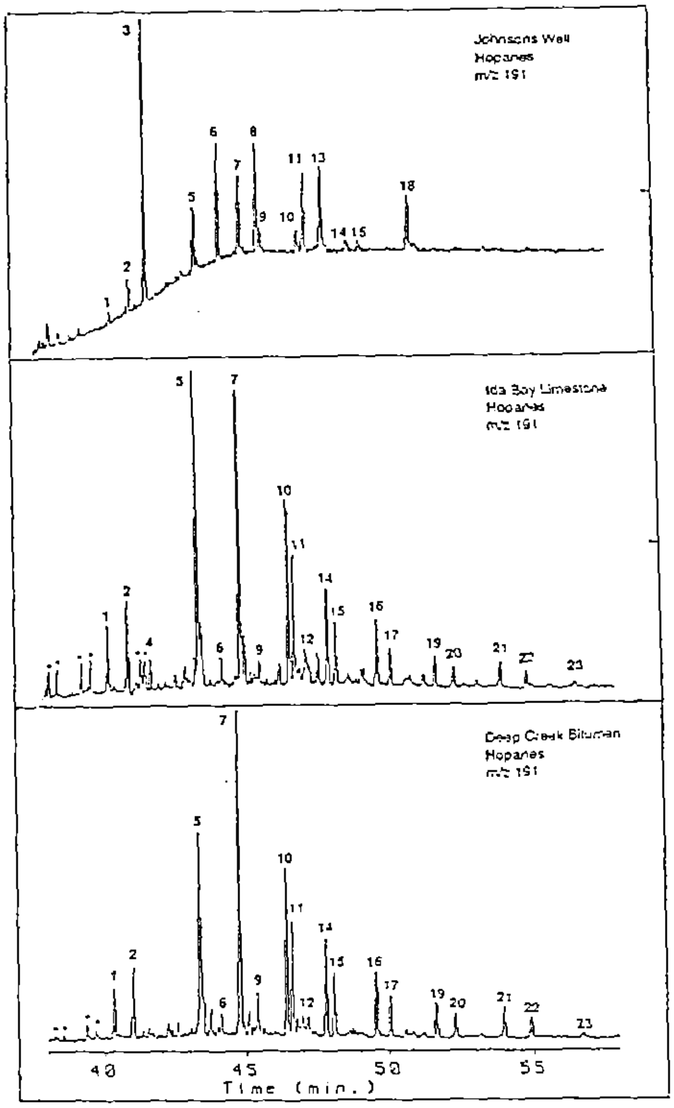

Figure 5. Mass fragmentograms for m/z 191 showing distributions of $C_{27}$–$C_{36}$ hopanes in (a) soil from Johnson's Well on Bruny Island, (b) Ordovician carbonate from Ida Bay and (c) tar from the mouth of Deep Creek on the west coast of Tasmania. Tricyclic alkanes are denoted by *. The baseline 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:

| Peak | | Hopane |
|---|---|---|
| 1 | $C_{27}$ | 18α(H)-22,29,30-trisnorneohopane (Ts) |
| 2 | $C_{27}$ | 17α(H)-22,29,30-trisnorhopane (Tm) |
| 3 | $C_{27}$ | 17β(H)-22,29,30-trisnorhopane |
| 4 | $C_{28}$ | 17α(H),21β(H)-29,30-bisnorhopane |
| 5 | $C_{29}$ | 17α(H),21β(H)-30-norhopane |
| 6 | $C_{29}$ | 17β(H),21α(H)-30-normoretane |
| 7 | $C_{30}$ | 17α(H),21β(H)-hopane |
| 8 | $C_{29}$ | 17β(H),21β(H)-30-norhopane |
| 9 | $C_{30}$ | 17β(H),21α(H)-moretane |
| 10 | $C_{31}$ | (22S)-17α(H),21β(H)-homohopane |
| 11 | $C_{31}$ | (22R)-17α(H),21β(H)-homohopane |
| 12 | $C_{31}$ | (22R+S)-17β(H),21α(H)-homomoretane |
| 13 | $C_{30}$ | 17β(H),21β(H)-hopane |
| 14 | $C_{32}$ | (22S)-17α(H),21β(H)-bishomohopane |
| 15 | $C_{32}$ | (22R)-17α(H),21β(H)-bishomohopane |
| 16 | $C_{33}$ | (22S)-17α(H),21β(H)-trishomohopane |
| 17 | $C_{33}$ | (22R)-17α(H),21β(H)-trishomohopane |
| 18 | $C_{31}$ | (22R)-17β(H),21β(H)-homohopane |
| 19 | $C_{34}$ | (22S)-17α(H),21β(H)-tetrakishomohopane |
| 20 | $C_{34}$ | (22R)-17α(H),21β(H)-tetrakishomohopane |
| 21 | $C_{35}$ | (22S)-17α(H),21β(H)-pentakishomohopane |
| 22 | $C_{35}$ | (22R)-17α(H),21β(H)-pentakishomohopane |
| 23 | $C_{36}$ | (22S)-17α(H),21β(H)-hexakishomohopane |

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 $C_{29}$ 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 (Twelvetrees, 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 3.9–6.7 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 ($<n\text{-}C_{10}$) are absent. The n-alkanes extend at least to n-$C_{35}$ 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-$C_{16}$ or n-$C_{18}$. 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 (McKirdy et al., 1986), was not detected. The pristane/phytane ratios of most samples fall in the range 1.30–1.38. All of the chromatograms show a small 'unresolved 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 $C_{29}$ steranes and $C_{25}$ 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 231 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 $C_{27}$ 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 $C_{23}$-$C_{36}$ 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. $C_{10}$ 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 17β(H),21β(H)-stereochemistry (peaks 8, 13 and 18) which is typical of biologically 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., 1988). 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 tricylic 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 $C_{29}$ 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 dolomites, 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 southem 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 find 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 22 km radius terrain corrections and were reduced using a crustal reference density of 2.67 $t/m^3$. 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 1000–5000 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 ultramafics. 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 or the Picton 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 south-east 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 ultramafics 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 Paleozoic 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. (1973) 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 (1985–). 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 Conga 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 1988, 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 300 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

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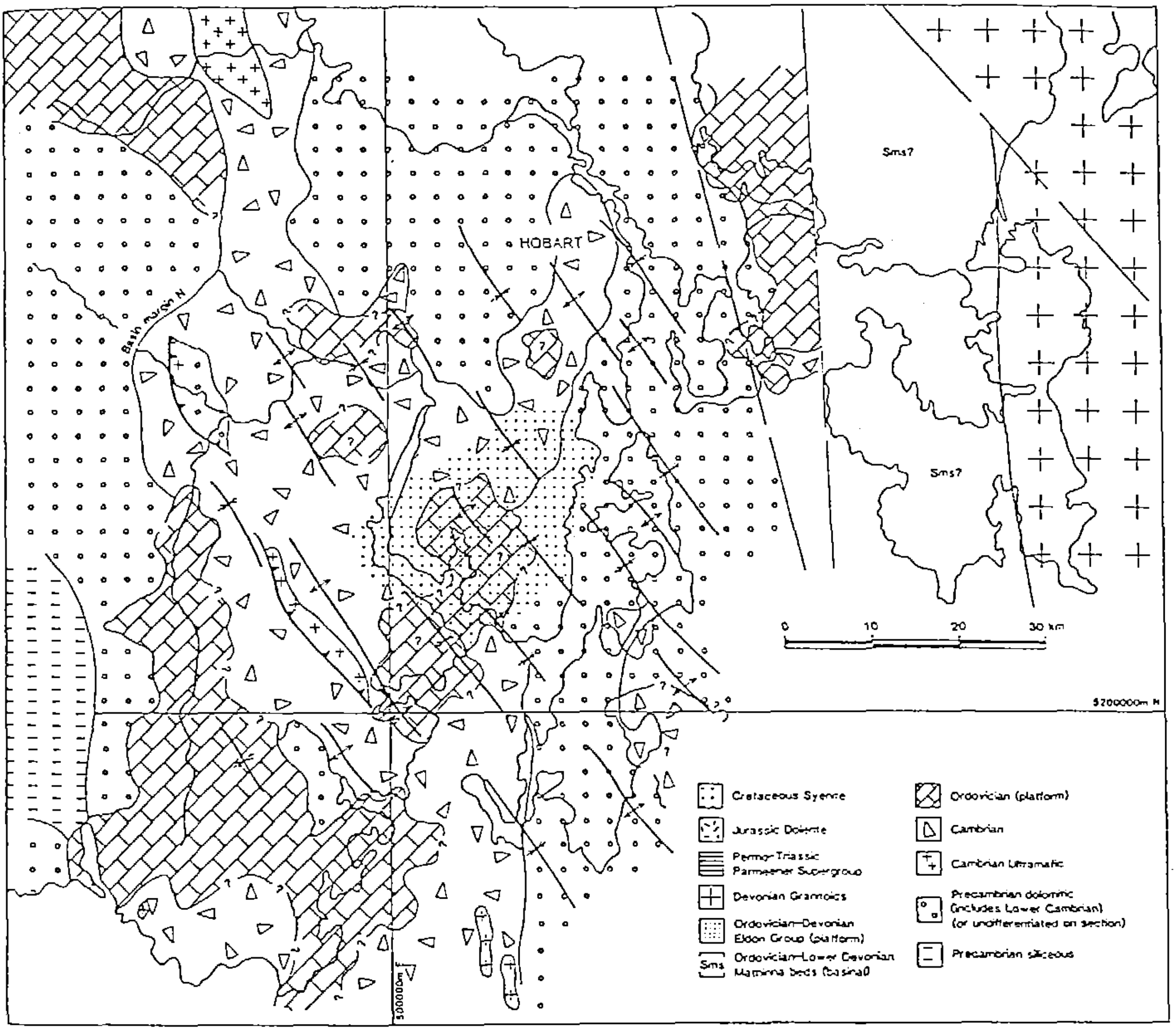

Figure 6. Pre-Parmeener geological map of southeast Tasmania based on magnetic and gravity interpretations supplemented by sparse drillhole data.

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

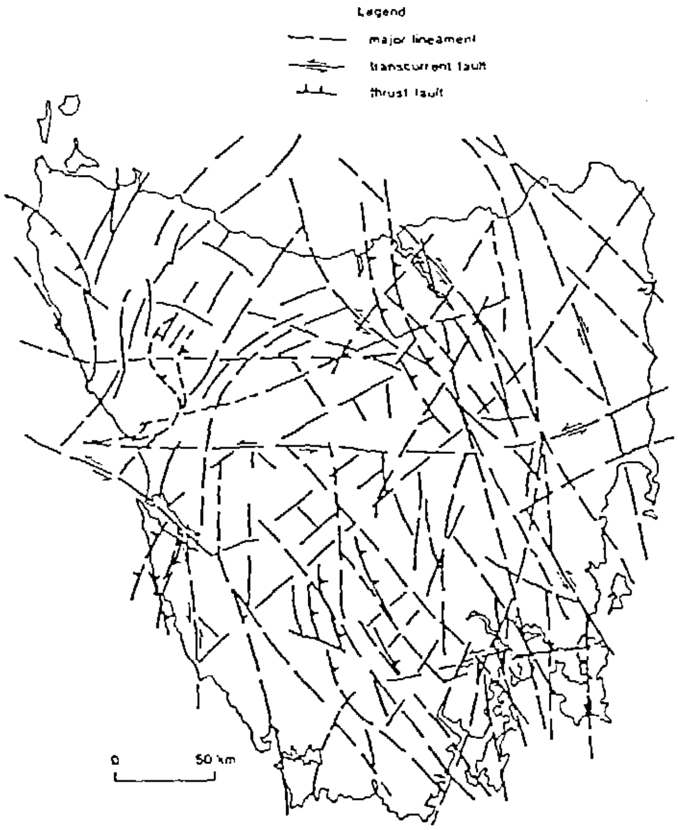

Figure 7. Major crustal lineations based mainly on magnetic and gravity surveys.

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 tillites. 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.

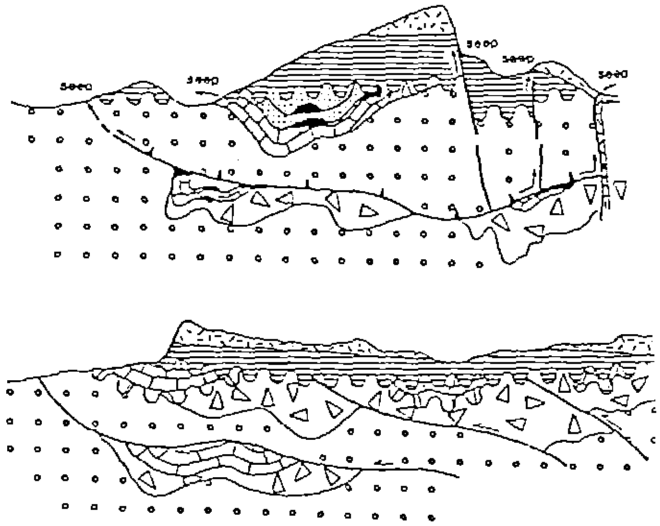

Figure 8. Schematic cross-sections showing possible play concepts in Tasmania. (Stratigraphy is denoted by same symbols as in Figure 6.)

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 wildcat hydrocarbon proposals.

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.

## ACKNOWLEDGEMENTS

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087054

# A HISTORY OF PETROLEUM OCCURENCES
# AND EXPLORATION IN
# TASMANIA.

M. R. BENDALL

January, 1990.

## CONTENTS

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ABSTRACT

087056

## ABSTRACT:

Archival research of petroleum sightings in Tasmania has revealed more than 100 occurences of liquids and tars in the last 100 years. Many of these ephemeral occurrences were confirmed by experts of the day. Some were attractive enough to encourage investors and drilling.

Little recovery was achieved and all wells were shallow and sited in ignorance of the geology at depth.

Unfortunately, government or bureaucratic support has never been provided due to incorrect assumptions and presumptions.

A "no oil in Tasmania" psychology has developed, these sightings not withstanding.

This archival search shows that reports of seeps are not random and correlate with structural lineament trends recognised from regional geophysical data - a correlation which adds to the credibility of the historical records.

## INTRODUCTION:

It is now 115 years since the first sign of petroleum was recorded on-shore in Tasmania. Since then 107 reported indications of petroleum, 127 exploration licences, and the sinking of 35 drill holes constitute the oil exploration histroy of Tasmania.

It is remarkable that the only paper to look seriously at the possibility of on-shore oil in Tasmania ("Twelvetrees, 1917") is 73 years old but remains the most recent Tasmanian Mines Department report on the subject.

The first prospecting syndicate searching for oil on-shore, in 1915, identified the Ordovician limestone as the source of the shows of oil and tar at New River Lagoon and correctly correlated the rocks with the upper Ordovician Trenton 'series' of the Texas Pan-Handle, famous at that time for oil gushes.

At that time many geologists called the Ordovician, Upper Silurian as the new term Ordovician had not really caught-on.

Archival records reveal a fascinating history of false preconceptions, plain ignorance, meddlesome belligerance, lack of scientific integrity and political and financial sabotage. All these elements have conspired to discourage on-shore petroleum exploration in Tasmania.

Although this history is best forgotten for the sake of a brighter future, it must, however, be recorded in order to understand how oil exploration in Tasmania has been retarded. Since the existence of any oil exploration in the State had been largely forgotten an archive search was undertaken. This paper records some of the findings.

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## COMPANIES AND EXPENDITURE

Many companies have been involved or floated on the basis of recorded sightings. Several instigative drilling programmes at seepage sights - a high risk and blind wildcat procedure were completed.
The companies were:-

| | |
|---|---|
| Port Davey Mineral and Oil Prospecting Syndicate | 1915 |
| The Asphaltum Glance and Oil Syndicate | 1915 |
| The Bruni Island Oil Company | 1916 |
| The Tasman Oil Company | 1921 |
| The Mersey Valley Oil Company | 1922 |
| The Adelaide Oil Exploration Company | 1922 |
| The Tasmanian Oil Company | 1929 |
| The Austral Oil Drilling Syndicate | 1936 |
| Producers Oilwell Supplies | 1939 |
| Nudec Pty. Ltd. | 1965 |
| E.Z. Company Pty. Ltd. | 1965 |
| B.H.P. Ltd. | 1980 |
| Conga Oil Pty. Ltd. | 1984 |

The most recent drilling was more than 20 years ago by Charlie Sulzberger's Company, Nudec Pty. Ltd. An estimated 10 million dollars, in 1990 terms, was spent. They found a gas show and two oil shows out of thirty five wells. The programme was, however, defeated by ignorance; the source of the shows was not Tertiary, Cretaceous or Permian, as then thought, but Ordovician.

No company succeeded in penetrating Permian or post-Permian cover; most rigs were either unsuitable for the rock types or too limited in capacity.

## OCCURENCES

The occurences related to seeps, licences and drill holes, have been listed in chronological order (Appendix, 1) and demonstrate the extent of oil exploration and interest. Regional groupings and recorded evaluations are discussed below.

### 1. SOUTH COAST OCCURENCES

The Asphaltum Glance Oil Syndicates oil leases were inspected by W.H. Twelvetrees in 1915 and reported under the title "Reconnaissance of Country between Recherche Bay and New River, Southern Tasmania". The syndicate found oozing tars in New River, tars in the lagoon, Prion Beach, and oil scums off shore as strong indications that the Ordovician limestone was both source and also reservoir for the shows. They compared the occurences with the Trenton Limestone in America (Ordovician) and the Devonian limestone of Canada as prolific producers of oil and gas and correctly correlated the Gordon Limestone of New River to the Trenton Limestone. (Burrett, et al. 1981)

Twelvetrees correlated the limestone to the Silurian (Ordovian in modern usage) states incorrectly that "signs of bitumen or oil have never been detected in this rock".

He goes on to state, "In any case there is no reason for regarding the New River Limestone as having any bearing on the question of the derivation of the pieces of asphaltum picked up off the New River Beach". He made this statement after assigning the oozing tars of New River to deep pockets of Tertiary within the Gordon Limestone, - all insubstantiated conclusion.

He did, however, determine that the specific gravities and physical characteristics of the tars, as listed below, were remarkably similar.

---

| | | |
|---|---|---|
| Upstream Gordon Limestone | Asphaltum from Port Davey | 1.0349 |
| On Gordon Limestone | Asphaltum from Rocky Boat Harbour | 1.0429 |
| On Gordon Limestone | Asphaltum from Surprise River Beach | 1.0426 |
| On Gordon Limestone | Asphaltum from North of Point Hibbs (Albina) | 1.0459 |

W.F. Ward, Government Analyst, confirmed that the S.G. of "The Tasmanian Asphaltum ranged from 1.0313 to 1.0459 (the S.G. of salt water is 1.03)".

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The most interesting of the tar's physical properties is that they all sink in salt water, a point discussed below. The syndicate also held a lease for oil at Recherche Bay. The D'Entrecasteaux River catchment contains Gordon Limestone, which has tars and has also been reported oozing oil, and the river is the main stream into Recherche Bay.

A kerosene stone reported at Southport, may be related to the Gordon Limestone hydrocarbons, laying beneath the Permian, both there and at Recherche Bay.

Leases taken out in 1915 around the Eastern mouth of the Davey River, at Deep Creek, are very interesting as a half tonne sample of asphaltum, heavier than salt water, was taken to Hobart. The leases were on Precambrian rocks, but Gordon Limestone outcrops upstream in the Davey River.

Another occurrence on the Precambrian rocks was at Louisa Bay, and on Triassic at South Cape Bay.

## 2. WEST COAST

Tars at the mouth of the Mainwaring River are in Cambrian rocks but Ordovician rocks may occur off shore and are exposed near Point Hibbs. Most tars have been reported on Ocean Beach. In 1923, the Mersey Valley Oil Company and a Mr H.E. Eveden pegged leases covering the area from the Strahan township to Ocean Beach and north towards the Henty River.

In 1942, Mr. W. Holmes, Manager of the Union Steamship Company, reported a stretch of water 4 miles long, suddenly became discoloured. This was just off Ocean Beach approximately due west of Strahan. After a subsequent storm a large amount of tar was collected by the coast guard. In this same position about 8 years later, over a period of two years, a school teacher, Mr. H. Fletcher, described oil seepages on Ocean Beach (irridescent films) and on the banks of a creek inland. He also described a black patch just off shore and tar being burnt in fires after storms. Mr. Fletcher also made sightings in dune lakes north of the Henty River. The Henty River itself has been reported as seeping gas, and tars can be found in the Gordon Limestone south of Zeehan.

The historical evidence seems to indicate the tars originate from strata inland of Ocean Beach, not from off-shore sources far removed. The possibility of an Ordovician source is highly likely since a thick Ordovician to Devonian sequence is exposed north and east of Strahan.

Tars (distinguished from fossil resins) within Macquarie Harbour, reported near Farm Cove caused an extensive search by a Sydney explorer in 1895 but no source was found.

Tars were located recently in the headwaters in the King River in Gordon Limestone which had thermal maturity within the oil window. Sediment samples of the King River delta taken by C.S.I.R.O. revealed hydrocarbons, but the source has not yet been determined.

## 3. D'ENTRECASTREAUX CHANNEL - SOUTH EAST TASMANIA

Six companies have concentrated their efforts in this district, the Bruni Island Oil Company, the Tasmanian Oil Company, Producers Oilwell Suppliers Pty. Ltd., E.Z. Company, B.H.P., and Conga Oil Pty. Ltd.

### (a) DOVER AREA

Oil and gas was reported in shallow sea water by separate observers somewhere near Dover in 1933 and 1957.

### (b) CYGNET AREA

Cygnet's first reported seep was in 1876 followed by two sightings in 1939 on opposite sides of the Cygnet dome structure, prompting a public meeting by Producers Oilwell Supplies, in both 1939 and 1953. Nebulous reports of seeps at Crabtree, 20 km North of Cygnet were made around 1960. Two deaths due to $H_2S$ were reported in a shaft at Cygnet, the source of the gas is open to Question.

### (c) BRUNY ISLAND AREA

This area consists mainly of Permo-Triassic Parmeener Supergroup sediments with Jurassic dolerite intrusions. The onshore seeps consist of tars, oils and gas mainly escaping along fault lines. On the basis of modern geophysical interpretation the basement is probably mainly Precambrian with some remnant Ordiovician sections, the edge of the main Cambrian trough being some 10 kilometres to the west of the island itself. (Leaman, 1990). The source of the seeps is thought to be from Gordon Limestone within this trough. (Analyses, Dr. J. Volkman, C.S.I.R.O.).

In 1916, with a capital of 50,000 pounds, the Bruni Island Oil Company put down 7 shallow holes on the basis of 2 seeps of exuding tars cited in their prospectus. The deepest of their holes was 450 feet, quite inadequate for any pre-Permian target. After this failed attempt, the Tasmanian Oil Company drilled 3 holes in 1929 on a confirmed show of oil and gas at the bottom of a well. (McIntosh Reid, 1929). Oil was collected in bottles after drilling to a depth of 125 feet.

Numerous leases have been held on Bruny Island, from Adventure Bay to Great Bay, on various seepages up until the present day. Various samples of marine sediment in the D'Entrecastreaux Channel collected by the C.S.I.R.O. and terrestrial samples on Bruny Island collected by Conga Oil Pty. Ltd. and analysed by the C.S.I.R.O. have shown Ordivician hydrocarbon signatures. (Volkman, 1989).

In 1940 a seep of oil was reported in an army well at Fort Direction, South Arm, and 1 km north, it was reported in 1988 that seeps had been occurring on Spring Beach over the last 40 years. Some 10 kilometres to the east in the lagoon behind Clifton Beach, a Mines Department seismic spread indicated an extensive sequence of reflections below the Permian cover which may possibly indicate a section of Palaeozoic rocks including limestone. (Leaman, 1978).

## 4. MIDLANDS

Seeps of light oil have been reported at Glenlusk, Colebrook, Cambridge, Tunnack and Jericho. Reports of tars from Brighton and Dysart in recent times indicate the reason for an exploration licence for oil taken out at Elderslie by S. Chapman, in 1919. Tar samples recently collected from Tunnack have been sectioned and show total impregnation of the rock by hydrocarbons. (Dr C. Burrett, D. Leaman, pers. comm.).

At the north end of this lineament are the gas shows reported at "Rose Neath", Ross, (1939) and 1 kilometre to the west is a reported show of oil in a water bore (1984, G. & G. Gleason).

## 5. NORTH - NORTHWEST

A line of oozings from Newstead through Relbia to Evandale, was reported by W.H. Twelvetrees, 1917. Recent geophysical interpretation implies a lower Palaeozoic section below these seeps. (Dr D. Leaman, R. Henuauto, pers. comm.). A continuation of this trend north of Launceston extends to the site of the 1939 Producers Oilwell Supplies drill rig at Danbury Park. Oil has been reported seeping from Permian rocks west of this hole at Bridgenorth (1962) and at Rosevale (1921) in Tertiary rocks. The most northerly seep was reported by a mine geologist at Beaconsfield; seepage directly into the mine water, presumably from the Flowery Gully Limestone (Gordon Limestone).

The Cressy - Port Sorell structures have been the most drilled for oil in Tasmania, with 20 holes sunk in 1922-23 alone (by the Mersey Valley Oil and Adelaide Oil Exploration Companies). Three more bores were sunk by C. Sulzberger, between 1966 and 1968. The original companies were greatly encouraged by increased rates of seepage following an earthquake in 1922. A major earth quake occurs in Tasmania every 20 years, it is 30 years since a major quake.

## 6. DERWENT VALLEY OCCURRENCES

The 1910 Annual Report to the Director of Mines, reported a bituminous exudation on the banks of the Derwent River at Kenmore Estate, Macquarie Plains, and 20 kms upstream, Mr. W.C. Inglis reported seeps of oil on his property in 1958. A drill hole for oil was put down 520 feet (158.5 m) at "Lawrenny" (1920) but was abandoned at that depth after the rods "stuck". Mr. G.C. Harris reported gas at Tarraleah in 1946.

An unbroken line of oil leases between Lake St. Clair and Cradle Mountain was taken up in the 1921 "oil rush". There is much confusion over the cause of the 1921 "oil rush", mainly because coal in the district contains thin petroliferous layers. (Mersey Coal Measures and Preolenna Oil Shales correlates). Tars were also exhumed from the glacial Moraines of the field but consultants did not believe the hydrocarbons to be derived from the Preolenna Oil Shales.

Consider two quotes:

(i) Report from the field, 1921.

On the 28th May, Mr. A.C. Black, Field Manager of the Tasman Oil Company, wired from Sheffield, Tasmania, to his Principals in Melbourne, as follows:-

> "Now in a position report absolutely, facts can be produced from data collected recent developments that oil exists at Barn Bluff".

Since his consulting geologist had just returned from a visit to this region, the Secretary of the Melbourne Company wired to him asking for his opinion regarding Mr. Black's statement and replied:

> "I have no hesitation in confirming Black's 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 process of distillation and may be *confidently sought for in the Anti-clines*".

(ii) Report of Mr. W.A. Dixon, F.I.C. F.C.S., Sydney, 1893.

> "On distillation, "pelionite" (from glacial Moraines) produced hydrocarbons of the aromatic series (benzene, naphalene etc.) and not as are contained in the Preolenna kerosene shale those of the aliphatic series (olefines, paraffines etc.)"

The Preolenna Kerosene Shale equivalent unit does outcrop in the Barn Bluff area but its products are waxy and immature. It is not able to account for gas shows in the area and cannot produce the composition of the "fossil tars" present in the glacial Moraine.

## 7. NORTH WEST TASMANIA

One of the first recorded tars was described from Chudleigh in Pettard's, 1896 "Catalogue of Tasmanian Minerals". He describes it as, "occuring about 4 miles from Chudleigh on the eastern bank of the Mersey River. It was perfectly black, sectile and burned with a dense smoke and strong odour. It occurs in drab coloured aluminous shale of (presumed) Ordovician age."

In 1956, at Mole Creek, seven kilometres to the west, on the Gordon Limestone, a well was reported to have seeps of oil. A further occurrence was at a small outcrop of Gordon Limestone directly under the capping Parmeener Supergroup in Muddy Creek, Golden Valley. This was reported emitting flammable gas in 1932. The Adelaide Oil Exploration Company Field Manager reported shows near Devonport. Drill hole no. 8, of this company at Port Sorell, was reported by a Government geologist, A. McIntosh Reid, 10.9.1923, as having penetrated a bed with natural gas under enormous pressure - causing an outbreak closing the hole. In the same report he sites numerous seeps of oil and gas escaping from both Permian and Tertiary strata in the Latrobe - Sassafras district.

A sample of mature oil was obtained by Conga Oil Pty. Ltd. from basal Permian rock at Poatina, which has neither a Permian Tasmanite nor Ordovician carbonate signature. (Dr. J. Volkman, C.S.I.R.O., pers. comm.)

Other occurrences have been reported from the Mount Read Volcanic Belt.

Oil was reported by McIntosh Reid (1923) on the west bank of Ray Creek at Nook, and at Stoodley in 1930. Two separate sightings of oil and gas (1920 and 1966) escaping from the bedrock of the Forth River about 2 km inland from the mouth have been reported - in 1920 and 1966. In 1966, Mr. C. Flowers of Ulverstone, described a tar exuding from a stretched pebble conglomerate (Precambrian) and provided a sample and photographs to the Department of Mines who did not investigate the occurence. Mr. J. Bates of Penguin, reported oil seeping at his property in 1968 and a Mr. L.F. Egan reported a similar occurrence at Burnie in 1962.

There are ten occurences reported from the far northwest. The first in 1915, was that of tar on the beach at Wynyard. Shows of oil have been reported since at Table Cape (1963), Fossil Bluff (1965), Flowerdale (1925) and Distillery Creek (1962). Three licences to search for oil were issued in the Inglis River. In 1956, Mr. B.A. Farquhar reported oil seeps at West Takone, and in 1921, Mr. N.J. Richardson reported oil seeping at his property at Cam Road, Somerset.

In 1921, a licence to search for oil was issued to F.W. Heritage on Precambrian rocks between the Interview and Lagoon Rivers. As far back as 1876, Mr. T.B. Moore, reported numerous tars on the beaches both north and south of Sandy Cape. Only Precambrian rocks, including some carbonates, occur on the rivers flowing to these beaches. At Green Point, (1962) and Redpa (1948) oil shows occurred in the Precambrian limestones and at Mt. Cameron in 1925, tar was reported seeping from the limestone. Constant reports of seeps at Mengha from 1930 are also near Precambrian limestone (dolomite).

In 1915, W.H. Twelvetrees reported on beach tars at King Island, presuming them to have been washed there. However, the Precambrian Granites on the foreshore presented petroleum seeping from the fractures which yields tars at the surface. This phenomenon was confirmed by the Department of National Development when Mr. S.P.J. Adams took samples to Canberra in 1960 after failing to elicit any interest from the Tasmanian Department of Mines. Two licences were issued to search for oil in 1960, one in his own name and one in his wife's name. Earlier in 1955 a Mrs. A.J. Smith held a licence to search and also offered to show the Mines Department the oozing tars. She stated her son would blast the rock to prove they were oozing and also sited seeps of tar inland along the Pass River. In that same period a licence to search for oil was issued to a Mr. W.K. Westley, in 1960. There are no records of what prompted his application.

## 8. NORTH EAST TASMANIA

The "oil rush" of 1936 was led by the Austral Oil Drilling Syndicate who cited abundant limestone and glauconite of Cape Barren and Flinders Island as excellent indicators of oil. Large lagoons burned for years when ignited after being drained; the corky substance present yielding 85 gallons per tonne of oil. Similar material was reported near Smithton and is thought to be derived by algal activity.

Mr. A.H. Thorpe has reported oil seeping to the surface in Muddy Creek, Bridport. He took up a licence to search but no evidence has been found to support his claim.

## DISCUSSION AND CONCLUSION

Many sightings, or possible sightings, have often been considered due to oxide scums on water. Many of the above references could also be considered suspect or due to neighbourhood publicity. Map 1 shows, however, that there are non random relationships in the observations and not all can be called into question - if any. The distribution of unambiguous onshore sightings suggests that several source materials may be present; Geochemical work by Dr. J. Volkman of C.S.I.R.O., for Conga Oil Pty. Ltd. has already shown that Ordovician limestones source seepages in Tasmania. Geophysical-structural work by Leaman (1990) has confirmed that the necessary structural styles and sequences are present, but concealed, in this region.

Most of the trends evident in Map 1 can be recognised in the preliminary crustal interpretation of Leaman & Richardson (1990). The recognition of a close correlation, suggesting a need for further work, between presumed/actual sightings and basement-induced gravity and magnetic trends adds considerable credibility to the archival records.

The overall spread of records indicates that Late Precambrian dolomites may also be source rocks. It is clear, therefore, Tasmania does contain onshore petroleum sources and reservoirs.

Archival records also show that enterpreneurs, companies, visiting consultants and agents of the Federal Government have been actively discouraged in their efforts to explore. Many legal actions have resulted. Most problems can be assigned to a widely held not just a bureaucratic view that "there is no oil in Tasmania", very similar to that once held in Arabia. This view derives from a number of false assumptions, some of which have been alluded to in the main text, and which are only now being resolved by Conga Oil Pty. Ltd. with assistance from the Mines Department.

The original prospectors of New River (in 1915) deduced the importance of the oil seeps and tars, identified the Gordon Limestone source and correlated it to similar prolific oil-producing limestones in the United States. The discovery of oil and gas in limestones of Ordovician age on mainland Australia, mainly the Amadeus Basin, points to the increased validity of the play concept. Current evidence and historical data suggests that the lack of exploration work for oil and gas does not reflect upon the prospectivity of the Tasmanian Basin or absence of indications of petroleum, but on the false preconception of several generations of Tasmanian geologists.

## ACKNOWLEDGMENTS

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I also thank both Dr. David Leaman and Dr. Clive Burrett for their support in the editing and technical areas, and their extensive contributions in the laying of the foundations upon which Conga Oil Pty. Ltd. now rests.

I would also like to thank Dr John Volkman for contributions through his precise geochemical work done at the C.S.I.R.O., Hobart.

I would also like to acknowledge myself as founder of Conga Oil Pty Ltd and father of the play concept now born.

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## APPENDIX 1.

## CHRONOLOGICAL LIST OF OIL SEEPS, LICENCES AND DRILL HOLES

| Date | Place | Occurrence | Name |
|---|---|---|---|
| 1871 | Prime Seal Is. | Tar | Mr. Chas Gould |
| 1876 | Sandy Cape | Tar | T.B. Moore |
| 1876 | Mainwaring River | Tar | T.B. Moore |
| 1876 | Point Hibbs | Tar | T.B. Moore |
| 1876 | Farm Cove | Tar | T.B. Moore |
| 1876 | Cygnet | Oil | Robert Taylor |
| 1889 | Ross | Salt | Mr. Barwick |
| 1893 | Barn Bluff | Oil | A. Montgomery |
| 1895 | Port Davey | Tar | P. Hutchings |
| 1896 | Chudleigh | Tar | M. Pettard |
| 1895 | Macquarie Harbour | Tar | Sydney Explorer |
| 1910 | Deep Crk, Port Davey | Tar | Twelvetrees |
| 1910 | Hamilton (River Bank) | Tar* | Twelvetrees |
| 1914 | Hamilton | Oil | Walter Blackwell |
| 1915 | Nth. Bruny Island | Tar | Bruni Is. Oil Company |
| 1915 | New River | Lease | The Asphaltum Glance & Oil Syndicate |
| 1915 | Davey River | Tar | W.H. Twelvetrees |
| 1915 | New River | Lease | The Asphaltum Glance & Oil Syndicate |
| 1915 | New River | Tar, Oil | The Asphaltum Glance & Oil Syndicate |
| 1915 | New River | Lease | " " " |
| 1915 | Flinders Island | Tar* | W.H. Twelvetrees |
| 1915 | Three Hummock Is. | Tar | W.H. Twelvetrees |
| 1915 | Marrawalt | Tar* | W.H. Twelvetrees |
| 1915 | Cape Barren Is. | Tar | W.H. Twelvetrees |
| 1915 | Wynyard Beach | Tar | W.H. Twelvetrees |
| 1915 | King Island | Tar* | W.H. Twelvetrees |
| 1915 | Albina (20km Nth Pt. Hibbs) | Tar* | W.H. Twelvetrees |
| 1915 | Point Hibbs | Tar* | W.H. Twelvetrees |
| 1915 | Louisa Bay | Tar* | W.H. Twelvetrees |
| 1915 | New River | Tar* | W.H. Twelvetrees |
| 1915 | Rocky Boat Harbour | Tar* | W.H. Twelvetrees |
| 1915 | Surprise River Beach | Tar* | W.H. Twelvetrees |
| 1915 | South Cape Bay | Tar* | W.H. Twelvetrees |
| 1915 | New River | Tar* | W.H. Twelvetrees |
| 1915 | Recherche Bay | Oil | The Asphaltum Glance & Oil Syndicate |
| 1916 | North Bruny Is. | Drill Holes 1 - 7 | Bruni Is. Oil Company |
| 1916 | Nth. Bruny Is. | Tar | Bruni Is. Oil Company |
| 1917 | Southport | Tar, Oil | Twelvetrees |
| 1917 | Arthur River | Tar | Twelvetrees |
| 1917 | Newstead | Oil | Twelvetrees |
| 1917 | Relbia - Evandale | Oil | Twelvetrees |
| 1917 | Longford | Oil | Twelvetrees |
| 1918 | Zeehan | Tar | Fredrick Chapman |
| 1918 | Nth. Bruny Is. | L.S. | W.H.T. Brown |
| 1918 | Nth Bruny Is. | L.S. | R.J.P. Davey |
| 1919 | Barn Bluff | Tar | A. McIntosh Reid |
| 1919 | Elderslie | L.S. | S. Chapman |
| 1920 | Spring Bay | Oil | Mr. Fielder |
| 1920 | Hamilton 'Lawrenny'. | Drill 1 | C.A. Brock |
| 1920 | Sth. Bruny Is. | L.S. | V.A. Chipman |

| | | | |
|---|---|---|---|
| 1920 | Sth. Bruny Is. | L.S. | C.C. Brown |
| 1920 | Davey River | L.S. | M.J. Donellan,<br>C. Smith & J. Jones. |
| 1920 | Forth River | Oil | E. Eastall,<br>G. Richardson & A.Stocks |
| 1920 | Barn Bluff | L.S. | C.C. Manton & A.C. Black |
| 1920 | Barn Bluff | L.S. | A.C.D. Bernaceli |
| 1920 | Barn Bluff | L.S. | P. Evans |
| 1920 | Cradle Mountain | L.S. | The Granville Prospecting & Mining Co. |
| 1920 | Mt. Olympus | L.S. | L.G. Thompson |
| 1920 | Narcissus River | L.S. | L.M. Stackhouse |
| 1920 | Sth. Bruny Is. | L.S. | S. Perry |
| 1920 | Barn Bluff | L.S. | W. Mudie |
| 1920 | Barn Bluff | L.S. | A.L. Nichols |
| 1920 | Mt. Achilles | L.S. | C.C. Reilly |
| 1920 | Barn Bluff | L.S. | E. Hawson |
| 1920 | Lake St. Clair | L.S. | T. McDonald |
| 1920 | Davey River | L.S. | W.T.A. Cleveland |
| 1921 | Sth. Bruny Is. | Oil | V.A. Chipman |
| 1921 | Sth. Bruny Is. | L.S. | S Perry |
| 1921 | Sth. Bruny Is. | L.S. | C.C. Brown |
| 1921 | Sth. Bruny Is. | Oil | J.L. Frizoni |
| 1921 | Nth. Bruny Is. | Oil | H. Thomas |
| 1921 | Nth. Bruny Is. | Oil | E. Thomas |
| 1921 | Sth. Bruny Is. | Oil | J.L. Frizoni |
| 1921 | Somerset. Cam Rd. | Oil | N.J. Richardson |
| 1921 | Between Lagoon & Interview River | Tar, L.S. | F.W. Heritage |
| 1921 | Douglas River | L.S. | H.G.R. McWilliams |
| 1921 | Mt. Pelion | L.S. | L.W. Mudie |
| 1921 | Mt. Pelion | L.S. | J. West |
| 1921 | Mt. Pelion | L.S. | J.T. Moate |
| 1921 | Mt. Pelion | L.S. | T.B. Harrington |
| 1921 | Mt. Pelion | L.S. | J.N. Duncan |
| 1921 | Mt. Pelion | L.S. | A.W. Duncan |
| 1921 | Mt. Pelion | L.S. | A.L. Kirkham |
| 1921 | Mt. Pelion | L.S. | R.P. Kirkham |
| 1921 | Mt. Pelion | L.S. | R.H. Nicholson |
| 1921 | Barn Bluff | L.S. | A.J. Forester |
| 1921 | Mt. Pelion | L.S. | Jean MacKenzie |
| 1921 | Mt. Pelion | L.S. | F.W. James |
| 1921 | Mt. Pelion | L.S. | K.B.C. Kirkham |
| 1921 | Mt. Pelion | L.S. | E.L. Potter |
| 1921 | Mt. Pelion | L.S. | A. Baker |
| 1921 | Mt. Pelion | L.S. | Stella Moate |
| 1921 | Mt. Pelion | L.S. | T.B. Harrington |
| 1921 | Mt. Pelion | L.S. | L.M. Beckwith |
| 1921 | Mt. Pelion | L.S. | R. Duncan |
| 1921 | Barn Bluff | L.S. | Lena Mofflin |
| 1921 | Mt. Pelion | L.S. | E.J. Stott |
| 1921 | Barn Bluff | L.S. | R.A. Mofflin |
| 1921 | Mt. Pelion | L.S. | C.H. Augas |
| 1921 | Barn Bluff | L.S. | G.B. McCutcheon |
| 1921 | Barn Bluff | Lease | R.J. McCutcheon |
| 1921 | Mt. Pelion | L.S. | C. Adams |
| 1921 | Mt. Pelion | L.S. | S.C. Hocking |
| 1921 | Mt. Pelion | L.S. | R. Sharples |
| 1921 | Mt. Pelion | L.S. | F.W. Reid |
| 1921 | Dulverton | L.S. | E. Morse |
| 1921 | Railton | L.S. | F.D. Kite |
| 1921 | Mersey | L.S. | J. Stewart |

| | | | |
|---|---|---|---|
| 1921 | Sth. Bruny Is. | L.S. | V.A. Chipman |
| 1921 | Sth. Bruny Is. | L.S. | C.C. Brown |
| 1921 | Barn Bluff | L.S. | C. Simson Hope |
| 1921 | Barn Bluff | L.S. | A.W. Craig |
| 1921 | Barn Bluff | L.S. | H.B. Denniston |
| 1921 | Adventure Bay | L.S. | J.L. Frizoni |
| 1921 | Sth. Bruny Is. | L.S. | J.L. Frizoni |
| 1921 | Nth. Bruny Is. | L.S. | H. Thomas |
| 1921 | Nth. Bruny Is. | L.S. | E. Mathias |
| 1921 | Rosevale | Oil | Loftus Hills |
| 1921 | Barn Bluff | Oil & Gas | Mr Black, Field Manager-Consulting geologist confirming seeps. |
| 1922 | Inglis River | L.S. | J.A. Wauchope |
| 1922 | Inglis River | L.S. | J.A. Wauchope |
| 1922 | Inglis River | L.S. | J.A. Wauchope |
| 1922 | Mersey | L.S. | G.D. Mendall |
| 1922 | Jericho | Oil | R. White |
| 1922 | Sth. Bruny Is. | L.S. | W.T. Rope |
| 1922 | Davey River | L.S. | W.C. Hart |
| 1922 | Davey River | Tar | W.T.A. Cleveland |
| 1922 | Kermode | L.S. | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 1 | The Mersey Valley Oil Co. |
| 1922 | Railton | Drill No. 1 | (Adelaide Oil Exploration Company.) |
| 1922 | Barn Bluff | Drill | |
| 1922 | Latrobe | Drill No. 2 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 3 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 4 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 5 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 6 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 7 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 8 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 9 | The Mersey Valley Oil Co. |
| 1922 | Latrobe | Drill No. 2 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 3 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 4 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 5 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 6 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 7 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 8 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No. 9 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No.10 | Adelaide Oil Exploration Company. |

| | | | |
|---|---|---|---|
| 1922 | Latrobe | Drill No.11 | Adelaide Oil Exploration Company. |
| 1922 | Latrobe | Drill No.12 | Adelaide Oil Exploration Company. |
| 1923 | Rockliffes Farm | Oil & Gas | A. McIntosh Reid |
| 1923 | Roches Farm | Oil & Gas | A. McIntosh Reid |
| 1923 | Harford | L.S. | W.B. Cocker |
| 1923 | Burgess | L.S. | J.A. Wauchope |
| 1923 | Mersey | L.S. | D.M.C. Griffin |
| 1923 | Port Sorell | L.S. | R.C. Grubb |
| 1923 | Port Sorell | L.S. | G.N. Levy & A. Brown |
| 1923 | Port Sorrell | L.S. | J.D. Johnstone |
| 1923 | Port Sorell | L.S. | E. Baker |
| 1923 | Franklin Rivulet | L.S. | L.J. Douglas |
| 1923 | Burgess | L.S. | F.M. McDonald |
| 1923 | Burgess | L.S. | E.J. McDonald |
| 1923 | Port Sorell | L.S. | J.H. Addison |
| 1923 | Burgess | L.S. | H.D. Green |
| 1923 | Port Sorell | L.S. | R.W. MacKenzie |
| 1923 | Barn Bluff | L.S. | G.R. Plante |
| 1923 | Barn Bluff | L.S. | L. Mudie |
| 1923 | Barn Bluff | L.S. | E.E. Black |
| 1923 | Barn Bluff | L.S. | R. Stoneham |
| 1923 | Little Henty River | Tar | S.A. Clark |
| 1923 | Strahan | L.S. | H.E. Evenden |
| 1923 | Strahan | L.S. | The Mersey Valley Oil Co. |
| 1924 | New River | L.S. | F.T. Boddy |
| 1924 | New River | L.S. | E. Hawson |
| 1924 | New River | L.S. | F. Heritage |
| 1924 | Henty River | L.S. | J.A. Wauchope |
| 1924 | Barn Bluff | L.S. | B.H. Edwards |
| 1924 | Barn Bluff | L.S. | B.D. Reynolds |
| 1925 | New River | L.S. | E.F. Heritage |
| 1925 | New River | L.S. | H.E. Everden |
| 1925 | Flowerdale | L.S. | D. Berechree |
| 1925 | Mt. Cameron | Tar | F.F. Ford |
| 1926 | Barn Bluff | L.S. Oil | C.S. Hope |
| 1928 | Nth. Bruny Is. | L.S. | H.M. Boddy |
| 1928 | King Island | L.S. Tar | O. Bonney |
| 1928 | Nth. Bruny Is. | L.S. Oil | C.F. Boddy |
| 1928 | Nth. Bruny Is. | L.S. | A.C. Black |
| 1928 | Nth. Bruny Is. | L.S. | M. Hayton |
| 1928 | Sth. Bruny Is. | L.S. | A.H. Jackson |
| 1929 | North Bruny Is. | Drill 1. | Tasmanian Oil Co. |
| 1929 | North Bruny Is. | L.S. | A.J. Miller |
| 1929 | No rth Bruny Is. | Drill 2 | Tasmanian Oil Co. |
| 1929 | Great Bay, Nth. Bruny Is. | Oil & Gas | A. McIntosh Reid |
| 1929 | North Bruny Is. | Drill 3 | Tasmanian Oil Co. |
| 1929 | North Bruny Is. | Oil, Tar & Gas | Tasmanian Oil Co. |
| 1929 | Sth Bruny Is. | Oil | (Sgd) L.W. Marsden |
| 1929 | Henty River | Gas | J.H. Robertson |
| 1930 | Nth. Bruny Is. | L.S. | J. McD. Hay |
| 1930 | King Island | L.S. | L. Gatenby |
| 1930 | Stoodley | Oil | A. Wright |
| 1930 | Mengah | Oil | J. Healy |
| 1931 | Cradoc | Oil | W.J. Armstrong |
| 1931 | Leprena | Oil (Kerosene) | G.H. Smith |
| 1933 | Dover | Oil | Lloyd J. Owens |
| 1933 | Golden Valley | Gas | B.H. Whittle |

| | | | |
|---|---|---|---|
| 1936 | Flinders Is. | L.S. | A.A. Summerhayes |
| 1936 | Flinders Is. | L.S. | Austral Oil Drilling Syndicate |
| 1936 | Flinders Is. | L.S. | C.S. Demaine |
| 1936 | Flinders Is. | L.S. | A.W. Imray |
| 1939 | Cygnet | Oil | R. Taylor |
| 1939 | Cradoc | Oil & Gas | Producers Oilwell Supplies Ltd. |
| 1939 | Danbury Park | Drill 1 | Producers Oilwell Supplies Ltd. |
| 1939 | Ross | Gas | C. Davis |
| 1940 | South Arm | Oil | E.Z. Company |
| 1940 | Port Davey | L.S. tar | H.E. Evendon |
| 1941 | Tunnack | Oil | A. Mackie |
| 1942 | Ocean Beach, Strahan | Tar | Mr W. Holmes |
| 1944 | Bridport | Oil | A.H. Thorpe |
| 1945 | Flinders Island | Oil | W. Carry |
| 1946 | Tarraleah | Gas | G. Harris |
| 1948 | Redpa | Oil | C. Burt Senr. |
| 1952 | Cambridge | Oil | P.W. Evans |
| 1953 | Cygnet | Oil | R. Dunning |
| 1953 | Strahan | Oil, Tar | H. Fletcher |
| 1955 | Prion Beach | Tar | H. Akerley |
| 1955 | King Island | L.S. | Mrs. A.J. Smith |
| 1956 | Arthur River | L.S. | R.K. Cumming |
| 1956 | West Takone | L.S. | B.A. Farquhar |
| 1956 | King Island | Tar | Mrs. A.J. Smith |
| 1956 | Mole Creek | Oil | Eva Marchant |
| 1957 | Dover | Oil, Gas | E.A. Haigh |
| 1958 | Tinderbox | Oil | Mrs. Wilkinson |
| 1958 | Hamilton | Oil | T.B. Gulline |
| 1960 | Crabtree | Oil | Unknown |
| 1960 | Port Sorell | Gas | C. Sulzberger |
| 1960 | King Island | L.S. | Mr. S.P.J. Adams |
| 1960 | Marrawah | Tar ** | F.W. Ford |
| 1960 | King Island | L.S. | F.J. Adams |
| 1960 | King Island | L.S. | W.K. Westly |
| 1960 | Central Highlands | Oil | K. Slater |
| 1960 | Detention River | Oil | C.R. Pyke |
| 1962 | Jericho | Oil | R. White |
| 1962 | Bridgenorth | Oil | W. Rattray |
| 1962 | Marrawah | Oil | C.K. Hine |
| 1962 | Burnie | Oil | L.F. Egan |
| 1962 | Distillery Creek, Wynyard | Oil | J. Carol |
| 1963 | Table Cape | Oil, Gas | Mr. Jackson |
| 1965 | S.E. Tasmania | Lease | E.Z. Company |
| 1965 | Fossil Bluff | Oil | S. Veenstra |
| 1965 | Ulverstone | Tar | Mr. C. Flowers |
| 1966 | Forth River | Gas | H.E. Flight |
| 1966 | Hagley | Drill 1 + Lease | C. Sulzberger |
| 1966 | Hagley | Drill 2 + Lease | C. Sulzberger |
| 1968 | Cressy | Drill 3 + Lease | C. Sulzberger |
| 1968 | Penguin | Oil | J. Bates |
| 1969 | Hagley | Oil | C. Sulzberger |
| 1980 | S.E. Tasmania | Oil Lease | B.H.P. |
| 1984 | Ross | Oil | G. & G. Gleeson |
| 1986 | Glenlusk | Oil | Unknown |
| 1986 | North Bruny Is. | Oil, Gas | Conga Oil Pty. Ltd. |
| 1987 | Ida Bay | Tar | R. Bender |

| | | | |
|---|---|---|---|
| 1987 | North Bruny Is. | Oil, Gas | C.S.I.R.O. |
| 1987 | Queenstown | Tar | Conga Oil Pty. Ltd. |
| 1987 | South Bruny Is., Cole Pt. | Oil | A. Farmer |
| 1988 | Spring Beach, South Arm | Oil | Mr. Morris Potter |
| 1989 | Cape Pillar | Oil | R. Billingham (Mines Dept.) |
| 1989 | South Bruny Is. | Tar | Steve Forsyth (Mines Dept) |
| 1989 | Brighton | Tar | C. Wallis |
| 1989 | Dysart | Tar | D. Green (Mines Dept.) |
| 1989 | Beaconsfield | Oil | Mine Geologist |
| 1989 | Colebrook | Tar | C. Wallis |

Tars marked * , ** represent occurences where samples exist in museum collections; Queen Victoria and Tasmanian Museum respectively. G.C.M.S. analysis of these tars have conclusively proved they originated from an Ordovician source. (Dr. J. Volkman, C.S.I.R.O., 1990)

# APPENDIX 2 - B.M.R results 1985(rock eval)

28/10/91

# TOC REval Data - J.Volkmann

| BMR No | Depth | Tmax | S1<br>kg/tonne | S2<br>kg/tonne | S3<br>kg/tonne | S2/S3 | TOC<br>(Whole Rock) | HI | OI | %CO3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5800 Douglas River | 321.33-321.05 | 446 | 6.28 | 147.53 | 0.15 | 983.53 | 16.99 | 868 | 1 | 10.69 |
| 5801 Ross Borehole #2 | 409.00-409.30 | 447 | 0.15 | 0.09 | 0 | | 1.19 | 8 | 0 | 8.86 |
| 5802 Tunbridge Borehole #2 | 676.4-676.7 | 458 | 0.56 | 0.92 | 0 | | 2.8 | 33 | 0 | 6.94 |

# ORGANIC PETROLOGY OF THE PARMEENER GROUP

The maceral compositions of the organic matter in the 17 samples provided fall into two distinct groups (see diagram). The organic matter in the Quamby Mudstone is very rich in exinite, from 65% (sample 4) to 100% in an oil shale (sample 9). The quantity of organic matter varies from traces (not plotted on diagram), 1% (sample 5) to 65% (sample 8).

The samples from the Lower Freshwater Sequence and below are all inertinite-rich, with 39% inertinite in sample 15 to 88% in sample 17. The organic matter in samples 11 and 12 (also 1 and 2) is very finely divided and opaque. (The particles are so small that they haven't taken a polish, and appear black.) It is even possible that these particles are not organic. It may be inertinite and/or heat-altered vitrinite and exinite macerals.

Most of the samples of the Quamby Mudstone appear to be in the early to main oil generation zone of maturity based on fluorescence colours, or mean average vitrinite reflectance where available.

| | Fluorescence colour of exinite |
|---|---|
| Sample 3 (84 CP3) | Golden yellow - spores |
| Sample 4 (84 CP4) | Golden yellow - spores |
| Sample 6 (84 CP6) | Golden yellow - spores |
| Sample 7 (84 CP7) | Golden yellow - spores |
| Sample 8 (84 CP8) | Dark orange - spores<br>pale green - Tasmanites |
| Sample 9 (84 CP9) | Green-yellow - Tasmanites |
| Sample 10 (84 CP10) | Deep orange - yellow, both spores and Tasmanites |
| Sample 13 (84 CP13) | Orange - yellow - algae (vitrinite reflectance = 0.62%) |
| Cample 14 (84 CP14) | Bright yellow - cutinite<br>(vitrinite reflectance = 0.55%) |
| Sample 15 (84 CP15) | Vitrinite reflectance = 0.48% |
| Sample 16 (84 CP16) | Vitrinite reflectance = 0.49% |
| Sample 17 (84 CP17) | Vitrinite reflectance = 0.49% |

TABLE 1

LOCATION: NORTH TASMANIA

FORMATION: PARMEENER SUPERGROUP

Organic Matter Content

Results are given as percentages by volume

| BMR No. | | | Total DOM | | | Lab. No. |
|---|---|---|---|---|---|---|
| 1. | 84CP1 | Wynyard Tillite | 1 | Bass Highway | | 90239 |
| 2. | 84CP2 | Wynyard Tillite | 1 | Hellyer Sheet | | 90240 |
| 3. | 83CP3 | Quamby Mudstone | 3 | Golden Valley B/H | 446 ft. | 90241 |
| 4. | 84CP4 | Quamby Mudstone | 4 | Golden Valley B/H | 559 ft. | 90242 |
| 5. | 84CP5 | Quamby Mudstone | 1 | Anderson's Creek B/H | 1,408 ft. | 90243 |
| 6. | 84CP6 | Quamby Mudstone | tr | Anderson's Creek B/H | 425 ft. | 90244 |
| 7. | 84CP7 | Quamby Mudstone | 1 | Hellyer Gorge | | 90245 |
| 8. | 84CP8 | Quamby Mudstone | 65 | Mersey Great Bend Oil Shale | | 90246 |
| 9. | 84CP9 | Quamby Mudstone | 21 | Hellyer Gorge | | 90247 |
| 10. | 84CP10 | Quamby Mudstone | 6 | Relapse Creek Area, Float | | 90248 |
| 11. | 84CP11 | Marine Mudstone | 3 | Musselroe Bay B/H | 56m | 90249 |
| 12. | 84CP12 | Lower Freshwater Seq. | 5 | Musselroe Bay B/H | 42m | 90250 |
| 13. | 84CP13 | Lower Freshwater Seq. | 7 | Golden Valley B/H | 54.5 ft. | 90251 |
| 14. | 84CP14 | Lower Freshwater Seq. | 10 | Fingal B/H 9 | 211 ft. | 90252 |
| | | | Total Coal | | | |
| 15. | 84CP15 | Preolenna Coal Meas. | 99 | Relapse Creeek | | 90253 |
| 16. | 84CP16 | Preolenna Coal Meas. | 41 | Relapse Creek | | 90254 |
| 17. | 84CP17 | Preolenna Coal [illegible]. | 67 | Relapse Creek | | 90255 |

## TABLE 2 (ii)

LOCATION: NORTH TASMANIA

FORMATION: PARMEENER SUPERGROUP

Maceral analyses of the organic matter

| | Lab. No. | Type of organic matter | Vitrinite | Sporinite | Cutinite | Resinite | Liptodetrinite | Alginite | Micrinite | Macrinite | Inertodetrinite | Semifusinite | Opaque matter | % of sample | No. of counts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11. Marine Mudstone | 90249 | DOM | - | - | - | - | - | - | - | - | 4 | - | 96 | 3 | 28 |
| 12. Lower Freshwater Sequence | 90250 | DOM | - | - | - | - | - | - | - | - | 100 | - | - | 5 | 16 |
| 13. " | 90251 | DOM | 13* | 19 | - | - | - | 2 | 2 | 4 | 60 | - | - | 7 | 48 |
| 14. " | 90252 | DOM | 28 | 5 | 14 | - | 1 | tr | - | 14 | 12 | 26 | - | 10 | 77 |
| | | $\bar{R}_o$(av) | | | | Coals | | | | | | | Fusinite | Clay Py Q. | |
| 14. " | 90252 | 0.55% | 12 | 6 | 14 | 2 | 7 | - | 4 | 2 | 27 | 15 | 1 | 6 tr 4 | |
| 15. Preolenna Coal | 90253 | 0.48% | 55 | 2 | 1 | 1 | 1 | - | 4 | 7 | 12 | 13 | 3 | 1 tr - | |
| 16. Measures | 90254 | 0.49% | 37 | 3 | 4 | 1 | 3 | - | 2 | 6 | 31 | 10 | 3 | not counted | |
| 17. Measures | 90255 | 0.49% | 6 | 1 | 1 | - | tr | - | tr | 2 | 7 | 43 | 7 | 10 1+1ϕ 21 | |

* mean average reflectance ($\bar{R}_o$(av)) = 0.62%

Py = pyrite

Q = quartz

ϕ carbonate

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## ROCK EVAL AND ORGANIC C ANALYSES PARMANEER SUBGROUP

by T. POWELL
(see attached Table)

The Rock Eval Pyrolysis Method is a firmly established technique for screening samples for source rock potential (see Tissot & Welte 1978). $S_4$ Yields from pyrolysis are related to both the amount of organic matter and its richness (H content) and are expressed in Kg per tonne.

$S_1$ = yield of free hydrocarbons in rock
$S_2$ = yield of pyrolysable hydrocarbons from kerogen in rock
$S_3$ = yield of carbon dioxide from pyrolysis of kerogen in rock
PI = Productive Index ($S_1$ /$S_1$ + $S_2$)
HI = Hydrogen Index (yield of hydrocarbon mg/g (organic carbon)
OI = Oxygen Index (yield of carbon dioxide mg/g organic carbon).

The Hydrogen and Oxygen Indices can be directly related to the atomic H/C and O/C ratios determined by elemental analysis. Thus the oil shale samples 84CP8 and 84CP9 have hydrogen indices in the range 700 to 950 and hence contain Type I oil prone kerogen. The samples from the Lower Freshwater Sequence and the Preolenna Coal Measures have somewhat lower Hydrogen Indices which indicate a oil prone terrestrial kerogen Type II/III not unlike the source for many of Australia's non-marine oils. All the remainder of the samples clearly have no source potential.

The $T_{MAX}$ value is the temperature at which the $S_2$ is cracked from the kerogen. With increasing maturation it systematically increases, the oil window is defined by the values 435-470°C. Unreliable values occur where the $S_2$ yields are low e.g. 84CP2, 84CP12. Most of the reliable values fall in the range 434 to 449 indicating that the samples are from the upper part of the oil window.

## ROCK EVAL AND ORGANIC CARBON DATA PARMANEER SUPERGROUP N. TASMANIA

| LAB NO. | FIELD NO. | ORG C % | $S_1$ | $S_2$ | $S_3$ | TMAX °C | PI | HI | OI |
|---|---|---|---|---|---|---|---|---|---|
| | | | Kg per Tonne | | | | | | |
| | | | **WYNYARD TILLITE** | | | | | | |
| 1988 | 84CP1 | 0.11 | 0.02 | 0.04 | 0.07 | 437 | 9.33 | 36 | 63 |
| 1989 | 84CP2 | 0.10 | 0.01 | 0.02 | 0.17 | 401 | 0.50 | 20 | 170 |
| | | | **QUAMBY MUDSTONE** | | | | | | |
| 1990 | 84CP3 | 0.67 | 0.16 | 0.49 | 0.05 | 442 | 0.25 | 73 | 7 |
| 1991 | 84CP4 | 0.95 | 0.29 | 1.74 | 0.07 | 447 | 0.14 | 183 | 7 |
| 1992 | 84CP5 | 0.33 | 0.02 | 0.10 | 0.08 | 445 | 0.17 | 30 | 24 |
| 1993 | 84CP6 | 0.29 | 0.02 | 0.11 | 0.09 | 425 | 0.17 | 37 | 31 |
| 1994 | 84CP7 | 0.36 | 0.00 | 0.05 | 0.33 | 363 | 0.00 | 13 | 91 |
| 1995 | +84CP8 | 25.65 | 15.02 | 236.80 | 0.92 | 442 | 0.06 | 925 | 3 |
| 1996 | +84CP9 | 5.43 | 1.30 | 38.90 | 2.50 | 449 | 0.03 | 716 | 46 |
| 1997 | 84CP10 | 1.61 | 0.65 | 4.37 | 0.31 | 449 | 0.13 | 271 | 19 |
| | | | **MARINE MUDSTONE BELOW LOWER FRESHWATER SEQUENCE** | | | | | | |
| 1998 | 84CP11 | 0.44 | 0.03 | 0.02 | 0.17 | 459 | 0.75 | 4 | 38 |
| | | | **LOWER FRESHWATER SEQUENCE** | | | | | | |
| 1999 | 84CP12 | 1.90 | 0.03 | 0.02 | 0.07 | 277 | 0.75 | 1 | 3 |
| 2000 | 84CP13 | 4.25 | 0.47 | 3.64 | 0.13 | 435 | 0.11 | 85 | 3 |
| 2001 | 84CP14 | 24.66 | 3.50 | 108.2[illegible] | 6.10 | 434 | 0.03 | 442 | 24 |
| | | | **PREOLENNA COAL MEASURES** | | | | | | |
| 2002 | 84CP15 | 25.25 | 7.30 | 100.6 | 5.2 | 442 | 0.07 | 398 | 20 |
| 2003 | 84CP16 | 25.43 | 10.10 | 102.4 | 5.2 | 444 | 0.09 | 402 | 20 |
| 2004 | 84CP17 | 25.85 | 6.60 | 68.4 | 4.9 | 445 | 0.09 | 266 | 19 |

+ oil shale.

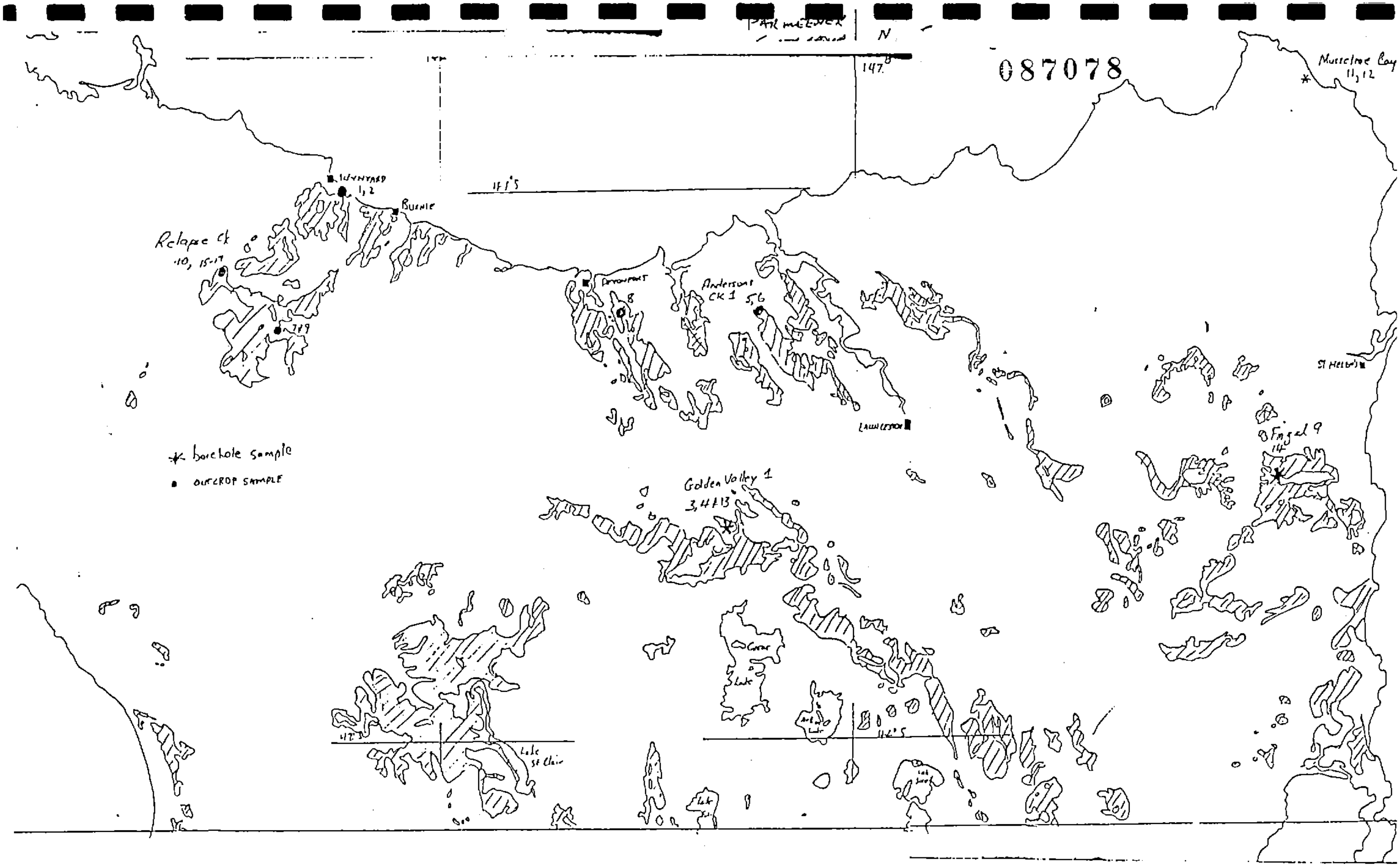

Fig ~~outcrop~~ Distribution of Parmeener Supergroup in Northern Tasmania and sample localities.

# APPENDIX 3 - B.H.P drilling results 1981

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# APPENDIX 4 - Domack ,E.W. Stratigraphic sections

# APPENDIX 5 - Domack ,E.W. T.D.C Douglas river

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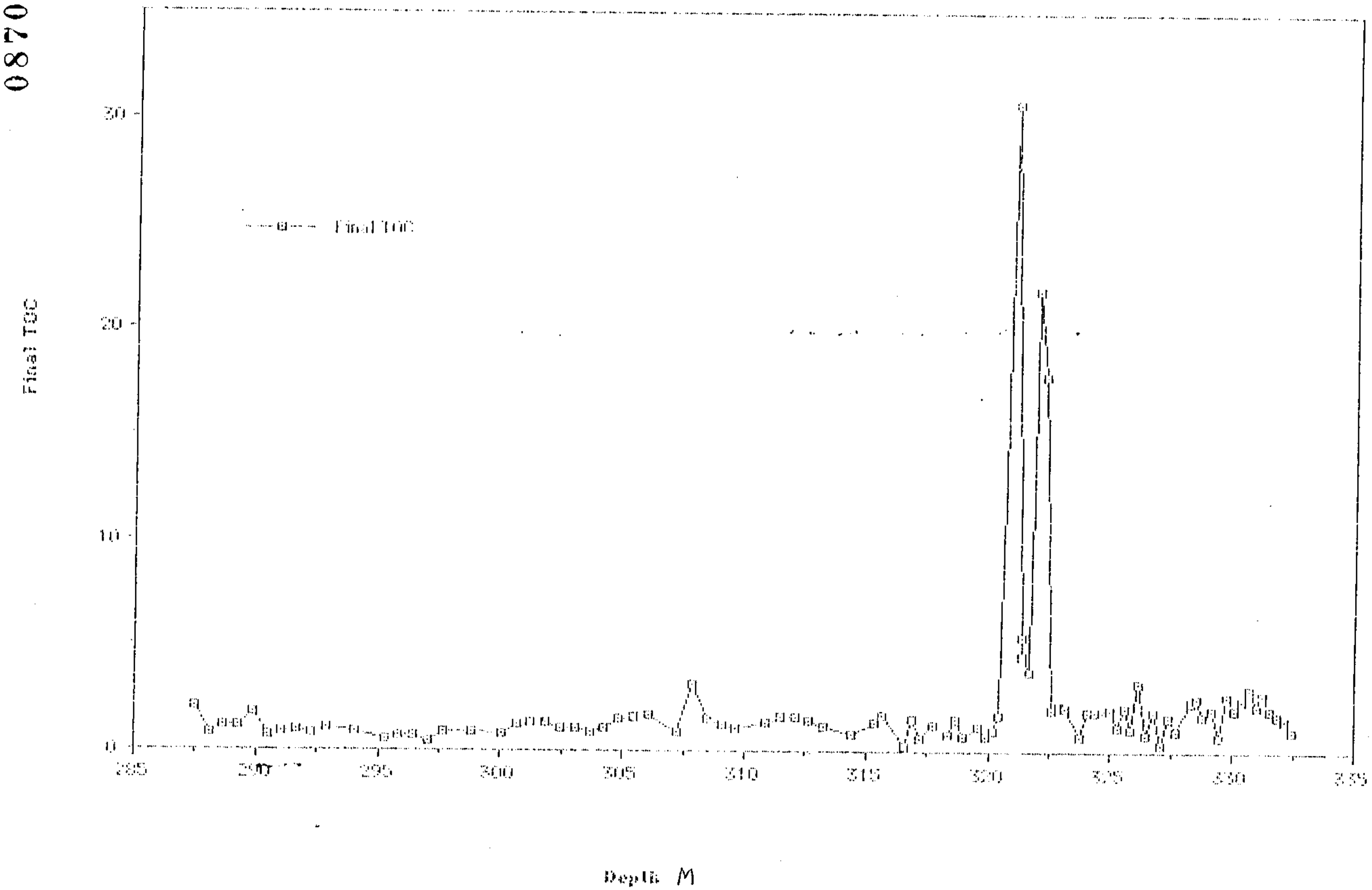
Data from "Douglas River Geochem"



# APPENDIX 6 - E.W.Domack 1991

# ORGANIC CARBON AND FACIES VARIATION IN GLACIAL-MARINE MUDROCKS: A PALEOCLIMATIC INDICATOR

## ABSTRACT

Eugene Domack and Lewis Burkley

Ancient polar glacimarine sediments are important paleoclimatic and paleooceanographic indicators. Consequently, as more is learned about these depositional environments, better paleoclimatic reconstructions can be produced. In addition, many glacimarine sequences contain organic-rich mudstones - potential petroleum source rocks. The development of a detailed depositional model for these ancient facies, a model that is closely tied to current ideas concerning recent Antarctic deposition, would greatly improve out ability to 1) recognize individual facies within these ancient deposits, 2) interpret and reconstruct paleoclimatic conditions, and 3) predict source rock potential and extent in basins where these types of deposits exist.

A detailed study of facies variation and associated organic matter changes (type, richness, dC13) for an ancient polar glacimarine sequence will be done. Results from this work will be compared to similar recent Antarctic sediments. This will enable us to develop a detailed depositional model that will include inorganic as well as organic variations.

Development of a successful depositional model for polar glacimarine sediments will provide 1) more precisely defined temperature ranges for specific facies, 2) more diagnositic ways in which to identify facies, 3) a predictive tool for source rock extent and quality, and 4) insight into dC13 variations in ancient glacimarine organic sequences.

## BACKGROUND AND OBJECTIVES

### Climatic Model

A climatic model presented in this proposal is modified from Trewartha (1968) for present climatic zones of the earth. In this model there are three major zones of interest focused around glacial activity near or adjacent to marine basins. These zones include: Polar-ice cap, Polar-tundra (or subpolar), and Boreal and/or Temperate Oceanic (Table 1). Though modified somewhat by oceanic circulation and orography the above climates can be found in transition today along roughly latitudinal directions. They represent a continuum from conditions of absent meltwater with dynamic sea ice, to glacially covered terrain with abundant meltwater, terrestrial vegetation, and glaciated valley systems (Table 1). Because of this variability, glacimarine facies within these environments have been found to be distinctive with respect to ice positions and the relative role of biogenic vs meltwater derived sedimentation (Domack, 1982; Anderson and others, 1983, Powell, 1983; Edwards, 1986; Domack, in review).

### Polar (Ice Cap)

The Polar (ice cap) situation is exemplified by the environment along the East Antarctic coast (Figure 1) where mean summer temperatures are less than -2.0 degrees C. In such settings meltwater production is severely restricted, thus limiting both organic and inorganic terrigenous sediment supply to the marine environment. Sea ice fluctuations and nutrient rich waters result in seasonal blooms of phytoplankton which feed benthic productivity. The combination of these climatic and oceanographic factors results in basinal and marine derived organic-rich (Table 1; Figure 2a) muds, shallow water carbonates, and bioclastic rich sediment gravity flow deposits (Figure 1).

Other facies (diamictons) in this environment are dominated by glacially

| | | | | | |
|---|---|---|---|---|---|
| Climatic Zone | Polar<br>(Ice cap) | | Polar<br>(Tundra) | | Boreal or<br>Temperate Oceanic |
| n Summer peratures | < 0° C | → | 0° C - 10° C | → | > 10° C |
| Limiting Factors | no terrestrial vegetation | → | limited terrestrial vegetation | → | abundant terrestrial vegetation |
| | no meltwater input | → | limited meltwater input (proximal) | → | abundant meltwater input (distal & proximal) |
| | extensive and dynamic sea-ice | → | limited sea-ice | → | no sea-ice |
| T. O. C. | 1 - 6%[a.] | | < 0.5%[b.] | | < 1.5%[c.] |

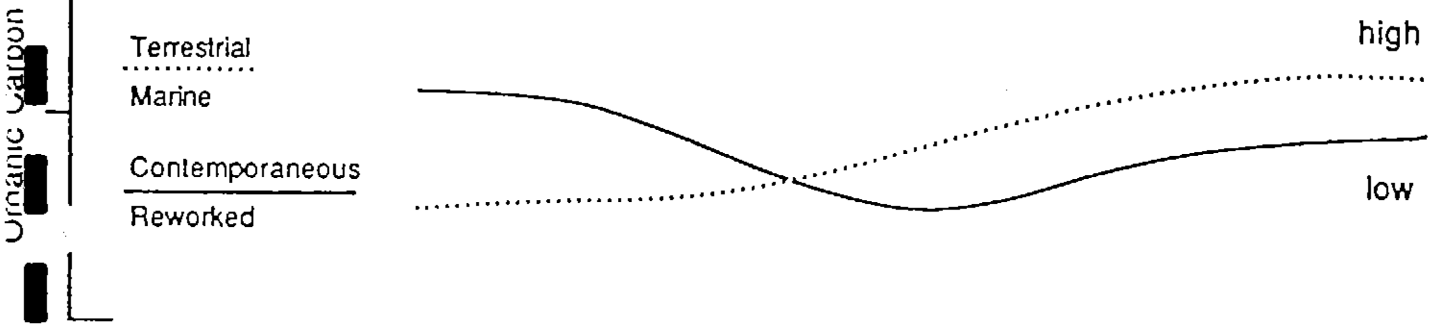


Table 1: Climatic zonation, summer temperature variation and limiting factors for various glacimarine environments. Resultant variations in organic carbon for basinal mudrock facies are also shown. Total organic carbon contents (T.O.C.) from, (a); Dunbar and others (1985) and Domack (in review), (b); Stevens (1985), (c); Atlas and others (1983).

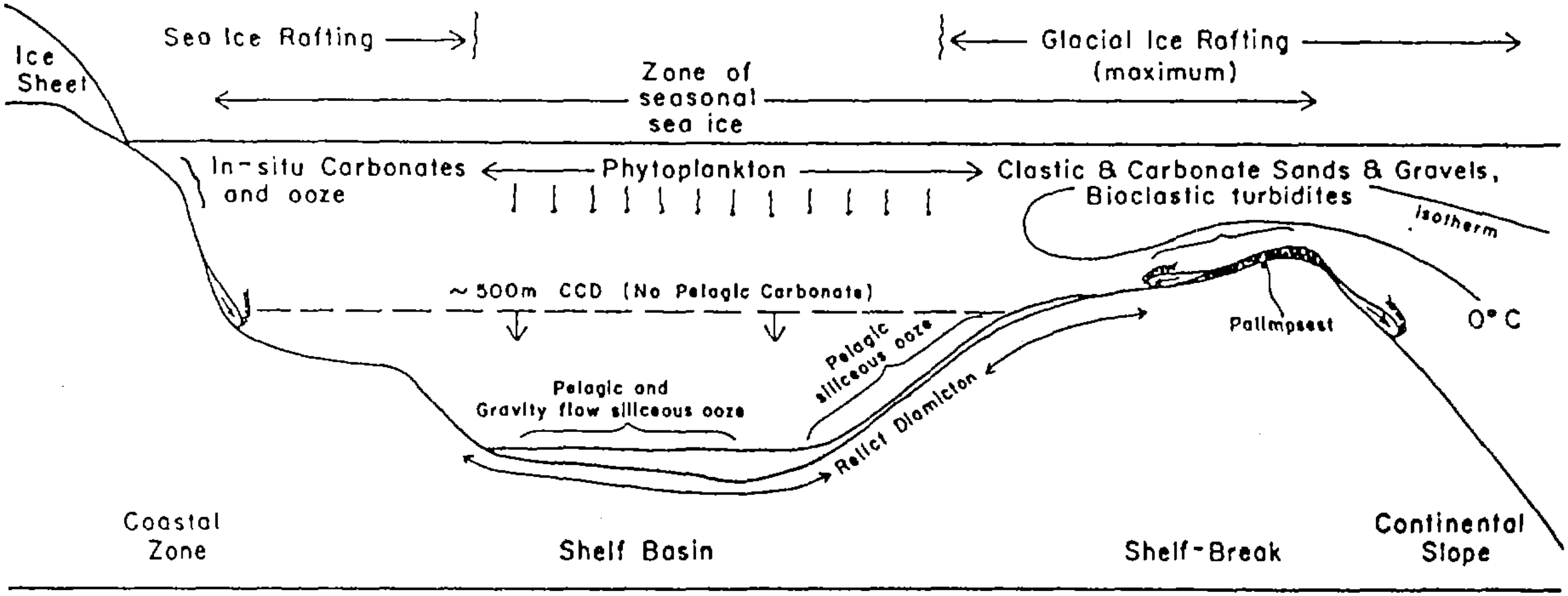


FIGURE 1 Depositional model for Antarctic polar glacial marine environment. Based on information in Domack (1980, 1982, in review,) Domack and Anderson (1983) and Anderson et al. (1983).

derived detritus and are deposited subglacially or beneath an ice shelf. These units contain low amounts of organic carbon (TOC<0.5%) and would be characterized by reworked (detrital) kerogen (Sackett, 1986a).

## Polar (Tundra)

Subpolar environments, such as those of Spitsenbergen and elsewhere, are marked by ice-proximal (<10 km) meltwater mud deposition which occurs adjacent to ice cap and outlet glacier systems (Gilbert, 1982; Pfirman, 1985). Mean summer temperatures are between 0 and 10 degrees C, therefore, limiting terrestrial vegetation on deglaciated terrain. Organics within glacimarine muds would be expected to be dominated by reworked (Table 1 and Figure 2b) organics transported and incorporated by meltwater depositional processes. Contemporaneous marine organics would be highly diluted with meltwater derived sediment, particularly in ice-proximal facies. Pleistocene examples suggest TOC of < 0.5% (Stevens, 1985).

## Boreal/Temperate Oceanic

Piedmont and valley glacier systems surrounding the Gulf of Alaska exist under Boreal or Temperate Oceanic climates and are marked by high net balance gradients (high accumulation and ablation). Under such conditions meltwater sedimentation in the marine environment is dominant in both proximal and ice-distal settings (Powell, 1981; Molnia and Hein, 1982; Molnia, 1983) and terrestrial vegetation is well established. The resulting glacimarine muds should contain low to moderate amounts of terrestrial organic carbon of both reworked and contemporaneous origin (Atlas and others, 1983).

## Ancient Analogs

In the ancient record the above climatic variations would be expected to be preserved as vertical changes in mudrock lithofacies and associated organic carbon (Figure 3). Marine basins that have undergone minimal uplift and sufficient subsidence during the climatic transition would be ideal places for the preservation of analogs to recent sequences.

Examples of ancient sedimentary deposits that may be analogs for recent Polar (Ice Cap) glacimarine sediments include: the Late Precambrian Hedmark and Pahrump Groups in Norway and SW North America (Tucker, 1983; Tucker, 1986; Tucker, personal communication - attached), the Early Paleozoic Bthaat Ergil Group (Trompette, 1973) and other Paleozoic units in Northwest Africa (Beuf and others, 1966; Combaz, 1967; Williams, 1978), and the Early Permian Quamby Group in Tasmania (Banks, 1962; Carey and Ahmad, 1961).

Of these, the Early Permian Quamby Group in Tasmania is most similar to the recent Antarctic glacimarine facies in three ways:

1. Both sequences consist of glacimarine diamict directly overlain by biogenic deposits (Banks, 1962; Clarke and Banks, 1972; Domack, 1982; Domack and Anderson, 1985) (see Figure 1).

2. In both sequences deep water organic-rich sediments grade laterally into bioclastic carbonates and bioclastic rich turbidites within shallow portions of the basin (Banks, 1962; Rao, 1981; Domack, 1982; Domack and Anderson, 1985) (see Figure 2).

3. Both sequences were deposited in polar latitudes (greater than 65 degrees).

## Objectives

We propose to compare the Quamby Group Mudstone facies with recent Antarctic glacimarine facies sedimentologically, petrographically, and geochemically. In so doing we anticipate developing a better understanding of the depositional history, ultimately in the form of a testable depositional model. We hope to do this by addressing the following ideas.

First, Do the facies change sedimentologically and petrographically as the climatic conditions shift toward warmer temperatures in recent sediments as is depicted in Figure 3.

Are there clear systematic facies variations as sea ice retreats and climate warms such that specific temperature limits (Table 1 and Figure 3) can be associated with the changes?

These questions will be answered by first examining recent antarctic sediments already available (at Florida State University) as well as sediments to be collected by E. Domack as part of NSF/RUI Research Grant DPP-8613565 "Depositional Environments of the Antarctic Continental Shelf" (refer to Part III in application - Current Research Activities). Then, the Quamby Group Mudstone facies will be similarly examined and compared to the recent sediments.

Second, how does the organic matter (type and richness) vary with the sedimentology and facies?

Do the facies show a systematic change in the ratio of land derived kerogen to marine derived kerogen as they become more distal, with respect to the ice, and as fluvial input and land plant communities expand under climatic warming and deglaciation? At what stratigraphic position is the greatest amount of organic material preserved and is it possible to predict the position of such facies? How does the depositional environment of present day organic-rich siliceous sediments compare to these ancient mudstones?

The accumulation of organic-rich well laminated sediments in the Antarctic occurs within basins that contain oxygenated bottom waters (Domack

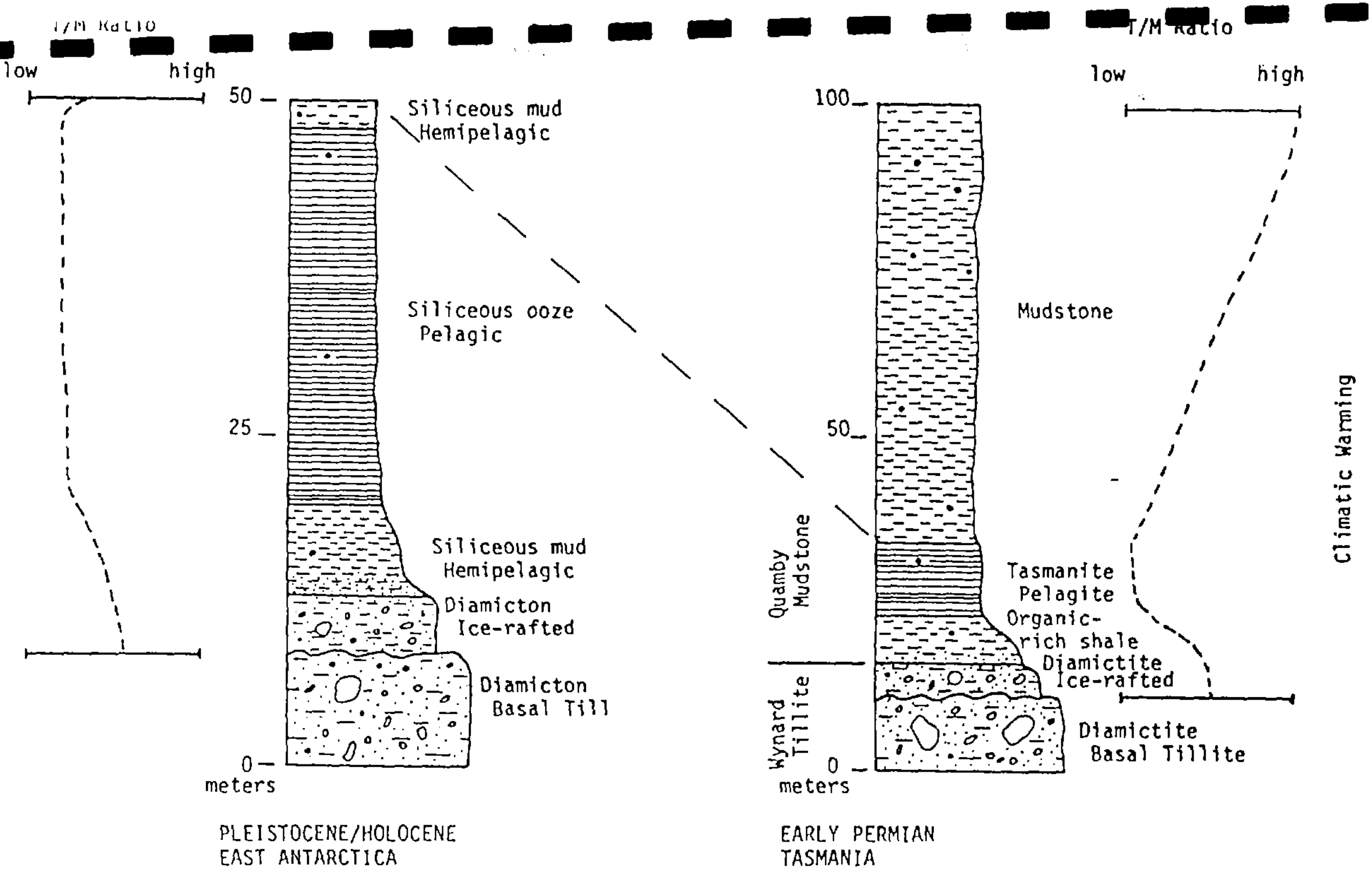


Figure 3: Cartoon showing correlation of facies between recent and ancient polar glacimarine sequences. Note, proposed climatic warming and possible terrestrial (T) to marine (M) kerogen ratios for ancient sequence. Antarctic stratigraphy from Domack (1982, in review), Domack and Anderson (1983). Early Permian stratigraphy from Banks (1962; 1985, personal communication), Clarke (1968) and Clarke and Banks (1972). Laminated and massive mudstones are indicated by continuous and discontinuous horizontal lines respectively.

and Anderson, 1983; Gordon and Tchernia, 1972). This is not typical of environments generally inferred for deposition and preservation of good source rocks (Demaison and Moore, 1980; Parrish, 1982; Parrish and Curtis, 1982).

To address this quandary the origin of laminations within these basinal muds needs to be addressed. Preliminary data indicate that laminated zones are essentially lacking in terrigenous detritus and, therefore, may represent quite rapid pelagic (?) sedimentation (Domack, in review). Such rapid deposition appears to be related to seasonal productivity associated with receding sea-ice (Smith and Nelson, 1985; Bodungen et al., 1986). Are laminated intervals within the Quamby similar in origin to the Antarctic oozes (Figure 2)? The lateral relationships of this facies, as observed in outcrop, would help clarify such questions and our understanding of modern Antarctic ooze deposition. Further, the preservation of laminated pelagic facies is generally thought to be an important indicator of bottom water anoxia (Byers, 1977; Savdra, et al., 1984) which prevents effective bioturbation and enhances organic carbon preservation. Clearly, this widely accepted model does not apply to the Antarctic oozes and may not apply to the Quamby and/or other glacial-marine, organic-rich, mudrocks. Other factors important in such settings may be the high, short-term sediment accumulation rates which may rival those of low concentration turbidity currents. Rapid deposition over a short time interval may effectively limit bioturbation and is in contrast to the "continuous pelagic sedimentation" included within the anoxic model of Savdra, et al., (1984, p. 1189) and others.

Thus, sedimentation rate is important in affecting organic preservation (Ibach, 1982). But, we question whether a rapid sedimentation rate is sufficient to result in highly organic-rich (>8% T.O.C.) sediment such as is observed in the Quamby Group (Reid, 1924)? Just how do the organic-rich Quamby mudstones (i.e Tasmanite) compare to the recent Antarctic organic-rich sediments? Do we have richer organic sediments accumulating today in the Antarctic that have not as yet been sampled, or are there definite differences between the recent sediments and the Quamby organic-rich facies?

Third, are changing ratios of land-derived kerogen to marine-derived kerogen, from facies to facies reflected in the stable carbon isotopes?

dC13 measurements of kerogen in source rocks are used for oil-source rock matching. This correlation tool often works well (Fuex, 1977). However, in some instances dC13 values of kerogen from different samples of the same source rock are highly variable. For example, the Kingak Formation in Alaska shows a dC13 spread of over 6 permil (Burkley and Castano, 1986). A spread of this magnitude prevents the use of dC13 values of kerogen for oil-source rock matching.

One possible cause of a large spread of measured dC13 values of kerogen is that the organic matter of different facies may differ, especially with respect to the ratio of terrestrial to marine material. Dean and Arthur (1983) interpreted observed differences in dC13 in ancient sediments as the result of different sources of organic matter as well as to diagenesis. Because land derived kerogen is generally depleted in 13C relative to kerogen of marine origin (Sackett, 1986a; Tissot and Welte, 1978; Stuermer and others, 1978), it is conceivable that the measured isotopic values reflect the mixing of these two components in varying proportions (Sackett, 1986a). As pointed out by Arthur and others (1985), the dC13 relationship may not be easily interpreted in ancient sediments without carefully observing the facies and palaeogeographic setting.

Facies dominated by indigenous marine kerogen (i.e. Polar ice cap, Table 1) may also show dC13 variation which is temperature, rather than facies dependent (Sackett, 1986b). Though the exact fractionation relationships would be difficult to establish for ancient (extinct?) phytoplankton species relative changes could be established if the various components of the kerogen are accounted for.

The Quamby Group is an excellent place to test these ideas. The depositional sequence will be thoroughly studied. Facies will be differentiated and the ratio of terrestrial-derived to marine-derived kerogen will be estimated visually by transmitted light microscopy in a method similar to that of Boulter and Andrew (1986). Then the richness (T.O.C.) and the dC13 kerogen value will be measured. If the proposed ice-distal and/or polar facies contain low amounts of terrestrial kerogen, as we suspect they will, we should be able to observe the dC13 values changing in a systematic pattern reflecting changing input of both inorganic and organic facies constituents.

In addition, limited dC13 analyses will be performed on kerogen from the recent glacimarine sediments from the Antarctic used in the initial stages of this study. Although these results may not be similar to those of the Quamby mudstones (Arthur and others, 1985), it will be important to compare them to these ancient sediments deposited in a similar environment. The problem with comparing d13C values of ancient kerogen to those of the Recent is chiefly the result of our lack of understanding of kerogen diagenesis (Tissot and Welte, 1978; Stuermer and others, 1978; Spiker and Hatcher, 1984), coupled with the incomplete and variable nature of the diagenesis in recent unconsolidated sediments (Tissot and Pelet, 1981; Tissot and Welte, 1978; Stuermer and others, 1978; Hatcher and others, 1983; Harvey and others, 1984; Harvey and others, 1986).

In summary, the objects of this project are:

1. To test current models of polar glacimarine sedimentation.

2. To develop a sedimentologic model for organic-rich mudrocks in polar

glacimarine environments.

3. To interpret the sedimentary record of these rocks with respect to glacial climatic and oceanographic changes.

4. To test the dC13 variation in organic-rich and organic-lean rocks as the result of facies variation and organic type.

Insofar as both ancient glacial marine sediments and mudrocks, in general, represent two major frontiers of sedimentologic research (see discussions by Reading (1986), Gorsline (1984) and Blatt (1982) we believe the results of the proposed project will be well received by the geologic community.

## METHODS TO ACHIEVE THE OBJECTIVES

Some sedimentological and petrological analyses of recent glacimarine sediments have already been done (Domack and Anderson, 1985; Domack, in preparation) while other samples are available to us (Florida State Antarctic Core Facility) to do more work. Additional sediment will be collected as a part of NSF/RUI grant (DPP-8613565). Two or more students will participate in the actual shipboard sampling.

Field study and sampling of the Quamby Group in Australia will be conducted in co-operation with the University of Tasmania which can provide some support for field and accomodation expenses (personal communication, Dr. Maxwell Banks; letter attached at end of proposal). One student will accompany E. Domack, the funds for which are available in a newly instituted "Rogers Grant in Geology" at Hamilton college (letter of explanation attached at end of proposal). These funds are specifically for student research and travel, the use of which is determined by the geology department faculty.

Detailed sedimentologic studies will focus on the Lower Permian Wynyard Tillite and Quamby Mudstone Group which contains several oil shale units (Figure 1). Outcrop and drill core material from the Quamby Group will be described and analyzed with the initial purpose being recognition of distinct lithofacies based on primary and biogenic sedimentary structures, lithology, and petrography. The nature of contained ice-rafted debris will also be examined in order to discern mechanisms of ice transport (i.e. sea-ice, basal or supraglacial debris). Sediment sample analysis will be conducted at the sedimentology laboratory at Hamilton College, Department of Geology (see research schedule page 14).

Comparison of results from the Quamby Mudstones with analyses of Antarctic glacimarine sediment will permit the development of a tentative depositional model (see research schedule, page 14). This model will be modified and altered as work progresses.

In the second year, the Total Organic Carbon (TOC) analyses for at least 75- 100 recent and ancient sediments will be determined by a service company (funds for which are requested in the grant at about $10 per analysis). Kerogen separates will be prepared and analyzed, in transmitted light, both as whole sediment sample and kerogen concentrates with estimates made of the types and percentages. The organic maturity of the Quamby is low (Marchand, et al., 1969), so that it is anticipated general recognition of much of the organic matter will be possible. With this information, samples for dC13 analysis will be selected to display the best possible range of organic type and richness. One or two students will travel to Case Western Reserve University in Cleveland to perform these analyses (see letter from S. Savin attached to end of proposal). This will cost about $15 per sample for an estimated 50-60 samples, plus student expenses and salary for two or three months in the summer. Some money for students should also be available through

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the Roger's Grant for student research mentioned previously. This phase of the study will provide an extremely valuable laboratory experience. Funds for analyses and student salaries are requested in the grant.

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# STUDENT PARTICIPATION

Four students will be actively involved with this research project as scholars (see research schedule, page 14). A general outline of their involvement is as follows:

Participation by Two Scholars involving sedimentological aspects

1. Sedimentologic and grain size analyses
2. Statistical evaluations of bedding style and lamination
3. Petrographic examinations and descriptions
4. Core and outcrop sample descriptions

Participation by Two Scholars involving geochemical aspects

1. Kerogen separation and visual identification
2. TOC sample preparations and analyses
3. Petrographic examination of organic-rich and lean mudstones
4. Isotopic analysis of selected samples

It is anticipated that each students will participate in at least two different aspects of the topics listed above. If students show an interest we also anticipate that they will participate in publications that result from this work.

Besides these four scholars, we expect several other students to be involved in smaller scale aspects of this study with senior theses or senior projects. As of 1987-88 Hamilton College will institute a senior requirement that will encourage each student to do some kind of independent work. We anticipate an increase in the number of geology students who will participate in senior related projects. As of 1989-90 this senior project will be manditory.

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## ADDITIONAL BUDGETARY COMMENTS

Field work request for $3000 will support one of us for about a one month reconnaissance field season in Australia. This will cover travel expenses to and from Australia, food, and some lodging. As stated in the body of the proposal Dr. Maxwell Banks from the University of Tasmania has offered some support for field work and lodging. The summer of 1988, E. Domack and one student field assistant will return for a two month field season. We anticipate enough money will remain after the first trip, plus salary to support E. Domack. The student will be supported by the Hamilton College Roger's Grant in Geology (see attached letter at end of proposal).

## RESEARCH SCHEDULE

| | |
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| Summer 1987 | One month reconnaissance field work, Australia (E. Domack) |
| Fall & Spring 1987-8 | Sedimentology and grain size analysis of recent sediments and initial Quamby Group samples.<br>Petrography of mudrocks. Visual kerogen and organic carbon analysis of glacial marine muds (including Quamby Group samples). |
| Summer 1988<br>May-June | Two months field work, Australia (E. Domack and student) |
| Summer, Fall & Spring 1988-9 | Continuation of studies from previous year with additional samples as available.<br>Possibly initial carbon isotopic analysis (L. Burkley and student).<br>Development of tentative facies model for Quamby Group samples. Petrography of mudrocks.<br>Development of facies model for Quamby. |
| Summer, Fall & Spring 1989-90 | Visual kerogen and organic carbon analysis of glacial marine muds and Quamby Group continue.<br>Petrographic analysis continues. |
| Summer 1990 | Completion of carbon isotope analysis of lithofacies of glacial-marine mudrocks.<br>Petrography completed.<br>Synthesis and correlation of data (E. Domack & |

L. Burkley).

Development of comprehensive paleoclimatic model for glacial-marine mudrocks.

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# APPENDIX 7 - Wilkinson ,W.M 1953

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 37, NO. 2 (FEBRUARY, 1953), PP. 250-265, 10 FIGS.

# FRACTURING IN SPRABERRY RESERVOIR, WEST TEXAS[1]

WALTER M. WILKINSON[2]
Midland, Texas

## ABSTRACT

The Spraberry formation of West Texas is developed in the lower Leonard of middle Permian, restricted in most part to the Midland basin. The main producing structure is a fractured permeability trap on a homoclinal fold. This homogeneous mass is undifferentiated except as to alternate layers of sands, siltstones, shales, and limestones, deposited in a deep basin under stagnant conditions with hydrocarbons formed throughout the 1,000 feet of sedimentary rocks.

Fractures were created by tensional forces after induration, probably during post-Leonard time. With storage of the oil reservoir in the sandstone matrix, the fractures serve as "feeder lines" to conduct the oil to the bore hole. Without these fractures commercial production would be from a seemingly "too-tight" reservoir rock.

The producing area of the Spraberry formation is a "fairway" 150 miles long and 50 miles wide at an average depth of 6,800 feet. The main area, however, is 50 miles long, with width ranging from a few miles to 48 miles, thus creating a triangle of 488,000 proved and semi-proved productive acres.

## INTRODUCTION

The Spraberry trend (Fig. 1) is distributed throughout the main part of the Midland basin, a geological province of the Permian basin. The major part of the trend extends north and south 150 miles and attains maximum width of nearly 75 miles.

Physiographically, the trend area is in the region between the south end of the Llano Estacado and the north part of the Edwards Plateau. The northern area is mostly sand and sandy soils, while the southern area contains tighter soils which are predominantly clay loams. The topography is marked by low hills, draws, and dry lakes without drainage. Recent sands and gravels, Tertiary gravels, Cretaceous limestones and sandstones, and Triassic redbeds are exposed with no recognized, but not necessarily unrecognizable, surface expression of the subsurface structures. The climate is semi-arid with a mean annual rainfall of 18–20 inches. The surface cover is mainly prairie grasses and mesquite.

## HISTORY OF DEVELOPMENT

In 1944 a dry pre-San Andres test was drilled by the Seaboard Oil Company on the Abner J. Spraberry farm of east-central Dawson County. During the drilling of this well, a sandstone was noticed to have a slight showing of oil or gas and was locally called the "Spraberry sandstone." No completion was attempted in this sandstone, and no significance was attached to the possible reservoir rock until the Seaboard Oil Company's Lee well No. 2-D was drilled in late 1948 to the Ellenburger formation. During the drilling of this well, a showing of oil was noted at approximately 7,000 feet and a decision was made to test this zone. The Lee No. 2 was subsequently completed as a producer with flowing potential of 319

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[1] Read before the Association at Los Angeles, March 28, 1952. Manuscript received, July 1, 1952.

[2] District geologist, Sohio Petroleum Company.

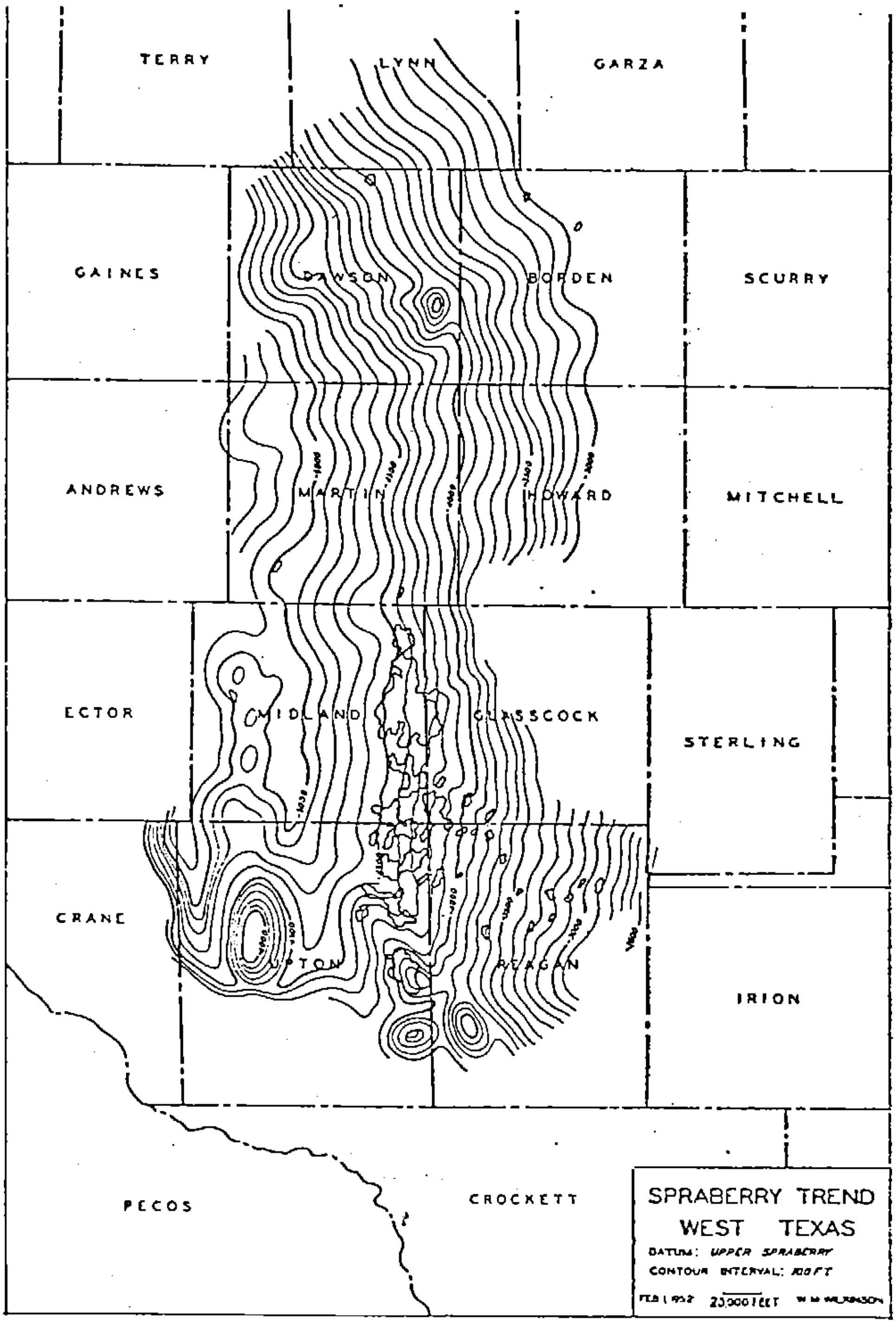

FIG. 1.—Spraberry trend, West Texas. Structure map contoured on top of Spraberry formation.

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barrels of oil per day after 640-quart nitroglycerine shot at 6,455–6,535 feet. This was on January 22, 1949.

In February, 1949, 65 miles south of the Seaboard discovery, the Tex-Harvey Oil Company's Floyd No. 1–16 was drilled to 12,063 feet. It stopped in Ellenburger and plugged back to be completed through casing perforations at 7,865–7,875 feet and 8,045–8,055 feet opposite the lower Spraberry sandstone. Its pumping potential was 135 barrels of oil per day, plus 13 per cent water. This discovery well was the beginning of the Tex-Harvey oil field in eastern Midland County.

In January, 1950, the Humble Oil and Refining Company's Pembrook No. 1, 30 miles south of the Tex-Harvey discovery, was drilled to the total depth of 12,660 feet in Ellenburger and plugged back to 7,169 feet and completed through casing perforations opposite upper Spraberry sandstone. Its pumping potential was 34 barrels of oil and 4 barrels of water per day.

In November, 1950, the Humble's Midkiff No. 1 in southeastern Midland County was completed as small pumping well from the upper Spraberry; it marked the most western extension of the trend at that time.

By this time some importance was being placed on the possibility of "shoreline trend" according to conversations with several area geologists. All of the previous discoveries and their extensions were correlated to show that the producing zone was in the same stratigraphic reservoir rock. Subsea limits on top of the Spraberry formation between 4,200 and 4,500 feet were considered geologically justifiable for a rush of wildcat activity in early 1951. All of these wildcats were important productive extensions.

During 1951 and 1952 additional wildcats were drilled structurally updip, proving productivity in the Spraberry formation without regard for possible shoreline trend, with a discovery in January, 1952, in southwestern Sterling County when the Honolulu Oil Corporation's Sugg No. 1 was completed as a producer with flowing potential of 349 barrels of oil per day. Upper Spraberry subsea datum was 2,450 feet, or 2,100 feet updip from the lowest subsea datum on top of the Spraberry formation which was then productive.

On May 1, 1952, there were 1,630 completed producing wells in the entire Spraberry trend, and 1,558 producing wells in the main productive region, known as the "Four-County area." This area includes parts of Midland, Glasscock, Upton, and Reagan counties. On May 1, 1952, there were 243 active rotary rigs in the Spraberry trend, 208 of which were busy in the Four-County area.

## STRATIGRAPHY

The Spraberry formation is overlain by approximately 7,000 feet of rocks beginning with 1,600 feet of Quaternary, Cretaceous, and Triassic sandstones and redbeds. Included in this sequence is a caliche unit which is prevalent throughout the entire area at depths of 5–10 feet. The shallow depth and areal extent of this caliche bed provide an excellent source of road metal for oil-field use.

The Triassic rests unconformably on the upper Permian Ochoa series, which

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consists of 1,000 feet, more or less, of redbeds, halite, polyhalite, and anhydrite.

Between the Ochoa series and the top of the Spraberry are approximately 4,700 feet of rocks belonging in the Guadalupe series and the upper part of the Leonard series. The upper 1,700 feet are interbedded dolomite and clastic beds and the lower 3,000 feet are interbedded dolomite and black shale with several sandstone beds prominent locally. It should be mentioned here that the black fissile shale and the thin dolomite beds of the Clear Fork group which directly overlies the Spraberry are fractured similarly to the Spraberry rocks and with the same lithologic appearance.

The Spraberry formation (Fig. 2) is approximately 1,000 feet thick and is generally composed of 852 feet of black shales and silty shales, 131 feet of siltstones, and 5 feet of thin-bedded limestones, or dolomites. This formation belongs to the lower Leonard[3] and rests conformably on the Wolfcamp. The mass of rocks can be separated into three distinct and correlative units, which are classified as upper Spraberry, middle Spraberry, and lower Spraberry, with approximately 330 feet of rocks assigned to each unit.

Some of the characteristics of the common rock types found in the Spraberry formation are listed and have been determined by petrographic descriptions from the Sohio Petroleum Company's Mary V. Bryans No. 1, Sec. 12, Block 37, T. 5 S., Glasscock County. The texture and mineralogical character of the major constituents have been considered more important than the identification of the heavy minerals and organic remains.

*Siltstones.*—The grain-size description indicates that the major percentage of grains falls in the silt-size range with approximately 60 per cent between the grade limits of 0.03–0.06 millimeter. The grains range from angular to very angular, and the sorting from fair to poor. Primarily, the cementing agent is dolomite with some silica. All gradations are present from a nearly pure siltstone to those containing nearly 50 per cent dolomite. In association with the siltstones are some minor constituents such as pyrite, mica, and plagioclase feldspars.

*Dolomites.*—The dolomites vary in texture from fine to crystalline, the fine crystals being primary. It was observed that the dolomites generally corrode quartz grains.

*Shales.*—Several types of shales have been encountered, such as massive, blocky type as well as the commonly found fissile, brittle type. Most of the shales have been classified as carbonaceous, but in all petrographic slides examined, the shales were found to be silty and very ferruginous.

In all of the wells examined it was observed that the siltstones, dolomites, and shales were very similar areally and vertically in texture and mineral character. Certain distinctions can be made by electrical-log study (Fig. 2) to separate the upper Spraberry from the middle Spraberry, as well as to separate the middle Spraberry from the lower Spraberry. However, there does not appear to be any

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[3] Lamar McLennan, Jr., and H. Waring Bradley, "Spraberry and Dean Sandstones of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 35, No. 4 (April, 1951), p. 899.

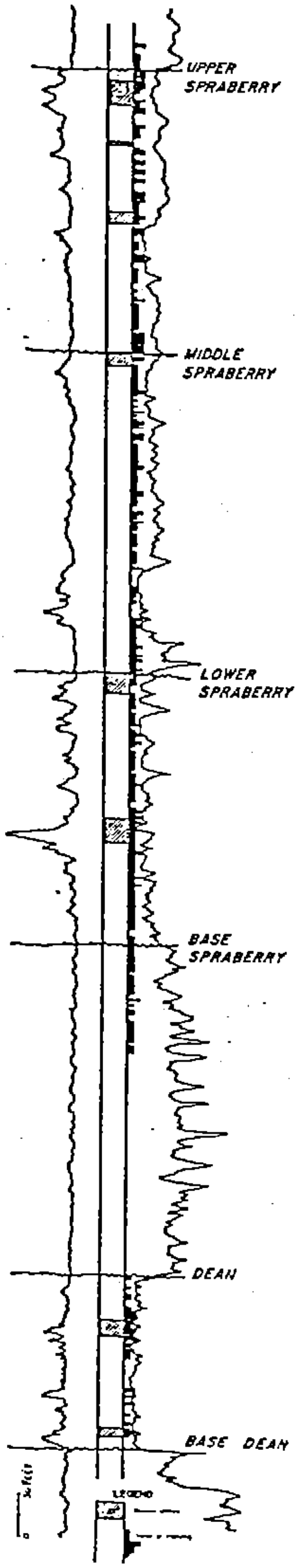

FIG. 2.—Generalized columnar section of Spraberry formation. Diagonal shading, massive siltstone. Solid black, degree of fracturing.

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easily identifiable characteristic which differentiates the clastic content in the three units, one from the other, if determination is made by binocular or petrographic microscope.

A generalized lithological description of each of the three units follows.

*Upper Spraberry.*—323 feet of sedimentary rocks composed of approximately 45 feet of siltstone, 3 feet of limestone, and 275 feet of black shale or gradations thereof, which include an increase in silt content.

*Middle Spraberry.*—361 feet of sedimentary rocks composed of approximately 26 feet of siltstone found in very thin beds and not of the more massive type similar to upper Spraberry, one foot of limestone, and 334 feet of black shale and silty shale.

*Lower Spraberry.*—304 feet of sedimentary rocks composed of approximately 60 feet of siltstone with the more massive type found near the base of the section, 1 foot of limestone, and 243 feet of black shale and silty shale.

Specific attention has been paid during the preparation of this paper to the type of deposits and original environment in the Four-County area. The remaining part of the Spraberry trend has a general similarity, but, with the exception of Spraberry Deep pool, commercial production of major significance has not been developed. The writer believes that the Midland basin as a whole had partly restricted water circulation during Spraberry time. The Four-County area was notably different from other parts of the basin, however, in that the circulation was so restricted as to cause toxicity in the bottom waters, with resulting sediments of euxinic facies. This region appears to have been a partly isolated part of the broad shallow basin with confinement of organisms to the top waters and with the deeper bottom waters oxygen-deficient and lacking in benthonic life, thus indicating true euxinic conditions.

The following is a general long-range correlation of texture. A well was examined in northwestern Lynn County (Anderson-Prichard's White No. 1, Sec. 154, HS&WT) in the northern end of the Spraberry trend. The upper Spraberry exhibits gross mineral character and texture nearly identical with rocks examined farther south in the Four-County area. The samples examined do not contain any appreciable clastics in the sand-size range. East of the Four-County area, there is an increase in the median diameter of grain size. In the Honolulu Oil Corporation's Sugg No. 1 of southwestern Sterling County, the texture is considerably coarser than other sections examined farther west. The sample of upper Spraberry in this well is very fine-grained sandstone with the largest percentage of grains in the upper limit of a very fine sand classification.

The feldspar materials examined contain no enlarged feldspar grains, but consist of a detrital core with a secondary rim. All shale samples examined are silty, even the black, carbonaceous types; nearly all specimens contain at least 10 per cent silt-sized material. Intermixed with the shale, here and there, is a bit of argillaceous material, which consists of predominantly fine, micaceous shreds (sericite) and kaolin.

### ACCUMULATION OF OIL

As previously mentioned, a representation of "shoreline trend" was developed during the early part of Spraberry exploration. Long north and south extensions restricted production to subsea limits on top of Spraberry formation between 4,200 feet and 4,500 feet. At this time, however, oil is produced between subsea limits

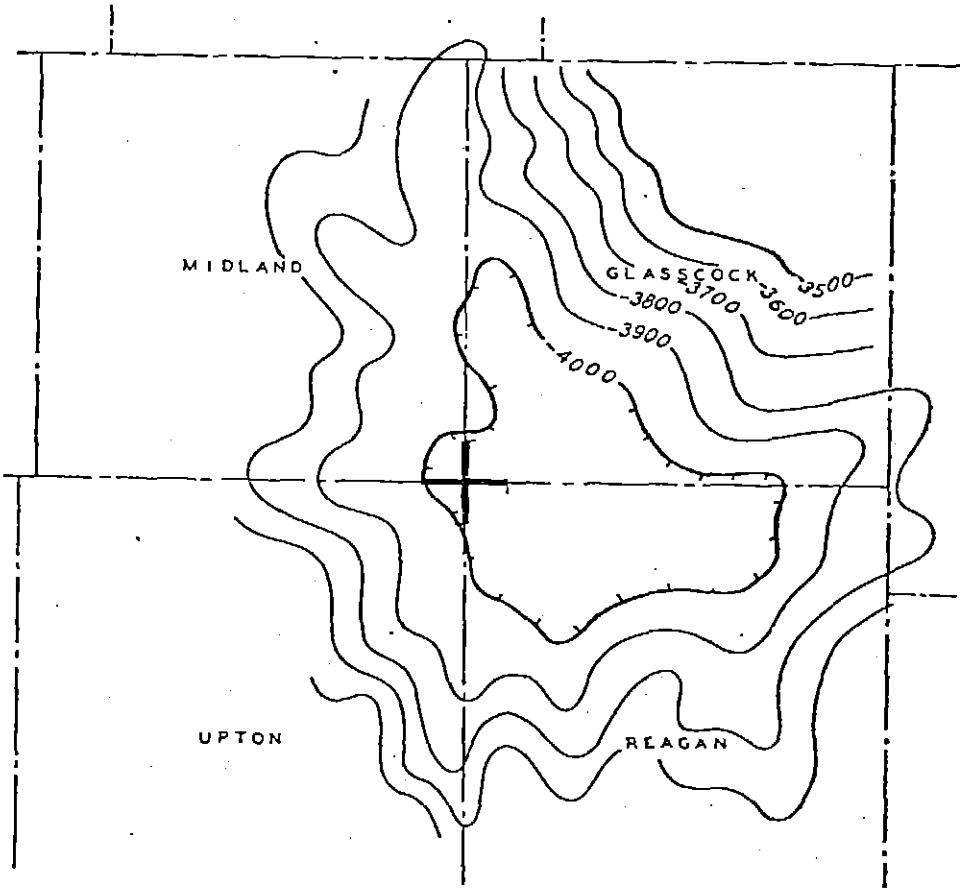

FIG. 3.—Structure map of Four-County area contoured on top of Dean sand, with regional dip eliminated.

of the Spraberry formation of 2,450–4,550 feet (Fig. 1). A sufficient number of dry holes were drilled in 1951 to partially delineate the producing area as approximately triangular. Only the western side of the triangle follows datum and roughly established water table, whereas the other two sides of the triangle follow no established geological pattern. It is evident, therefore, that some controlling factor is present for the accumulation of Spraberry oil in its present position other than a "shoreline trend," or facies change. With this idea in mind, a map (Fig. 3)

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of the Four-County area was prepared to eliminate regional dip and approximate the probable topography of the sea floor during early Spraberry deposition.

During the preparation of paleogeographic maps, several mapping techniques are used, Figure 3 illustrating only one. Such a map merely aids in the technique of visually restoring rocks to their relative original position of deposition. To show the topographic features at the end of Wolfcamp time, the top of Dean sand was selected to represent the near close of Wolfcamp time. The stratigraphic position of the Dean sandstone relative to the Spraberry is shown in Figure 2. The Dean sand has been identified as Wolfcamp in age, but used as datum point since base of Spraberry—top Dean interval is consistent in thickness. With the Dean data, the present subsurface was rotated vertically from an arbitrary hinge line that approximated the western edge of the Eastern platform. The map is, of necessity, a rough semblance of the ideal, but it does show a gentle, closed low area that closely follows the areal distribution of the major productive region.

During Permian time the Midland basin was a mildly negative area receiving sediments from far-removed emergent lands, and these sediments were deposited in deep, quiet waters. The basin was not necessarily restricted in the environmental sense. Circulation was open at the north and south; however, isolated low areas on the main basin floor were locally restricted in circulation. In such closed low areas the sea water could maintain its volume but would stagnate. Surface waters were favorable for supporting many planktonic forms in its pelagic realm. Contribution of organic material from these surface forms, as well as floating débris, could be preserved on basin floors where oxygen was deficient and hydrogen sulphide content was high. Rich organic muds were thus formed, as evidenced by much bituminous matter and in this type of environment, anaerobic bacteria would be encouraged to break down the organic material into simpler and more basic hydrocarbons. The writer believes that such conditions did exist in the gentle, closed low area shown in Figure 3 at the beginning of Spraberry deposition.

This writer believes that the Midland basin was relatively non-toxic in most part, and yet it was probably pitted with several low restricted spots of varying depths. In these low areas would be the richer accumulation of organic muds. Present distribution of oil or gas points to these areas individually, and tends to show that the generation of oil was localized to a great degree.

A lithofacies map (Fig. 4) of the Four-County area further substantiates the reconstruction of the geological features at the close of Wolfcamp time. Northeast of the Spraberry trend non-clastics are dominant with a gradual facies change toward the productive area, where approximately 87 per cent of the Spraberry is shale. West of the producing area a rather abrupt shale to limestone facies change occurs, with several wells on the west side of the present structural highs containing 85 per cent non-clastics. This probably means that during the time of Spraberry deposition, the west side of the Midland basin was elevated sufficiently to provide an environment of warm, shallow waters, in which carbonates were

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precipitated and deposited. Superimposed on the lithofacies map are isopach contours representing the thickness of Spraberry-type rocks after total deposition and after accounting for all structural movements. Included in the interval thickness is the 1,000 feet of Spraberry section plus approximately 500 feet of upper Wolfcamp rocks to the base of the Dean sand. The area of thickest sedimentation is found in the south-central part of Glasscock County and the north-central part of Reagan County, and appears to be associated with the original low area,

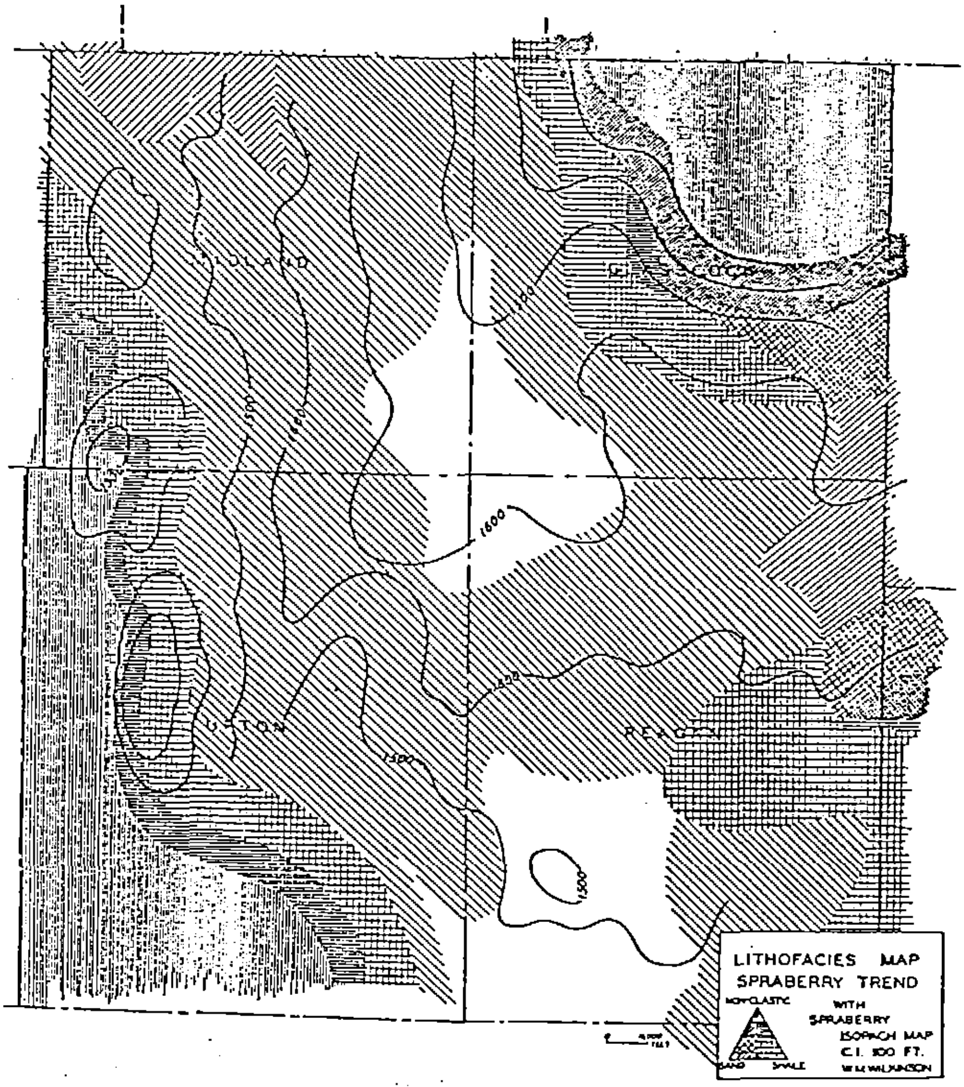

FIG. 4.—Lithofacies map, Four-County area, with Spraberry isopach contours.

interrupted only by slight structural growth around the common corners of the Four-County area.

The accumulation of Spraberry oil was probably directly associated with a relatively deep, closed basin since present structural position is no determining factor for the presence or absence of a productive reservoir, nor is a lithologic change a determining factor for the presence or absence of oil. Specific reference is made to an arbitrary line representing the south limb of the triangular area trending eastward through central Reagan County. The rocks north of this arbitrary line are generally the same as the rocks south of this line; however, productive reservoirs are found at the north and increase in productivity toward the center of the triangular area.

## FRACTURES

Even though many diagnostic characteristics of jointing are present, there is no evidence of vertical displacement, but there is a fairly well defined pattern of fracture trend, both major and minor, which may establish a fracture, or joint system.

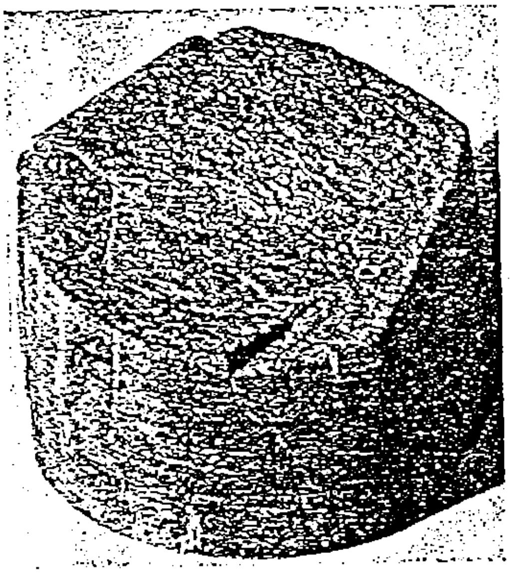

FIG. 5.—Core showing incipient or latent vertical fractures. Diameter of core, 3⅞ inches.

Fractures have been assigned a set of arbitrary indices by the writer: (1) latent fractures (Fig. 5); (2) single vertical or oblique fractures, discontinuous for a relatively short distance; (3) single vertical fracture, extending for entire length of lithologic unit (Fig. 6); (4) single vertical fractures parallel with each other; and (5) vertical fractures parallel, intersected by oblique or vertical cross fractures (Fig. 7).

The most common type of fracture with the greatest continuous vertical extent is found in the black, brittle shales and in the varved, sandy shales. Oblique fracturing occurs by far the most commonly in the silts but, where present in the shales, occurs alone and is discontinuous up to 18 inches in length. The oblique fracturing has a tendency to assume a position of shattering with the end result representing a pattern of shingles. This type of shattering has been classified as imbricate. It is interesting to note that the oblique fracturing on one side of the core generally has a compensating latent fracture on the opposite side of the core, but at an opposing angle. The writer suggests that the shattering effect produced in the sands and silts could be a result of compositional difference, as compared with shales, with the sands and silts having reached an elastic limit, and then shattering to relieve the tensional pressure when exposed by the bore hole.

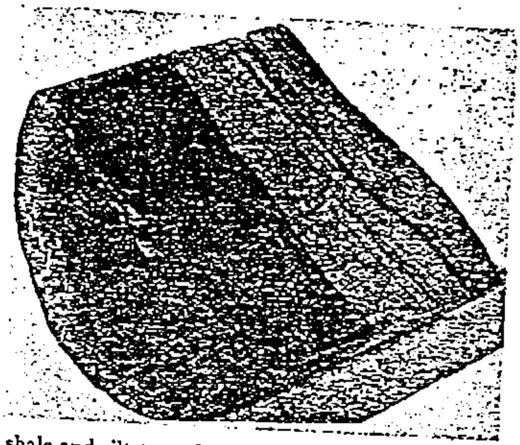

FIG. 6.—Core of shale and siltstone showing single vertical fracture extending across lithologic units. Diameter of core, 3¼ inches.

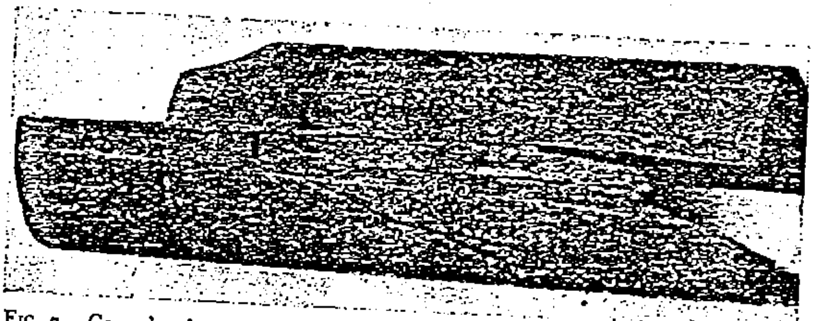

FIG. 7.—Core showing combination of fracture types. Diameter of core, 3¼ inches.

All fractures tend to be centered in the cores, particularly where only single vertical fractures are found. It would be an unlikely geological phenomenon that fractures would fall naturally in a vertical plane within bore-hole deviation tolerances. Several hypotheses can be assumed for this phenomenon. It may be that fracturing is artificial to some degree and is created by stress relief along predetermined lines of weakness, or planes of microscopic fracturing. It may be that the lines of fracturing are so closely spaced that the wandering action of the drill bit or core head would find the line of weakness and follow it, as in steeply dipping beds in areas of thrust faulting. However, mineralization of fracture planes (Fig. 8), presence of lost circulation materials, and cement within fractures after coring certainly prove that fissures are open, even though the presence of cement is highly overrated. Abnormal injection pressures would aid in forcing foreign materials into the earth opening. Some operators have introduced carnotite into the cement slurry before casing is cemented above the Spraberry formation. The gamma-ray log showed no evidence of cement below casing point.

Pore space in the fractures before coring has been partly determined by the use of micrometer gauge. An over-all average for a single vertical fracture is 0.002 inch. Certainly capillary and sub-capillary openings can not be measured, even though they have been proved to be present. These immeasurable openings play a tremendous role in the movement of fluids. Since shales constitute 87 per cent of the Spraberry rocks and since the presence of sub-capillary openings is established, the shales are apt to be reservoir rocks in part. Oil has been retorted from some samples to prove the presence of hydrocarbons within the shale matrix.

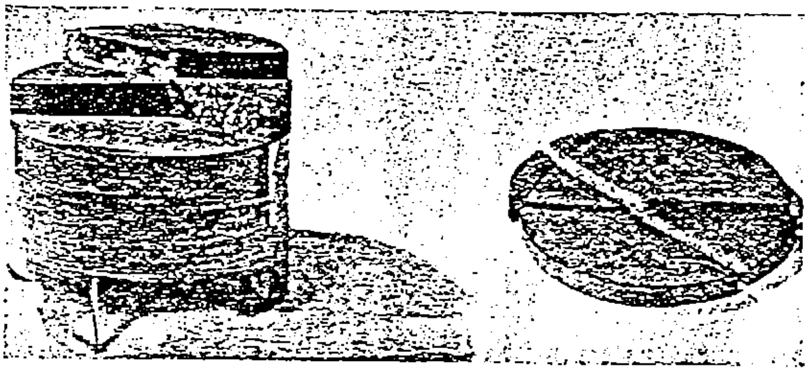

FIG. 8.—Cores showing intersecting vertical fractures and mineralization. Diameter of core, 2⅞ inches.

The matrix siltstone which serves as the main reservoir rock has an average permeability of 0.50 millidarcy and an average porosity of 8 per cent. With this type of permeability in the reservoir rock, it becomes obvious that the fractures serve mainly as "feeder lines" to conduct oil to the well bore. In very few places has commercial production been developed without a rupturing process to create more fracture permeability channels.

The genesis of Spraberry fracturing can be attributed to two forces: (1) nondirectional reduction in volume, and (2) regional tensions created by basinward subsidence. These two changes occurred independently of each other, even though the latter was associated with structural growth from deeper tectonic forces.

Reduction in volume by the removal of interstitial waters is inherent in lithification of muds to form shales. Shrinkage is possible by changes in the various clay minerals making up the shales. The process necessary for creating fissility of shales results in microscopic lateral openings. All of these processes resulted in shrinkage cracks, and after sufficient lithification had taken place for the rocks to become brittle, latent fracturing took place as the volume changed, but resulted only in microscopic lines of weakness without definite direction or trend.

Tests have been made in Sohio laboratories of the different rocks of the Spraberry formation and prove the presence of sub-capillary openings. Fracture plane faces were washed with lubricating gasoline for sufficient length of time to permit absorption of the lubricating material into any sub-capillary openings that might be present. Exposure to air and heat provided rapid evaporation from the fracture plane. In a very short time the fracture face was free of gasoline, but a comprehensive system of shrinkage cracks was proved by the remaining lubricating material in the cracks themselves (Fig. 9). Experiments have shown that this system is present only in the shales. There is very minor evidence of latent fracturing in the siltstones. The presence of the shrinkage crack system in the shales further proves the non-directional reduction in volume.

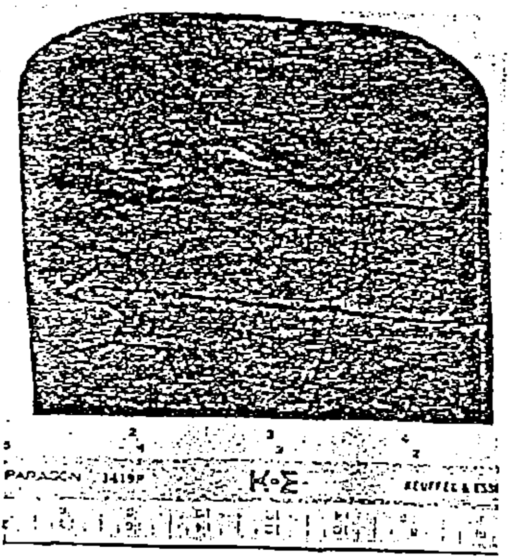

FIG. 9.—Core showing shrinkage cracks in Spraberry shale. Diameter of core, 3¼ inches.

Core orientation tests have been made in several wells in the Four-County area, and a major fracture trend has been indicated to have a general N. 25° E. direction, with a more poorly developed set of cross fractures normal to the main trend. These wells are: (1) Sohio's TXL "A" No. 6, Sec. 35, Block 37, T. 4 S., Glasscock County; (2) Sohio's Davenport "B" No. 1, Sec. 2, Block 37, T. 5 S., Glasscock County; and (3) Sohio's Bernstein No. 1, Sec. 5, Block N, Upton

County. An initial potential map (Fig. 10) prepared of the Tex-Harvey pool has indicated the same general north-northeast direction. On the initial potential map the black coloring represents the wells of highest productivity and further indicates the very close proximity to better developed fracture system.

The writer suggests that possibly the system of open fractures shown by potential and productivity tests and core orientation tests was created by the effects of regional tension as the basin subsided after Leonard time. The gentle subsidence would stretch the pre-existent mass of rocks from the buttressing positive element of the Eastern platform. This stretching would have a tendency to create the greatest amount of rock rupturing in the area closest to the deepest part of down-warping, but still would be confined to those rocks of highest shale content. Tectonic movements near the end of Permian time re-uplifted certain areas such as the Reagan anticline and the Wilshire-Pegasus fold (Fig. 1). The Reagan anticline has a N. 45° W. direction, and the Wilshire-Pegasus fold has a northerly direction. The down-warping of the basin, combined with the structural growth and uplifting of the two anticlinal folds, would have a tendency to create certain torsional effects on the mass of rocks nearest the area of movement. The torsional and tensional effects of these combined movements on the Spraberry rocks would be apt to produce northwest to west nosings, and any such movement, however slight, would tend further to rupture and connect the ancient lines of weakness.

## PRODUCTION STATISTICS AND SUMMARY

Since the date of the discovery well in the Spraberry Deep pool, and since the time of completion of the original Spraberry well in the Tex-Harvey field, an ever-increasing tempo of activity has confronted the oil industry in the Spraberry trend. The greatest concentration of drilling activity and completions has been confined, for the most part, to parts of the Four-County area. It is not important to quote individual month or year statistics, but rather, comparison can be made by quoting widely separated statistics.

In October, 1951, within the Four-County area there were 531 completed wells and 241 drilling operations. Outside of this area there were 72 completed wells with 5 drilling operations.

During the month of April, 1952, there were 1,558 producing wells within the Four-County area, an average of 176 completions per month. During this same month 2,744,156 barrels of oil were produced, which represents 77 per cent of the assigned allowable.

On February 1, 1952, there were 766 rotary drilling units in operation in the Permian basin areas of West Texas and southeastern New Mexico. The Four-County area had 315 of those operations, which represents 41 per cent of the actual drilling rigs in the Permian basin.

With an activity so concentrated, there is a constantly changing picture day by day, and any production charts of to-day would be obsolete tomorrow. It is expected that approximately 488,000 acres will be proved productive at the con-

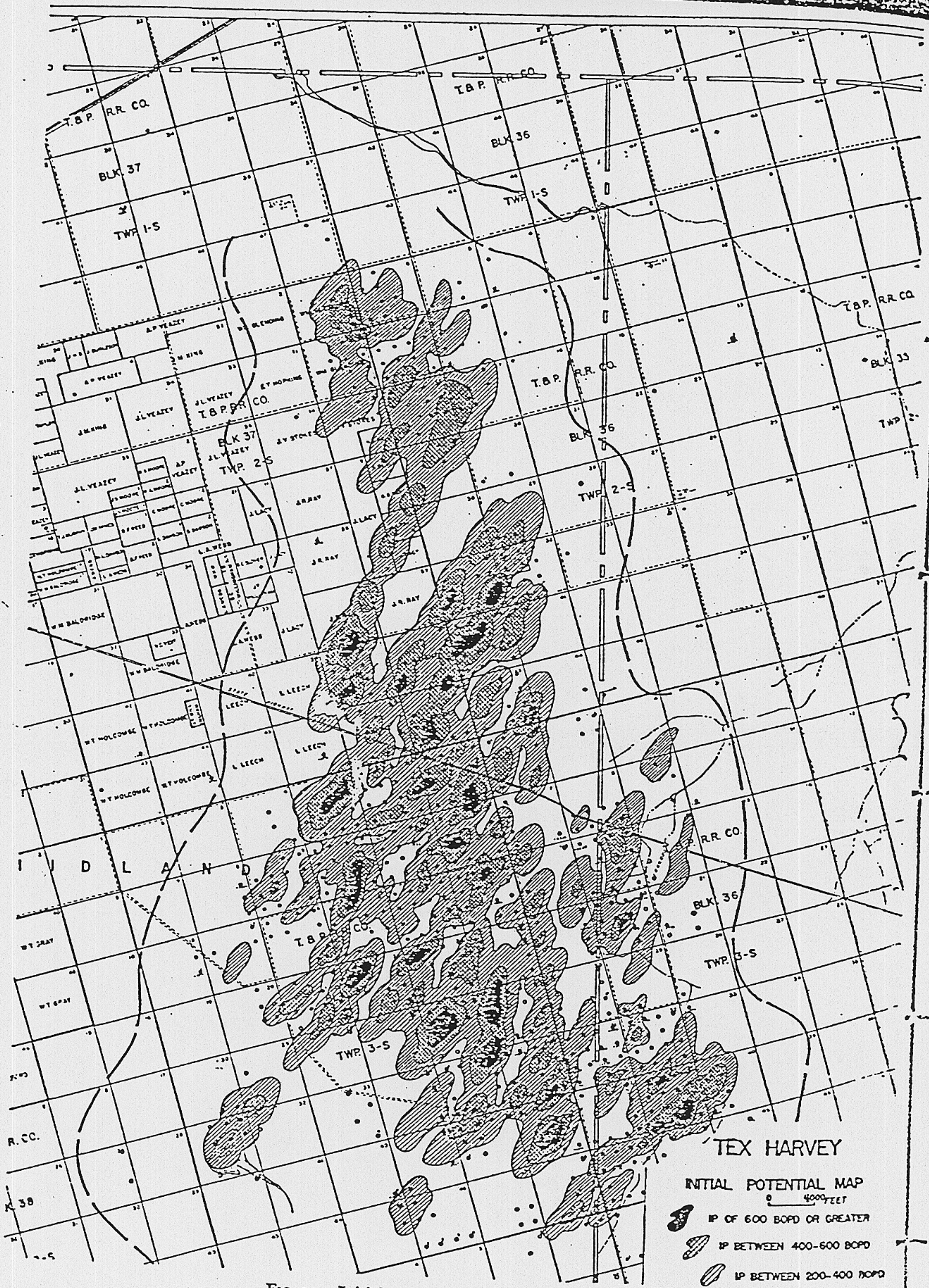

FIG. 10.—Initial potential map of Tex-Harvey field.

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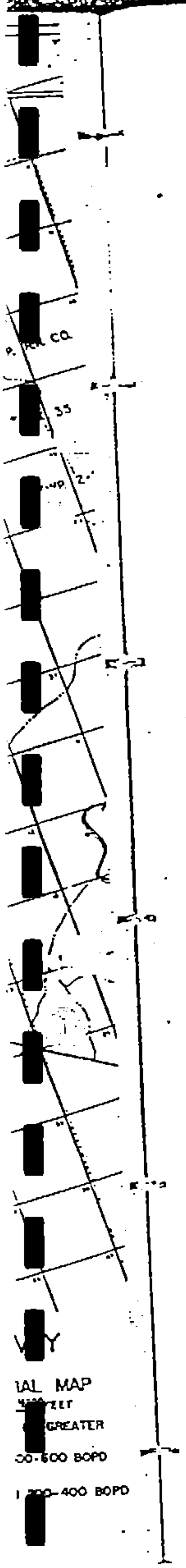

clusion of developmental drilling within the Four-County area. Outside areas appear to be marginal at present and yet areas favored by optimum accumulation of oil and associated with greater fracturing would be favored for production unknown at this time.

Truthfully, it may be said that the Spraberry is a unique reservoir. It is fabulous in areal extent, puzzling with its production problems, and baffling with its geological phenomena. Here in an area devoid of typical folded traps, and from a mass of rocks that would be classified as non-commercial under average conditions, flowed the aforementioned 2,744,156 barrels of oil from 1,558 wells during the month of April, primarily the result of fractures.

# APPENDIX 8 - Summons ,T. 1981

The Northwest Bay Co. Pty Ltd

# PRELIMINARY REPORT ON
# PETROLEUM POTENTIAL - ONSHORE TASMANIA

by T.G. Summons

August, 1981.

087125

## ABSTRACT

A review has been made of potential hydrocarbon source and reservoir rocks of Ordovician to Triassic age in Tasmania. The appraisal of post-Cambrian to pre-Tertiary regional geology, in conjunction with current concepts on source rock characteristics, paleo-geothermal gradients, and known occurrences of sapropelic kerogen, implies the presence of potential source rocks at several horizons of differing age and lithology. The most likely hydrocarbon source rocks are the Ordovician Gordon Sub Group (carbonate), and the Carboniferous - Permian section of the Parmeener Super Group (clastic). Recent discoveries of Petroleum seepages were made in the basal section of the Parmeener Super Group; this lower section appears to fulfill the accepted criteria for source rocks, although the limited number of samples collected precludes authoratitive conclusions. High heat flow during the Devonian in western and north western Tasmania, and possibly relict as late as Permian time, has effectively down graded the prospectiveness of these parts of the state for hydrocarbon potential.

However, the remainder of the state appears to have been shielded from the high heat flow, as evidenced by the Gordon Limestone in Southern Tasmania, which was subjected to the requisite maturation conditions for the generation of hydrocarbons.

087126

# PRELIMINARY REPORT ON PETROLEUM POTENTIAL
# - ONSHORE TASMANIA

## INDEX

# PRELIMINARY REPORT ON
# PETROLEUM POTENTIAL - ONSHORE TASMANIA

by T.G. Summons

August, 1981.

## 1:0 INTRODUCTION

This review of current literature and ideas of Tasmanian geology, applicable to exploration for liquid and gaseous hydrocarbons, is intended to review some of the aspects of petroleum origin, migration and retention in Tasmania, with the object of rationalising future petroleum exploration programs.

Critical physical and chemical data on potential source and reservoir rocks are either poorly known, or non existent; accordingly, many of the comments made in this report are speculative and will almost certainly be modified after collection, compilation and interpretation of the requisite data.

The report is divided into a discussion of lower Palaeozoic and Carboniferous Permian-Triassic age rocks, under the following headings:-

1. Regional Geology
2. Comments on Source Rock Types
3. Geothermal History
4. Potential Oil Source Rocks
5. Potential Oil Reservoir Rocks

## 2:0 REGIONAL GEOLOGY

### 2:1 ORDOVICIAN

The Ordovician period is represented by the Junee Group, which consists of the Denison Sub Group, overlain by the Gordon Sub Group. The type area of the Junee Group is the Florentine Synclinorium (Maydena - Florentine Valley).

### 2:1.1 Denison Sub Group

This sub group consists of three formations:-

| | | |
|---|---|---|
| - | Reeds Conglomerate | 1500m |
| - | Tim Shea Sandstone | 300m |
| - | Florentine Valley Mudstone | 600m |

As the formation names imply, the lithogies consist of conglomerate, sandstone and siltstones with minor impure limestone. A widespread marine transgression occurred at the top of the subgroup, with sand deposited in N.W. and W. Tasmania, while silt was deposited in the Florentine Valley (Florentine Valley Mudstone), suggesting a source area in the N.W. and W. of the state; support for this model is seen in the higher proportion of calcareous beds in the Florentine Valley and Beaconsfield areas, than elsewhere.

### 2:1.2 Gordon Sub Group

This sub group consists of three formations:-

- Karmberg Limestone
- Cashions Creek Limestone
- Benjamin Limestone (Corbett and Banks, 1974).

The Karmberg Limestone consists of approximately 400m of impure nodular limestone, calcareous siltstone and chert; it is richly fossiliferous, and contains large spherulites of pyrite. The Cashions Creek Limestone consists of approximately 100m of dolomitic limestone with abundant algal colonies (Girvanella).

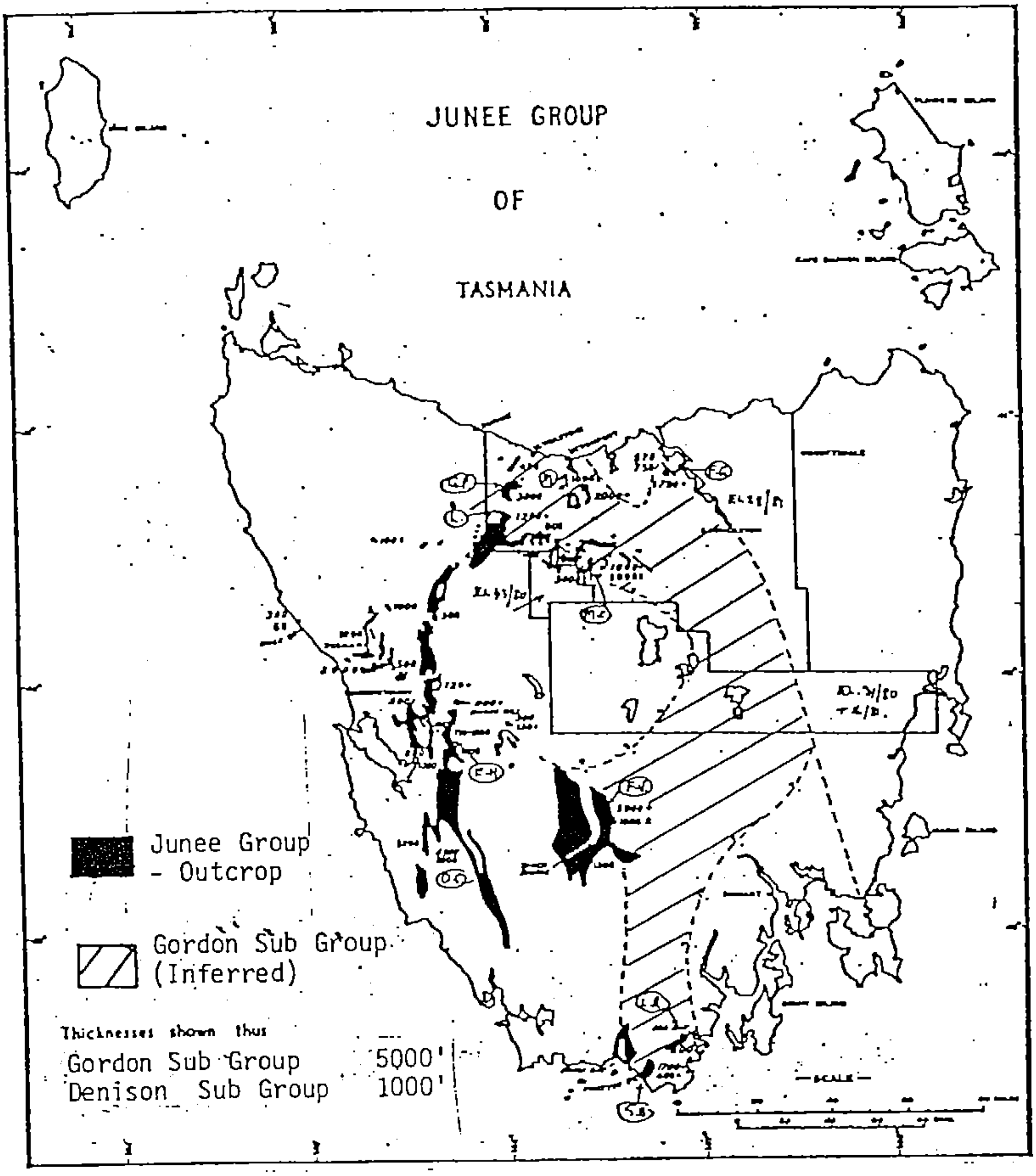

Fig. 1: Distribution of the Junee Group
Gordon Sub Group Localities shown as follows:

FG - Flowery Gully
M - Melrose
GP - Gunns Plains
MC - Mole Creek
L - Loongana
EH - Everlasting Hills
OS - Olga Synclinorium
FV - Florentine Valley
LR - Lune River
SB - Surprise Bay

5 cm

Gordon Sub Group (Contd.)

The Benjamin Limestone consists of approximately 1200m of dolomitic and stylolitic limestone of variable purity; several horizons rich in corals, stromatoporoids, sponges, cephalopods, brachiopods, and gastropods occur, and are considered by C.F. Burrett (pers. comm.) to represent possible back reefs. The limestones represented by these formations consist of supratidal dolomites, intertidal calcisilitites, and subtidal calcisiltites, calcarenites and shelly/ coralline calcirudites. During Chazyan time (Cashion Creek Limestone) algal lawns were widespread across the state, and from Blackriveran through Trentonian to early Cincinnattian time (Benjamin Limestone) coral gardens/baffles became widespread.

The depositional environments for the Gordon Sub Group and the upper part of the Denison Sub Group were shallow water/platform. The youngest unit in the Junee Group is the Westfield Beds, consisting of approximately 150m of siltstone and sandstone overlying the Gordon Sub Group.

## 2:2 SILURIAN - DEVONIAN

### 2:2.1 Eldon Group

This group consists of formations of three major alternations of sandstone and siltstone, which, with minor limestone, ranges in thickness from 1800m to 2300m.

Thus the Crotty Quartzite is overlain by the Amber Slate, the Keel Quartzite by the Austral Creek Siltstone, and the Florence Sandstone by the Bell Shale.

The general cyclicity of sandstone alternating with siltstone also occurs within each of the major sandstone and siltstone units referred to above.

All Eldon Group lithologies were deposited under shallow marine conditions (including the siltstones); the greater coarseness and the higher sand : shale ratio of the Eldon Group in western Tasmania, imply a source area to the west of the state (Banks, 1962).

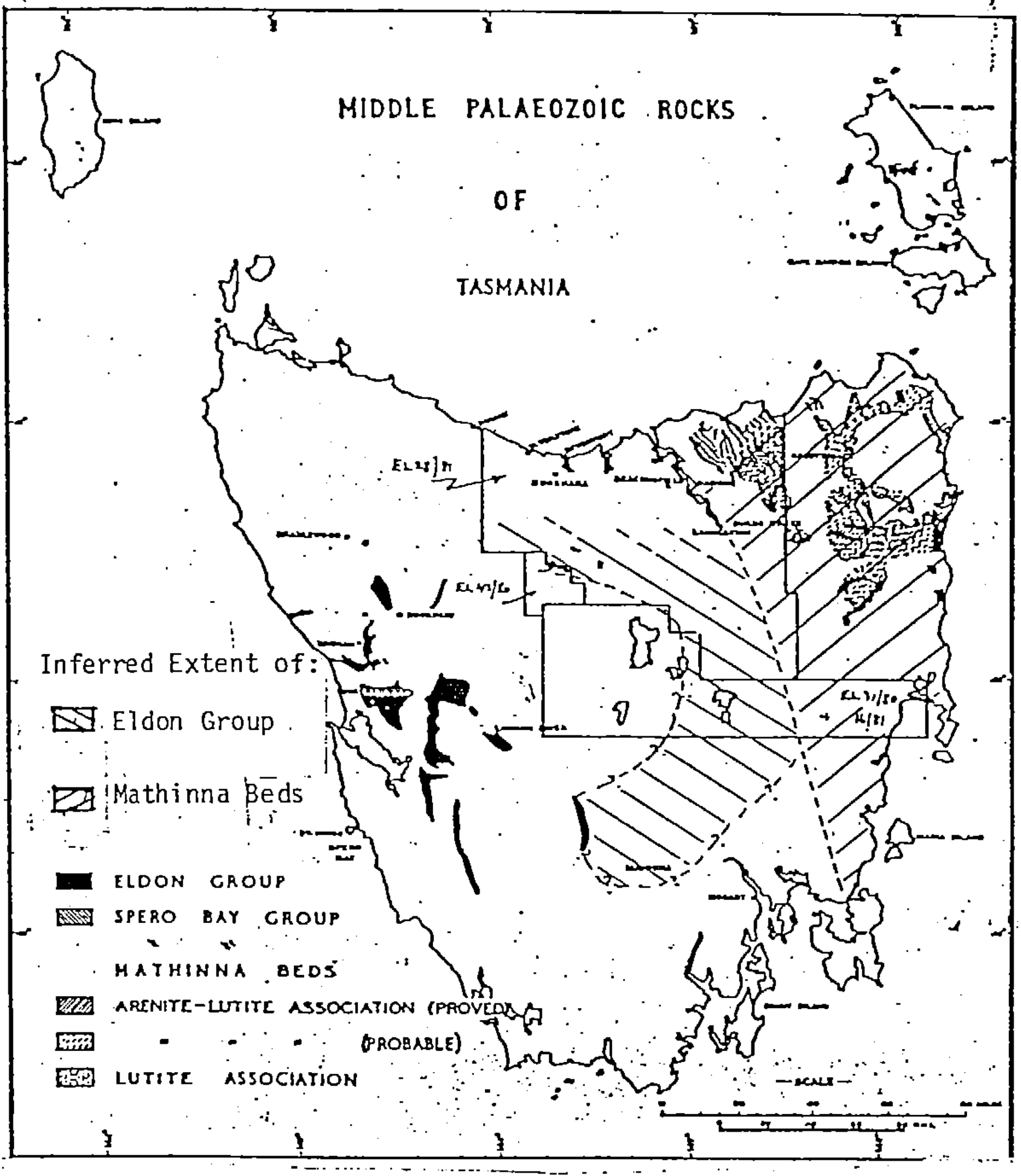

Fig. 2: Distribution of Eldon Group and Mathinna Beds

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### 2.2.2 Mathinna Beds

The Mathinna Beds occur in N.E. Tasmania, and consist of more than 2400m of sandstone, siltstone, and mudstone (variably metamorphosed), which were deposited under deep water conditions. A crude twofold subdivision into a sandstone/greywacke - siltstone, and a mudstone association (now slate and phyllite) is recognisable. The age ranges from Ordovician to Devonian, and the sequence shows strong contrasts on faunal and sedimentological grounds with the rest of Tasmania. Banks (1962) postulated a facies change from shallow water shelf type deposition in western Tasmania to continental type deposition in N.E. and E. Tasmania; the margin of the continental shelf is inferred to occur in the vicinity of Flowery Gully. The Mathinna Beds are separated from the rest of Tasmania by a NNW trending transcurrent (?sinistral) fault known as the Tamar Fracture System (Williams, 1979).

## 2:3 CARBONIFEROUS - PERMIAN - TRIASSIC

### 2:3.1 Parmeener Super Group

The Lower Parmeener Super Group consists of the Lower Marine, Lower Freshwater and Upper Marine Sequences, with a total aggregate maximum thickness of 1300m (Williams, 1979).

The Lower Marine Sequence includes units such as the Wynyard Tillite, Quamby, Woody Island Siltstone, Darlington Limestone and Bundella Formations, and the Golden Valley and Masseys Creek Groups. Typical rock types are dark coloured siltstone and mudstone (often carbonaceous) with minor limestone, sandstone, conglomerate, and oil shale ("Tasmanite"). Uraniferous, pyritic black shales (some of which are oil shales) occur at Rossarden, and may represent marginal marine conditions at the junction of the Quamby Formation and the Basal Conglomerates in N.E. Tasmania.

The environment of deposition was medium to shallow depth marine, cold (as indicated by the Wynyard Tillite, glendonites and rare dropstones in the overlying formations), and anaerobic, as indicated by the abundant pyrite.

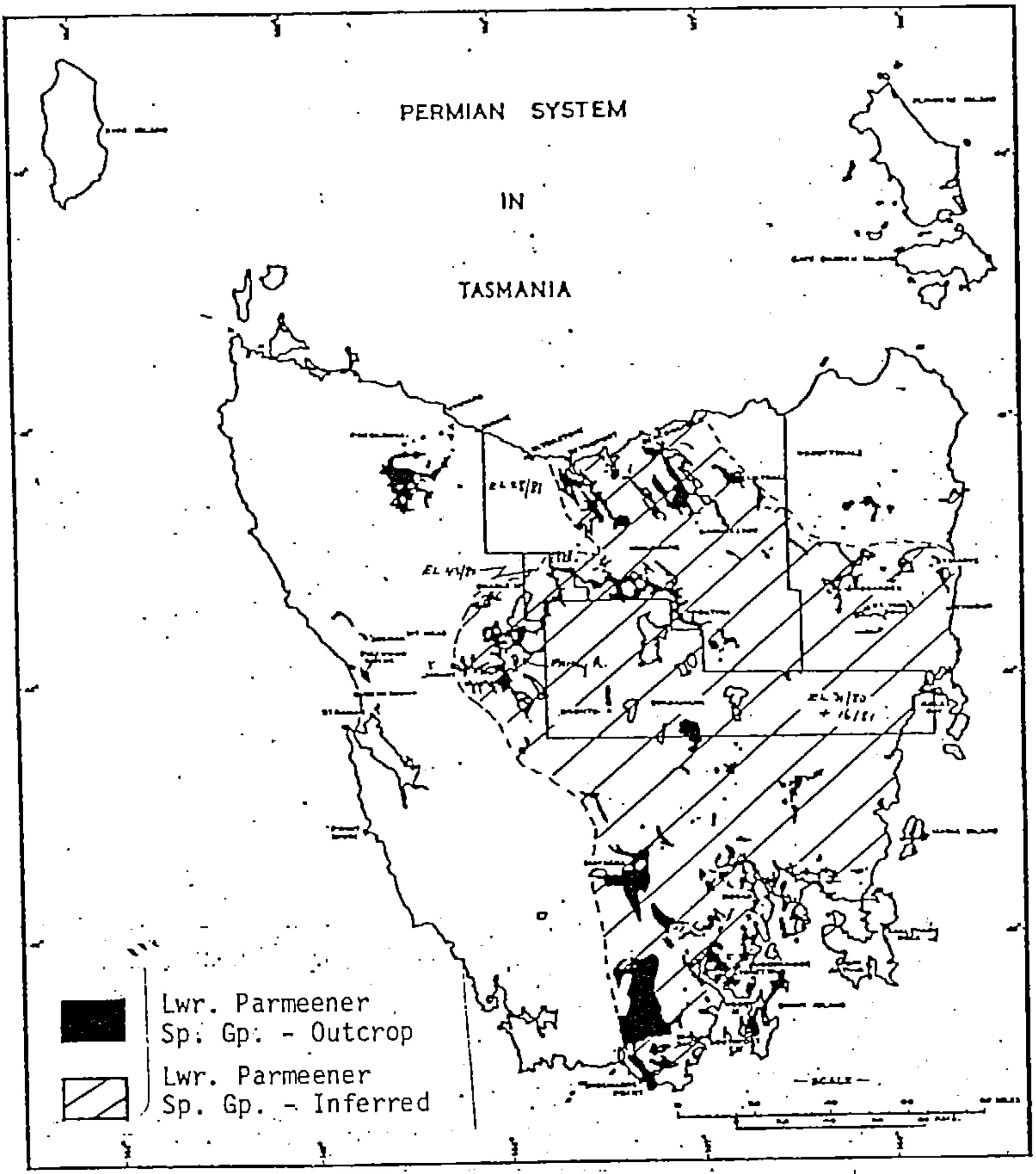

Fig. 3: Distribution of the Lower Parmeener Super Group

5 cm

TABLE 1

PARMEENER SUPER GROUP

Upper Parmeener Super Group (Upper Freshwater Sequence)

| 1:250,000 Map Sheet | Locality | Cygnet Coal Measures (m) | Ross Form'n (m) | Cluan Form'n (m) | Tiers Form'n (m) | Brady Form'n (m) | Total (m) |
|---|---|---|---|---|---|---|---|
| Hobart | - | ND | ND | ND | ND | ND | ND |
| Oatlands | (Poatina | 60 | 200 | 140 | 90 | 165 | 655 |
|  | (Great Lake | ND | ND | ND | ND | ND | 580 |
| Launceston | Quamby | ND | ND | ND | ND | ND | 630 |
| Burnie | West.Bluff | ND | ND | ND | ND | ND | 365 |
| Queenstown | Cent. Plat. | ND | ND | ND | ND | ND | ND |
|  |  |  |  |  |  | Average: | 550 |

Lower Parmeener Super Group (Lower Marine, Lower Freshwater and Upper Marine Sequences)

| 1:250,000 Map Sheet | Locality | Lower Marine Sequence |  |  |  | Lower Fresh- Seq. (m) | Upper Marine Seq. (m) | Total (m) |
|---|---|---|---|---|---|---|---|---|
|  |  | Tillite (m) | Silt/ms (m)* | SS/Silt/LS (m) | Sub Tot. (m) |  |  |  |
| Hobart | Cygnet/ Glenorchy | 300 | 200 | 100 | 600 | 30 | 300 | 930 |
| Oatlands | Poatina/ Friendly Beaches | 105 | 90 | 60 | 255 | 110 | 280 | 645 |
| Launceston | Quamby | ND | ND | ND | 350 | 45 | 265 | 660 |
| Burnie | Wynyard/ West.Bluff | 490 | 135 | 60 | 685 | 36 | 260 | 981 |
| Queenstown | Central Plateau/ Florentine Valley | 45 | ND | ND | ND | ND | ND | ND |
|  | Averages: | 235 | 142 | 73 | 472 | 55 | 276 | 804 |

(* Includes the Woody Island Siltstone and "Tasmanite" horizons)

Maximum Thickness preserved: 655 + 981 = 1636m ( ≃ 1.6m).
This contrasts with the figure given by Williams (1979) of 1930m.

The Lower Fresh-water Sequence includes the Mersey and Prelonna Coal Measures, with an average thickness of 30m. Typical lithogies are sandstone, carbonaceous siltstone and coal; oil shale and cannel coal occur near the top of the sequence, adjacent to the Malbina Formation.

The Upper Marine Sequence includes the Cascades Group, the Malbina Formation, Risdon Sandstone, Ferntree Mudstone and Poatina Group. Lithogies range from calcareous siltstone and limestone to siltstone and mudstone, with minor arkosic and glauconitic sandstone.

The environment of deposition was probably similar to that of Lower Marine Sequence, namely medium/shallow water shelf conditions; the climate was cool as indicated by rare glacial dropstones.

The Upper Parmeener Super Group consists of the Upper Freshwater Sequence with a total maximum thickness of approximately 650m (Williams, 1979). It includes the Cygnet Coal Measures, Ross, Cluan, Tiers and Brady Formations.

Lithogies range from quartzose to lithic sandstone, siltstone, carbonaceous to grey/green mudstone, to coal and acid/intermediate volcanics.

The environment of deposition was similar to that for the Lower Freshwater Sequence - continental and freshwater (lacustrine).

Parmeener Super Group localities and thicknesses are shown in Table 1, where it should be noted that the apparent maximum preserved thickness is approximately 1600m.

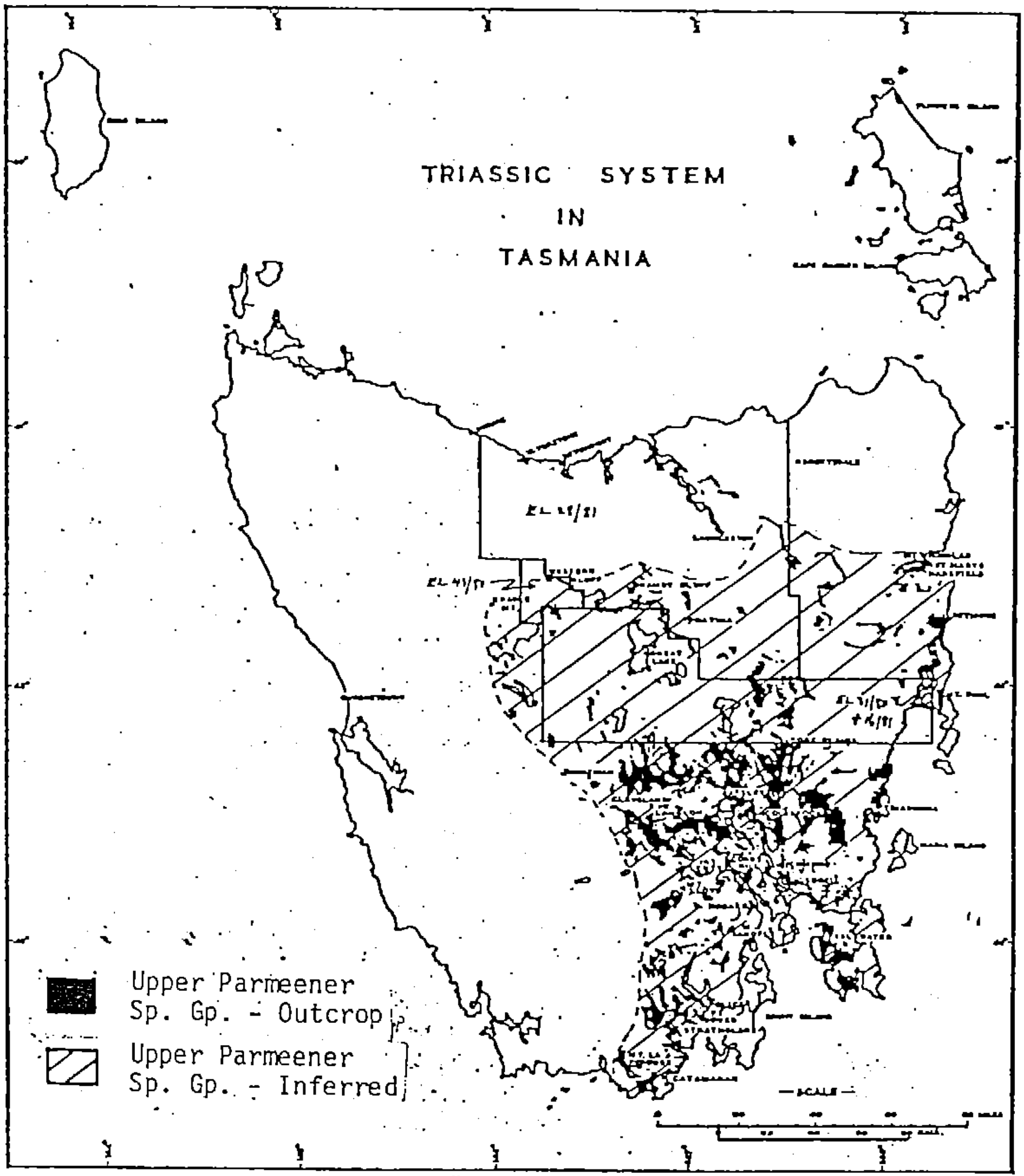

Fig. 4: Distribution of the Upper Parmeener Super Group

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## 3:0 COMMENTS ON SOURCE ROCK TYPES

### 3:1 CARBONATE

3:1.1 Pure limestones are able to generate heavy oil with the requisite maturation conditions, and organic matter (OM) content. Impure limestones, containing more clay minerals (to act as Lewis Acid Catalysts) would modify the tendency to produce heavy oil (Hunt, 1979). The Karmberg Limestone contains ≃75-85% $CaCo_3$ while Cashions Creek Limestone contains ≃ 93% $CaCo_3$, and the Benjamin Limestone ≃ 85-90% $CaCo_3$.

3:1,2 Dark or brown coloured limestone/dolomite is generally a good source rock; most of the Karmberg, and some of the Cashions Creek and Benjamin Limestones are impure and argillaceous. Litho correlates of these units at Lune River (Summons, 1981), are similarly dark brown, with bituminous stylolites, disseminated pyrite, and with interbeds of carbonaceous phosphatic shale/siltstone. Bituminous stylolites are recorded from several localities in the Gordon Limestone (e.g., Railton, Deloraine).

3:1.3 Fine grained carbonate rocks generate more hydrocarbons from the same amount of total organic matter (TOM) than a clastic source rock, because limestones contain sapropelic OM (rich in algal/amorphous kerogen). These kerogen types have the highest H/C ratio, and thus the highest yield of petroleum of all the kerogens (Hunt, 1979).

The Gordon Limestone is essentially fine grained (micrites and calcisiltites) across the state, and this feature is important in maximizing the amount of associated OM within it.

3:1.4 Typical source beds were formed in low energy coastal marine environments, where clays and carbonates were deposited with 0.5-5% OM. The critical factor in preservation of the OM is the existence of toxic, anaerobic conditions. Sapropelic OM, which was formed in marine environments, is able to generate both oil and gas.

The Gordon Limestone was formed under shallow water, marine conditions (as discussed previously), and the frequent occurrence of pyrite in conjunction with the carbonaceous shales implies an anerobic and toxic environment.

3:1.5 A possible parallel of the Karmberg-Cashions Creek Limestones (Florentine Valley) and the Lower Sequence at Lune River exists in the lower part of the Marl Slate of N.E. England (Turner et al, 1978), where the sapropelic facies (laminated siltstone, dolomite and bitumen) is overlain by evaporite facies sediments. Details on the evaporitic nature of the Middle Sequence at Lune River were described by Summons (1981).

3:1.6 Catalytic cracking of hydrocarbons can be induced by salts of V, Mo, Ni (Levorsen, 1966); the black shales in the Gordon Limestone at Lune River are phosphatic, and anomalous in their content of Mo and Ni.

3:1.7 The association of oil brines with hypersaline dolomitizing brines responsible for the formation of the Mississippi Valley Type ore deposits has been noted by several authors, e.g. Hall and Friedman (1963), Hall and Heyl (1968), and Carpenter et al (1974).

Dolomitization of the Gordon Limestone has occurred at several localities, and a mechanism of transport of any oil that may have been generated may be envisaged.

## 3:2 CLASTIC

3:2.1 Catalytic cracking of hydrocarbons is a significant process in the generation of petroleum below ≈125°C (Goldstein, in Hunt, 1979); typical naturally occurring catalysts are smectite clay minerals and zeolites. Levorsen (1966) cites an example of polymerization of propylene at 35°C in response to natural catalyst bearing rocks.

The Lower Marine Sequence of the Parmeener Super Group is reported to contain altered glass shards in southern Tasmania and the Upper Marine Sequence (Cascades Group) contains beds of bentonite, (Banks, 1962). These occurrences are interpreted as indicating volcanism (possibly that recorded in N.S.W.), during the Permian, and the original presence of zeolitized tuffs may be inferred.

The original presence of smectite clays in the Lower Marine Sequence is currently unknown, but the concept of smectite/zeolite initiated catalytic decomposition of OM may have been significant in view of the geothermal gradients estimated for the Permian in Tasmania.

3:2.2 Sapropelic OM is formed by decomposition and polymerization of spores and planktonic algae, and may be converted to one of the following with increasing maturation; boghead coal/oil shale, cannel coal, or oil. Sapropelic OM is known to occur in both the Lower and Upper Marine Sequences of the Parmeener Super Group as follows:

(a) The "Tasmanite" oil shale from N. and N.W. Tasmania (Quamby Formation) consists of a single celled alga named Tasmanites Punctatus, which has H/C ratio of ≒1.5, and an O/C ratio of ≒0.12.

As stated previously, sapropelic organic matter is the most productive generator of oil, because its kerogen constituents (algal, amorphous and herbaceous) can contribute H in the range of H/C from 1.7 - 0.30. Thus the "Tasmanite" oil shale may be viewed as representing the optimum type of source rock OM.

(b) Banks (1962) recorded oil shale and cannel coal from the top of the Mersey Coal Measures; however, it is equally possible that these occurrences of sapropelic OM occur at the base of the overlying Malbina Formation; similar comments (to those made for "Tasmanite" oil shale), apply as to the petroleum prospectiveness of this OM, given the necessary maturation conditions. The presence of cannel coal (world ave. H/C ≒1.0, O/C ≒0.11) suggests that it has progressed along the maturation pathway from the "Tasmanite" oil shale.

3:2.3 Radioactive elements may aid in the transformation of kerogen to petroleum through the action of alpha particle bombardment (Levorsen, 1966); however, the evidence for the significance and extent of such transformation is conjectural.

Uraniferous black shales occur beneath the Permian Basal Conglomerate (and possibly in the Quamby Formation) at Rossarden.

## 4:0 GEOTHERMAL HISTORY

The geothermal history of a basin involves an analysis of the time intervals during which the sediments were subjected to various temperatures. It represents the optimum mode of evaluating hydrocarbon generation in a basin, providing reasonable palaeo temperatures can be established.

The three main optical organic metamorphism indices are vitrinite reflectance,palynomorph colour change (Thermal Alteration Index - TAI), and conodont colour change (Colour Alteration Index - CAI). The colour and preservation of palynomorphs is a function of the thermal alteration (Staplin, 1969), but it is only recently that Epstein et al (1977) and Harris (1979) have demonstrated that the conodont colour is similarly temperature dependant. These authors have correlated colour changes with the amount of fixed C in the conodonts and the host sediments; the conodonts darken with increasing temperature as a result of carbonization of the OM in the inter lamellar spaces. Further indications of the potential of using CAI values were summarised by Harris (1979) as follows:-

(a) Conodont colour alteration is progressive, cumulative and irreversible.

(b) The colour alteration is dependant on time and temperature, but is independent of pressure.

(c) An Arrhenius plot of experimental and field data indicate that colour alteration of conodonts ranges from 50-450$^{\circ}$C.

(d) Time is of minor importance for CAI values in rocks older than 50 million years.

(e) The 6 CAI values can be correlated with vitrinite reflectance, translucence photometry,and chemical analyses.

## 5:0 PALAEO - GEOTHERMAL GRADIENTS

### 5:1 Gordon Sub Group

Burrett (1978) showed that CAI values in the Gordon Limestone vary considerably across the state, outlining an arcuate trend around the Precambrian blocks of central Tasmania. This arcuate trend follows Cambrian volcanics and lower Palaeozoic synclinoria, which both fringe and overlie the Precambrian blocks (Cradle Mtn., Prince of Wales blocks).

The Cambrian volcanics (which host the major base metal orebodies of Mt. Lyell, Rosebery, etc.), have been interpreted as an island arc adjacent to an east plunging subduction zone (Solomon and Griffiths, 1974), and more recently as a rift valley-caldera structure by Corbett (1979).

The zone of darkest Ordovician conodonts (Flowery Gully, Melrose, Loongana, Everlasting Hills, Olga synclinorium), coincides with a belt of thinned Cambrian crust (represented by the Mt. Read Volcanics, Dundas Group, etc.), and a belt of maximum deformation in Gordon Sub Group localities. The Cambrian geothermal gradient would have been appreciably higher within this region of thinned crust, and assuming this region was not underlain by Precambrian crust, high heat flows would have occurred in post-Cambrian times.

The corallary to this interpretation is that post-Cambrian rocks, floored by Precambrian crust, would have been relatively insulated from the postulated high heat flow values within the Cambrian volcanics.

Table 2 depicts CAI, change ($\Delta$) in temperature, thickness and geothermal gradients ($\beta$) for the Gordon Limestone. No gradients appear to have existed across the Gordon Limestone at Flowery Gully, Melrose, Gunns Plains and Everlasting Hills as indicated by the CAI values. The Gordon Limestone in these areas was heated to $\geqslant 300^{0}$C, and a consideration of the maximum depth of burial by post-Ordovician rocks implies the presence of abnormally high geothermal gradients. A high, post-Ordovician (probably middle Devonian) heat flow is assumed for W. and N. Tasmania for the following reasons:

(i) In several localities (referred to previously), the "normal" geothermal gradient due to depth of burial (with attendant increase in temperature), does not exist, suggesting that it has been obscured by another source of thermal energy. The lowest CAI values in, and the lowest geothermal gradients across, the Gordon Limestone occur in those areas floored by Precambrian crust; other areas marginal to the Cambrian volcanics (e.g. Mole Creek, Olga River) have intermediate geothermal gradients.

TABLE 2

## ORDOVICIAN (GORDON SUB GROUP) SAMPLES

| Locality | C.A.I. | | Min. ΔTemp. (°C) | Max. ΔTemp. (°C) | Thickness (km) | | β Min. (°C/km) | β Max. (°C/km) |
|---|---|---|---|---|---|---|---|---|
| | Base | Top | | | Present | + 35% | | |
| Flowery Gully | 5 | 5 | - | - | 0.47 | 0.72 | - | - |
| Melrose | 5 | 5 | - | - | ?0.25 | ?0.39 | - | - |
| Gunns Plains | 4 | 4 | - | - | 0.90 | 1.39 | - | - |
| Loongana | 5 | 4 | 100 | 210 | 0.65 | 1.00 | 100 | 210 |
| Mole Creek } | 5 | 3 | 100 | 290 | 1.30 | 2.00 | 50 | 145 |
| Mole Creek* } | 4 | 3 | <80 | 190 | 1.30 | 2.00 | <40 | 95 |
| Bubs Hill | 5 | 3 | 100 | 290 | 0.35 | 0.54 | 185 | 537 |
| Everlasting Hills | 5 | 5 | - | - | 0.25 | 0.39 | - | - |
| Olga River | 5 | 4 | <100 | 210 | 1.50 | 2.31 | <43.3 | 90.9 |
| Florentine Valley | 4 | 2 | 50 | 240 | 1.70 | 2.62 | 19.1 | 91.6 |
| Lune River | 2 | 1 | 20 | 90 | >0.70 | >1.08 | <18.5 | <83.3 |
| Average Mole Creek* and Olga River: | | | | | | | 41.6 | 92.9 |
| Average Florentine Valley & Lune River | | | | | | | 18.8 | 87.4 |

NB:

(i) CAI - Conodont Colour Alteration Index

(ii) Thickness recalculated to allow for volume reduction due to pressure solution (diagenetic and tectonic stylolites).

(iii) β - Geothermal gradient within Gordon Limestone, before volume reduction (shortening). The β values shown here are reproduced as $\beta_0$ values in Table 4.

(iv) CAI data from Burrett (1978), and change in temperature (Δ) from Harris (1979).

## 5:2 Parmeener Super Group

Harris (1981) examined samples collected by Victor Exploration Pty. Ltd. staff from several localities in the Lower Marine Sequence of the Parmeener Super Group. AMDEL (1981) analysed 10 out of 12 samples collected, and Harris (1981) was only able to find herbaceous kerogen in 5 of the 10 samples, and consequently, could only assign reliable TAI values to half the samples. This data is shown in Table 3, which also depicts change in temperature, thicknesses, and geothermal gradients for the Parmeener Super Group and Jurassic dolerite.

Although it is not possible to construct TAI isograds from the limited number of samples, it is apparent that those samples collected from the N.W. of the state (Bronte, Mersey River)show higher thermal maturity than those elsewhere in the state (Poatina, Quamby Brook, Maydena). Inclusion of the 5 samples devoid of kerogen (and assuming the inferred TAI values are valid), generally enhances the thermal maturity pattern described above, the exception being the Poatina Power Station sample, the true location of which cannot be determined.

This pattern may be a reflection of a relict, high Devonian heat flow as discussed previously.

Similarly to the Gordon Limestone samples, the problem in determining the "normal" geothermal gradient during Permian and subsequent time appears to be one of screening out the effects of high heat flow; accordingly, the best estimate of the "normal" geothermal gradient can be obtained from the Maydena/Styx River area (Sample 12A), which ranges from 28-50°C/km, and has an average of 39°C/km. The Quamby Brook - Poatina areas range from 32-70°C/km (average 57°C/km.).

Although the number of useful (herbaceous kerogen bearing) samples is inadequate to permit statistically reliable conclusions to be made about the thermal history of the Parmeener Super Group, the following observations may be of possible significance:

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TABLE 3

## PERMIAN SAMPLES

| Sample | Locality | TAI | Min. Δ Temp (°C) | Max Δ Temp (°C) | Thickness |  |  | $\beta$ Min. (°C/km) | Max. $\beta$ (°C/km) |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | PSGp | Dol. | Total |  |  |
| 4/6 | Mersey River | (4) | - | - | - | - | - | - | - |
| 5 | Mersey River | 3 | 100 | 155 | 0.86 | 0.50 | 1.36 | 73.5 | 114.0 |
| 7 | Bronte | 3 | 100 | 155 | 1.20 | 0.50 | 1.70 | 58.8 | 91.2 |
| 11 | King William Saddle | (4) | - | - | - | - | - | - | - |
| 12 | Styx River | (4) | 155 | 200 | 1.30 | 0.70 | 2.00 | (77.5) | (100.0) |
| 12A | Styx River | ≃2 | ≃50 | ≃90 | 1.10 | 0.70 | 1.80 | 27.8 | 50.0 |
| 1 | Hobart | - | - | - | - | - | - | - | - |
| 2 | Quamby Brook | 2 | <40 | 100 | 1.29 | 0.50 | 1.79 | <22.3 | 55.9 |
| 3 | Poatina | (4) | 155 | 200 | 1.20 | 0.50 | 1.70 | (91.2) | (117.6) |
| 8 )<br>9 )<br>) | Poatina )27m<br>HEC DDH )<br>5021 )242m | 2)<br>)<br>3) | ≪30 | 60 | 0.22 | 0.50 | 0.72 | <41.7 | 83.3 |
|  | Average for W. Tasmania (Samples 5,7) |  |  |  |  |  |  | 66.1 | 102.6 |
|  | Average for N.E. Tasmania (Samples 2,8,9) |  |  |  |  |  |  | 32.0 | 69.6 |
|  | Apparent oil threshold (Maydena, Sample 12A) |  |  |  |  |  |  | 27.8 | 50.0 |
|  | Average for S. and N.E. Tas. (Samples 12A, 2, 8, 9) |  |  |  |  |  |  | 30.6 | 63.1 |

NB:

(i) TAI - Thermal Alteration Index; values in brackets are estimates only, as the samples did not contain any herbaceous kerogen.

(ii) PSGp - Parmeener Super Group thickness from the top of the Wynyard Tillite, except for sample 12A, for which the thickness was taken from the top of the Woody Island Siltstone correlate.

(iii) Sample 12A is from the Woody Island Siltstone correlate, Maydena.

(iv) Maydena section (above Wynyard Tillite) taken as 630m. (lwr. PSGp), 640m. (upper PSGp) and 700m. (J. dolerite). The section above the Woody Island Siltstone correlate excluded this unit (200m).

(v) $\beta$ - Geothermal gradient, calculated assuming a ground temperature of 10°C. The $\beta$ values shown here are reproduced as $\beta_2$ values in Table 4.

The majority of the geothermal gradients measured in Tasmania are in excess of 30°C/km (D.C. Green, pers. comm.). Nicholas et al (1980) produced an uncorrected geothermal map of Australia, and reported the measurements of geothermal gradients from 5 Bass Basin oil wells, which averaged 35°C/km.

However, corrections for mud circulation effects (cooling) in the holes were not applied (+10, +14%, D.C. Green, pers.comm.), nor were corrections for climatic controls, as discussed by Cull (1979). Cull observed that variations in the geothermal gradient were caused by surface warming following the retreat of the Pleistocene glaciers in Southern Australia, and estimated positive corrections of 10-25% for all geothermal data obtained from depths of < 300m.

Assuming that the Bass Basin oil well measurements were made at depths > 300m., the only correction to be made to the data is that for mud circulation, i.e., the geothermal gradient in Bass Basin is approx. 35+10% to 35 +14%°C/km, which is approximately 40°C/km. Thus the present geothermal gradient for Tasmania would appear to range from 30-40°C/km.

The generally higher heat contents of granite rocks is a function of the concentration of naturally radioactive elements (K, U, Th) which are concentrated in the upper portion of the earth's crust, and contribute ⩾ 50% of the heat flow measured at the surface.

In a recent gamma ray survey of granite rocks in Tasmania conducted by the Geological Survey of Tasmania and the B.M.R., by Collins, Wyatt and Yeates (1981, in press), the granites were found to be areas of high heat productivity with U ⩽ 25ppm, and Th ⩽ 50ppm. These values are clearly elevated from the world averages for granite of U ≃ 5ppm and Th ≃ 17ppm (Levorsen, 1974).

The high heat flow in the Tasmanian crust is probably due to two factors:-

(i) The abundance of granitic rocks, as indicated by gravity surveys (Leaman, Richardson and Shirley, 1980), with apparently anomalous levels of U and Th as discussed above.

(ii) The combinations of thin crust overlying abnormally hot, conductive mantle. Electric conductivity anomalies in Bass Strait and northern Tasmania were reported by Lilley (1976). Sutherland (1981) postulated that northward migration of Australian continental plate has controlled volcanism in Queensland, New South Wales, Victoria and Tasmania, from the start of the Tertiary period 55 million years ago (i.e. the Gondwanaland break up). He suggests that volcanism has occurred as the Australian plate passed over a fixed mantle magma source ("hot spot"), and that the present heat flow anomalies are due to magmatism (crust/mantle), and extension of the crustal plate.

Further discussion on the high heat flow in Tasmania is made in the Appendix.

## 7:0 POTENTIAL OIL SOURCE ROCKS

### 7:1 GORDON SUB GROUP

The Gordom Limestone is fine grained, often dark coloured, impure/ argillaceous, and frequently has bituminous stylolites. The most likely source rocks would be the Karmberg and Cashions Creek Limestones (or their correlates), particularly the algae rich Cashions Creek limestone. Beds of pyritic, carbonaceous shale/siltstone imply the requisite toxic, anaerobic conditions existed for the preservation of organic matter.

The type and amount of OM is not known, but it can be predicted as being sapropelic.

Although pure limestones have a higher threshold temperature for petroleum generation than clastic source rocks, the impure nature of the Gordon Limestone, and the Mo, Ni bearing carbonaceous phosphatic shales would offset this effect.

The geothermal history of the Gordon Limestone varies considerably across the state; lowest geothermal gradients occurred in the south, and highest in the west and north west. The low values are believed to be representative of the normal geothermal gradient in those regions underlain by Precambrian crust.

The effect of these Ordovician geothermal gradients in terms of generation of hydrocarbons has to be viewed in context of the total sequences in given areas, as shown in Figure 1.

The optimum generation of petroleum from Gordon Limestone potential source rocks would have occurred in Southern Tasmania (based on present data - the thermal history of the inferred Gordon Limestone in eastern Tasmania is currently highly speculative.

Using the 60-150°C temperature interval to represent the interval of oil generation, and 150-200°C to represent the interval of gas generation (from Hunt,1979), the following observations can be made:-

7:1.1 Florentine Valley - Oil would have been generated from the Benjamin and possibly the Cashions Creek Limestones, and gas from the Karmberg Limestone.

7:1.2 Lune River - Oil would have been generated from the basal portion of the Middle Sequence, and all of the Lower Sequence (which includes an algae rich litho correlate of the Cashions Creek Limestone).

7:1.3 Mole Creek - Mainly gas, with very minor oil, would have been generated from the upper half of the sequence. Other areas of Gordon Limestone in the state appear to have been very hot, and any organic matter present wouldhave been metamorphosed to pyrobitumen; however, minor gas occurrences may be present.

## 7:2 PARMEENER SUPER GROUP

### 7:2.1 Lower Marine Sequence

This sequence is one of fine grained, dark coloured (often carbonaceous), pyritic clastics, with minor sandstone and limestone; it is variably fossiliferous, and toxic, anaerobic conditions are implied by the pyritic, carbonaceous nature of the sediments (i.e. preservation of organic matter). The nature and amount of OM is not known with a high level of statistical significance, but of 12 samples analysed by AMDEL (1981) and examined by Harris (1981):-

(i) The clastic samples (11) contained an average of 0.74% TOC, and the only carbonate sample contained 0.44%TOC.

(ii) The clastic samples contain sapropelic kerogen in the range 30-95%, averaging 58%; coaly kerogen averages 40%, which is in contrast to the comments made by Harris (1981).

(iii) The clastic samples contain EOM in the range 44-192 mg/gTOC, averaging 96 mg/gTOC.

(iv) Only half the clastic samples contained herbaceous kerogen, so that only half the samples have reliable TAI values.

Clastic source rocks generally require ≯ 0.4% TOC (Hunt, 1979) and carbonate source rocks require ≯ 0.2% TOC (Ruth and Cooper, 1976). Extractable organic matter (EOM) in source rocks should be ≯ 150mg/g TOC (Tissot et al, 1974) or ≯ 200 mg/g TOC (Ruth and Cooper, 1976), although the latter authors observed that a significant quantity of EOM is insufficient by itself to identify a source rock.

Liquid hydrocarbons have recently been discovered by M.C. Forster and R. Hine in the Woody Island siltstone Formation correlate at Maydena. A single sample from this locality contained 1.19% TOC, 80% sapropelic kerogen, and 192 mg/g TOC of EOM; the sample was assigned by TAI value of 4 by Harris (1981), but did not contain herbaceous kerogen.

Liquid hydrocarbons have also recently been located (M.C. Forster, pers.comm.) at Poatina and at the head of the Mersey River; the Poatina sample contained 0.62% TOC, 70% sapropelic kerogen, 122 mg/g TOC of EOM, and has a TAI value of 4; the Mersey River samples average 0.85% TOC, 58% sapropelic kerogen, 91 mg/g TOC of EOM, and have TAI values of 3 and 4.

However, all these TAI values of 4 are not based on palynomorph colours, and are enigmatic in view of the apparent source nature of the rocks. Alternatively, if the TAI values are reliable, it suggests the rocks sampled are reservoirs, although the other source rock parameters (TOC, EOM, etc.) indicate them to be a source rocks (particularly the Woody Island Siltstone Correlate at Maydena). The Mersey River sample with the TAI value of 3 seems a plausible indication of a source rock from which petroleum has been produced. Oxidation and irradiation of palynomorphs may also complicate the interpretation of TAI values.

Oil shale ("Tasmanite") occurs in the north of the state near the base of the Quamby Formation; oil shale is also known at Rossarden (probably the Quamby Formation). The inter relationships between the "Tasmanite" oil shale, other oil shales and the petroleum occurrences, in the Lower Marine Sequence are not known at present, and a knowledge of such relations appears imperative to the understanding of the hydrocarbon potential.

NB: TOC: Total Organic Carbon

### 7:2.2 Upper Marine Sequence

This sequence is one of limestone, mudstone, siltstone and sandstone; on present knowledge, the sequence as a whole would not appear as prospective for source rocks as the Lower Marine Sequence. Potential source rocks appear restricted to the carbonaceous mudstones and the impure limestones.

Oil shale and cannel coal occur at the interface of the Mersey Coal Measures and the Malbina Formation. No analytical data is available for these concentrations of ?sapropelic organic matter; however, the presence of cannel coal suggests a higher level of maturation than the "Tasmanite" oil shale.

The significance of this occurrence of sapropelic OM apparently much younger than the Woody Island Siltstone Formation - "Tasmanite" oil shale horizon has yet to be thoroughly evaluated.

The geothermal history of the Parmeener Super Group (similarly to the Gordon Limestone) varies considerably across the state; lowest geothermal gradients occur at Quamby Brook, Poatina and Maydena, and highest values occur in the Bronte and Mersey River areas. Similarly to the Gordon Limestone, the minimum geothermal gradients are believed to represent the "normal" values while the higher gradients may reflect a relict high Devonian heat flow.

The effect these geothermal gradients had on the generation of hydrocarbons can be elucidated from Figure 1. Values range from 39°C/km (Poatina, Maydena) to 62°C/km (Poatina) and 84°C/km (average for Bronte and Mersey River). Using the data in Table 3, it is apparent that most of the occurrences of the Lower Marine Sequence have undergone the requisite maturation histories for petroleum generation. This observation may explain the "petroliferous odour" noted in the Mersey River, Poatina and Maydena localities, the apparent exceptions being the Bronte, King William Saddle and Poatina drill hole No. 5021 localities. The apparent lack of liquid hydrocarbons in these areas may be the result of the ratio of sapropelic to humic kerogen, or the result of the samples being overmature.

Hunt (1979) observed that the yield of hydrocarbons per volume of sediments is higher in basins of high heat flow. The oil present in the Woody Island Siltstone Formation Correlate at Maydena appears to have been generated in the temperature interval 80-90°C.

An interesting feature of the geothermal gradients shown in Figure 1 concerns the gradient across the Wynyard Tillite and the Eldon Group, which is very slightly positive to markedly negative; this may be due to the following:

(i) A high thermal conductivity of the sandstone rich Eldon Group, or,

(ii) A positive geothermal gradient across the Eldon Group which was cancelled by a negative gradient across the Wynyard Tillite, or,

(iii) An inflated figure for the thickness of the Eldon Group in the Florentine Valley area, and conversely a deflated figure for the thickness of Eldon Group in the Lune River area. If this interpretation is correct, it would modify the hypothesis advanced concerning hydrocarbon generation (potential) in the Gordon Limestone at Lune River.

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## 8:0 POTENTIAL OIL RESERVOIR ROCKS

### 8:1 Gordon Sub Group

As mentioned previously, the Gordon Limestone is generally fine grained (micritic), a feature which would have assisted diagnetic calcite cementation so that the present intergranular porosity would be ≪ 2%. As the micrite facies of the Gordon Limestone seldom contain < 2% of acid insoluble residue (AIR), some compaction would have occurred.

Impure limestone (eg. Karmberg) with an estimated composition of ≪ 85% $CaCo_3$ and 5-10% AIR (clay minerals, chert) would experience fluid losses through compaction, thus enabling primary migration mechanisms to operate. Other evidence of inferred migration mechanisms comes from those sections of Gordon Limestone which have been dolomitised. Potential reservoirs in the Gordon Limestone appear limited to coral reefs, and those areas of secondary (granular) dolomite. Coral gardens were common from Blackriveran to Cincinnattian time, but no authentic bioherms have yet been found.

The presence of an Ordovician continental slope has been inferred east of Flowery Gully, where Mathinna Group rocks overlie Gordon Limestone; more recently (C.F. Burrett, pers.comm.) the discovery of a deep water facies of the Gordon Limestone at Surprise Bay, has led to the recognition of a continental slope in the south of the state.

The base of the Gordon Limestone is strongly diachronous, and the Ordovician sea is inferred to have advanced over the Tyennan Geanticline in a generally westward direction. C.F. Currett (pers.comm.) postulates that the coralline facies at the top of the Benjamin Limestone in the florentine Valley was a back reef, with a yet to be discovered fore reef to the east; M.R. Banks (pers.comm.) believes the Ordovician sea contained several islands (e.g. Vale of Rasselas, Glenorchy). Thus a model may be envisaged whereby the Ordovician continental slope extended south from Flowery Gully along what is now the Tamar Fracture System (itself activated in Carboniferous time) and south west to Surprise Bay.

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Deposition of Gordon Limestone west of this line would have been under shallow water platform conditions, possibly with fore reefs which would have migrated west (landward) in the westward transgressing sea.

Secondary dolomites are known from several places in the Gordon Limestone; at Lune River secondary dolomite was formed by the action of hypersaline brines which originated in supratidal facies limestone during diagenesis; this dolomite is porous and vuggy, but no details of its intergranular porosity are known.

## 8:2 Eldon Group

This group consists of alternating sequences of sandstone and siltstone with minor limestone; it has a high sand : shale ratio and should be viewed as hosting potential reservoirs. No data on its intergranular porosity is available at present.

## 8:3 Parmeener Super Group

Mention has already been made of the smectitic nature of some of the clays in this group; the dehydration of smectite to illite provides extra pore water for migration mechanisms. Possible reservoir rocks include:-

(i) Lower Marine Sequence - Darlington Limestone and the basal conglomerates.

(ii) Lower Freshwater Sequence - Mersey Coal Measures.

(iii) Upper Marine Sequence - Malbina Formation, Risdon Sandstone.

(iv) Upper Freshwater Sequence - Cygnet Coal Measures, Ross Sandstone.

No data on intergranular porosites is known; the Woody Island Siltstone correlate at Maydena may be a reservoir as a function of its microfracture porosity.

## APPENDIX

### GEOTHERMAL ENERGY

The use of geothermal energy is relatively modern, and it differs from conventional energy sources (fossil fuels, uranium) in that it may be directly utilized without prior combustion or fission.

Three types of geothermal systems are commercially operative or feasible, namely vapour dominated systems, and liquid dominated systems of both high and low enthalpy (natural circulation).

Extraction of geothermal energy from hot, dry granite is currently being investigated at Fenton Hill, New Mexico, U.S.A.; the technique used involves drilling to depths where the temperature is $>160^{\circ}C$, and then creating an artificial fracture system through which water is circulated, and the thermal energy recovered by heat exchangers, or by using the steam produced as a result of the method.

A similar program of research is being undertaken on granites in Cornwall, U.K., which have heat productivities of similar and lesser magnitude to the five areas of hot dry geothermal energy outlined by Collins et al (1981, in press) in Tasmania.

The Tasmanian Government has approved the drilling of a geothermal test hole at Coles Bay, but is unable to provide finance for the program.

It is apparent that in an increasingly energy short world alternative energy forms will assume greater significance. On present indications, the geothermal energy available in Tasmania is comparable and possibly superior to that elsewhere, and its future utilization should be given serious consideration.

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(ii) Lower Devonian conodonts, in rocks which were unlikely to have been buried to any appreciable depth, have been metamorphosed (Burrett, 1978).

(iii) The K-Ar ages of late Devonian granite have not been reset by heat induced leaking of Ar; however, the K-Ar ages of late Cambrian granites have been reset to Ordovician ages (McDougall and Leggo, 1965), presumably by Devonian heating.

Thus the best estimates of the "normal" (due to depth of burial alone), geothermal gradient across the Gordon Limestone, are the values indicated for Florentine Valley and Lune River (Table 2), which range from 19°C/km to 87°C/km, with an average of 53°C/km.

The average of the Mole Creek (less altered sample) and Olga River samples indicates a geothermal gradient of 42-93°C/km and an average of 67°C/km. Inclusion of the more altered sample from Mole Creek indicates an average value for the two areas of 77°C/km.

The CAI values for Flowery Gully, Melrose, Gunns Plains and Everlasting Hills indicate heating to > 300°C for the entire Gordon Limestone, which compares with temperatures of $\simeq$ 200°C and $\simeq$ 80°C at the top of the Gordon Limestone, in the Mole Creek/Olga River, and Florentine Valley/Lune River areas respectively.

If it is assumed that the rocks overlying the Gordon Limestone were similar in thickness and thermal conductivity, and that the Gordon Limestone had approximate constant thermal conductivity, then temeprature is proportional to heat flow; accordingly, the CAI data imply that the Devonian heat flow (relative to Florentine Valley/ Lune River), was 150% and 275% higher in the Mole Creek/Olga River and Flowery Gully, etc. areas respectively.

TABLE 4

## ESTIMATED GEOTHERMAL GRADIENTS (ORDOVICIAN - JURASSIC) - TASMANIA

| Locality | Thickness (k/m) | | | | Ave. Geothermal Gradient ($^{o}C/km$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Dolerite | PSGp | E.Gp. | Og. | | | | |
| Quamby/Poatina Mole Creek | 0.5 | 1.3 | <1.0 | 1.3 | 51 | >52 | <68-69 | 57-67 |
| Olga River | (0.5) | (1.5) | 2.0 | 1.5 | (75) | (59) | 67 | (61) |
| Maydena/ Florentine Valley | 0.7 | 1.6 | 2.0 | 1.7 | 39 | 21 | 55 | 31 |
| Lune River | 0.5 | 1.6 | (-) | >0.7 | 39 | 19 | <51 | <27 |
| Average for Sthn. Tasmania: | | | | | 39 | 20 | 53 | 29 |

NB:

(i) PSGp - Parmeener Super Group (Including Wynyard Tillite).

(ii) E. Gp. - Eldon Group (Silurian - Devonian).

(iii) Og - Gordon Sub Group (Ordovician)

(iv) Geothermal gradients, $\beta$ =

$\beta_2$ = Average geothermal gradient across dolerite + PSGp to the top of the Wynyard Tillite.

$\beta_1$ = Average geothermal gradient across dolerite, PSGp (total) and E.Gp.

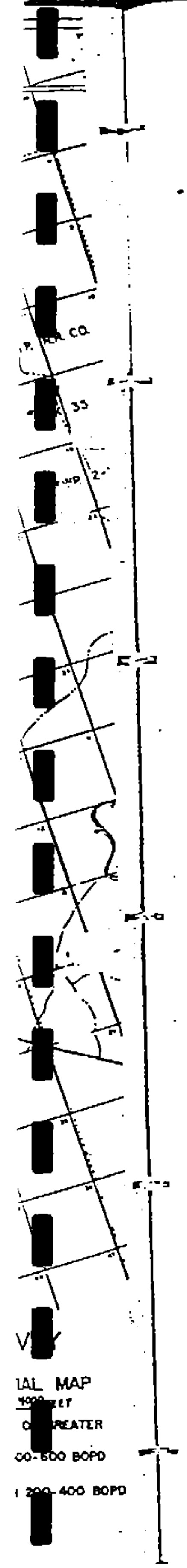
$\beta_o$ = Average geothermal gradient across Og (Original thickness).

$\beta_T$ = Average geothermal gradient from dolerite to the base of Og (present thickness).

(v) The original thicknesses of dolerite and PSGp in the Olga Synclinorium are unknown, and are assumed to have been similar to the Bronte data, with 300m. of Wynyard Tillite. Similarly, the $\beta_2$ value was taken as the Bronte value; accordingly, the $\beta_2$, $\beta_1$, and $\beta_T$ values for the Olga River, are only very approximate, although the $\beta_1$ and $\beta_T$ figures are notably similar to those for the Quamby/ Poatina/Mole Creek area.

clusion of developmental drilling within the Four-County area. Outside areas appear to be marginal at present and yet areas favored by optimum accumulation of oil and associated with greater fracturing would be favored for production unknown at this time.

Truthfully, it may be said that the Spraberry is a unique reservoir. It is fabulous in areal extent, puzzling with its production problems, and baffling with its geological phenomena. Here in an area devoid of typical folded traps, and from a mass of rocks that would be classified as non-commercial under average conditions, flowed the aforementioned 2,744,156 barrels of oil from 1,558 wells during the month of April, primarily the result of fractures.



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APPENDIX 8 - Summons ,T. 1981

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The Northwest Bay Co. Pty Ltd

# PRELIMINARY REPORT ON PETROLEUM POTENTIAL - ONSHORE TASMANIA

by T.G. Summons

August, 1981.

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## ABSTRACT

A review has been made of potential hydrocarbon source and reservoir rocks of Ordovician to Triassic age in Tasmania. The appraisal of post-Cambrian to pre-Tertiary regional geology, in conjunction with current concepts on source rock characteristics, paleo-geothermal gradients, and known occurrences of sapropelic kerogen, implies the presence of potential source rocks at several horizons of differing age and lithology. The most likely hydrocarbon source rocks are the Ordovician Gordon Sub Group (carbonate), and the Carboniferous - Permian section of the Parmeener Super Group (clastic). Recent discoveries of Petroleum seepages were made in the basal section of the Parmeener Super Group; this lower section appears to fulfill the accepted criteria for source rocks, although the limited number of samples collected precludes authoratitive conclusions. High heat flow during the Devonian in western and north western Tasmania, and possibly relict as late as Permian time, has effectively down graded the prospectiveness of these parts of the state for hydrocarbon potential.

However, the remainder of the state appears to have been shielded from the high heat flow, as evidenced by the Gordon Limestone in Southern Tasmania, which was subjected to the requisite maturation conditions for the generation of hydrocarbons.

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# PRELIMINARY REPORT ON PETROLEUM POTENTIAL
# - ONSHORE TASMANIA

## INDEX

# PRELIMINARY REPORT ON
# PETROLEUM POTENTIAL - ONSHORE TASMANIA

by T.G. Summons

August, 1981.

## 1:0 INTRODUCTION

This review of current literature and ideas of Tasmanian geology, applicable to exploration for liquid and gaseous hydrocarbons, is intended to review some of the aspects of petroleum origin, migration and retention in Tasmania, with the object of rationalising future petroleum exploration programs.

Critical physical and chemical data on potential source and reservoir rocks are either poorly known, or non existent; accordingly, many of the comments made in this report are speculative and will almost certainly be modified after collection, compilation and interpretation of the requisite data.

The report is divided into a discussion of lower Palaeozoic and Carboniferous Permian-Triassic age rocks, under the following headings:-

1. Regional Geology
2. Comments on Source Rock Types
3. Geothermal History
4. Potential Oil Source Rocks
5. Potential Oil Reservoir Rocks

## 2:0 REGIONAL GEOLOGY

### 2:1 ORDOVICIAN

The Ordovician period is represented by the Junee Group, which consists of the Denison Sub Group, overlain by the Gordon Sub Group. The type area of the Junee Group is the Florentine Synclinorium (Maydena - Florentine Valley).

### 2:1.1 Denison Sub Group

This sub group consists of three formations:-

| | |
|---|---|
| - Reeds Conglomerate | 1500m |
| - Tim Shea Sandstone | 300m |
| - Florentine Valley Mudstone | 600m |

As the formation names imply, the lithogies consist of conglomerate, sandstone and siltstones with minor impure limestone. A widespread marine transgression occurred at the top of the subgroup, with sand deposited in N.W. and W. Tasmania, while silt was deposited in the Florentine Valley (Florentine Valley Mudstone), suggesting a source area in the N.W. and W. of the state; support for this model is seen in the higher proportion of calcareous beds in the Florentine Valley and Beaconsfield areas, than elsewhere.

### 2:1.2 Gordon Sub Group

This sub group consists of three formations:-

- Karmberg Limestone
- Cashions Creek Limestone
- Benjamin Limestone (Corbett and Banks, 1974).

The Karmberg Limestone consists of approximately 400m of impure nodular limestone, calcareous siltstone and chert; it is richly fossiliferous, and contains large spherulites of pyrite. The Cashions Creek Limestone consists of approximately 100m of dolomitic limestone with abundant algal colonies (Girvanella).

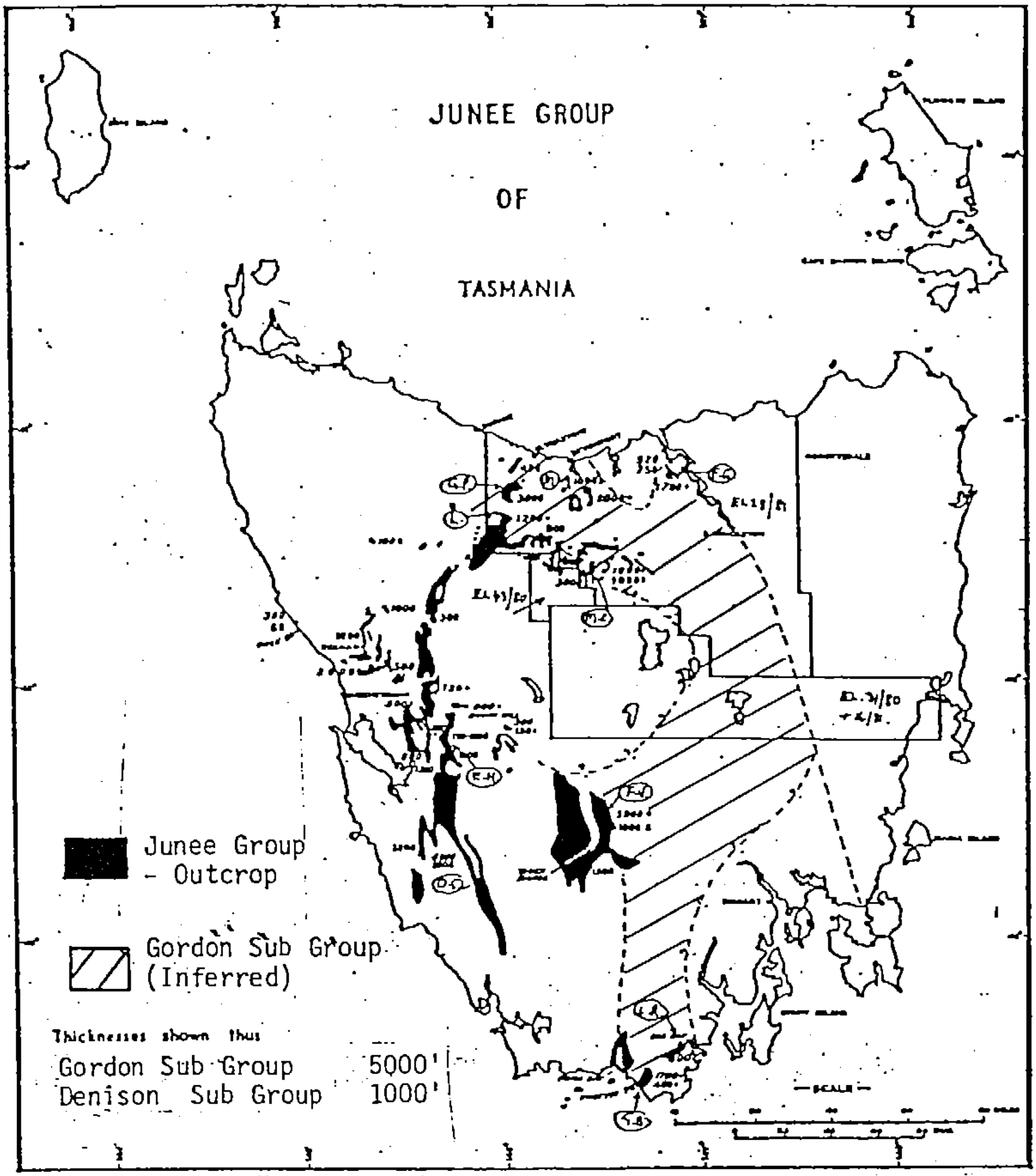

Fig. 1: Distribution of the Junee Group
Gordon Sub Group Localities shown as follows:

FG - Flowery Gully
M - Melrose
GP - Gunns Plains
MC - Mole Creek
L - Loongana
EH - Everlasting Hills
OS - Olga Synclinorium
FV - Florentine Valley
LR - Lune River
SB - Surprise Bay

5 cm

Gordon Sub Group (Contd.)

The Benjamin Limestone consists of approximately 1200m of dolomitic and stylolitic limestone of variable purity; several horizons rich in corals, stromatoporoids, sponges, cephalopods, brachiopods, and gastropods occur, and are considered by C.F. Burrett (pers. comm.) to represent possible back reefs. The limestones represented by these formations consist of supratidal dolomites, intertidal calcisilitites, and subtidal calcisiltites, calcarenites and shelly/coralline calcirudites. During Chazyan time (Cashion Creek Limestone) algal lawns were widespread across the state, and from Blackriveran through Trentonian to early Cincinnattian time (Benjamin Limestone) coral gardens/baffles became widespread.

The depositional environments for the Gordon Sub Group and the upper part of the Denison Sub Group were shallow water/platform. The youngest unit in the Junee Group is the Westfield Beds, consisting of approximately 150m of siltstone and sandstone overlying the Gordon Sub Group.

## 2:2 SILURIAN - DEVONIAN

### 2:2.1 Eldon Group

This group consists of formations of three major alternations of sandstone and siltstone, which, with minor limestone, ranges in thickness from 1800m to 2300m.

Thus the Crotty Quartzite is overlain by the Amber Slate, the Keel Quartzite by the Austral Creek Siltstone, and the Florence Sandstone by the Bell Shale.

The general cyclicity of sandstone alternating with siltstone also occurs within each of the major sandstone and siltstone units referred to above.

All Eldon Group lithologies were deposited under shallow marine conditions (including the siltstones); the greater coarseness and the higher sand : shale ratio of the Eldon Group in western Tasmania, imply a source area to the west of the state (Banks, 1962).

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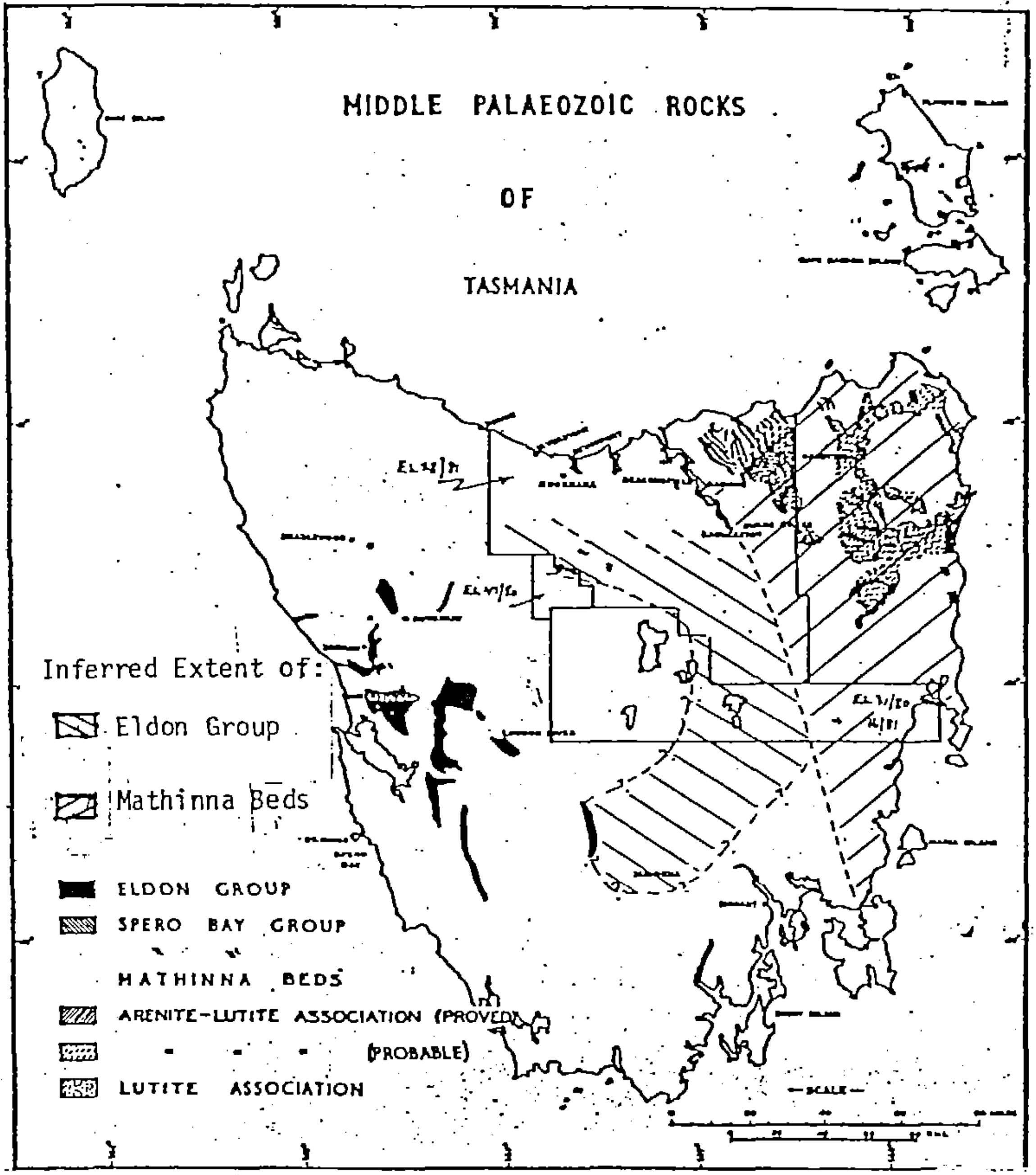
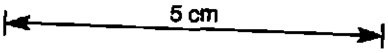


Fig. 2: Distribution of Eldon Group and Mathinna Beds



### 2.2.2 Mathinna Beds

The Mathinna Beds occur in N.E. Tasmania, and consist of more than 2400m of sandstone, siltstone, and mudstone (variably metamorphosed), which were deposited under deep water conditions. A crude twofold subdivision into a sandstone/greywacke - siltstone, and a mudstone association (now slate and phyllite) is recognisable. The age ranges from Ordovician to Devonian, and the sequence shows strong contrasts on faunal and sedimentological grounds with the rest of Tasmania. Banks (1962) postulated a facies change from shallow water shelf type deposition in western Tasmania to continental type deposition in N.E. and E. Tasmania; the margin of the continental shelf is inferred to occur in the vicinity of Flowery Gully. The Mathinna Beds are separated from the rest of Tasmania by a NNW trending transcurrent (?sinistral) fault known as the Tamar Fracture System (Williams, 1979).

## 2:3 CARBONIFEROUS- PERMIAN - TRIASSIC

### 2:3.1 Parmeener Super Group

The Lower Parmeener Super Group consists of the Lower Marine, Lower Freshwater and Upper Marine Sequences, with a total aggregate maximum thickness of 1300m (Williams, 1979).

The Lower Marine Sequence includes units such as the Wynyard Tillite, Quamby, Woody Island Siltstone, Darlington Limestone and Bundella Formations, and the Golden Valley and Masseys Creek Groups. Typical rock types are dark coloured siltstone and mudstone (often carbonaceous) with minor limestone, sandstone, conglomerate, and oil shale ("Tasmanite"). Uraniferous, pyritic black shales (some of which are oil shales) occur at Rossarden, and may represent marginal marine conditions at the junction of the Quamby Formation and the Basal Conglomerates in N.E. Tasmania.

The environment of deposition was medium to shallow depth marine, cold (as indicated by the Wynyard Tillite, glendonites and rare dropstones in the overlying formations), and anaerobic, as indicated by the abundant pyrite.

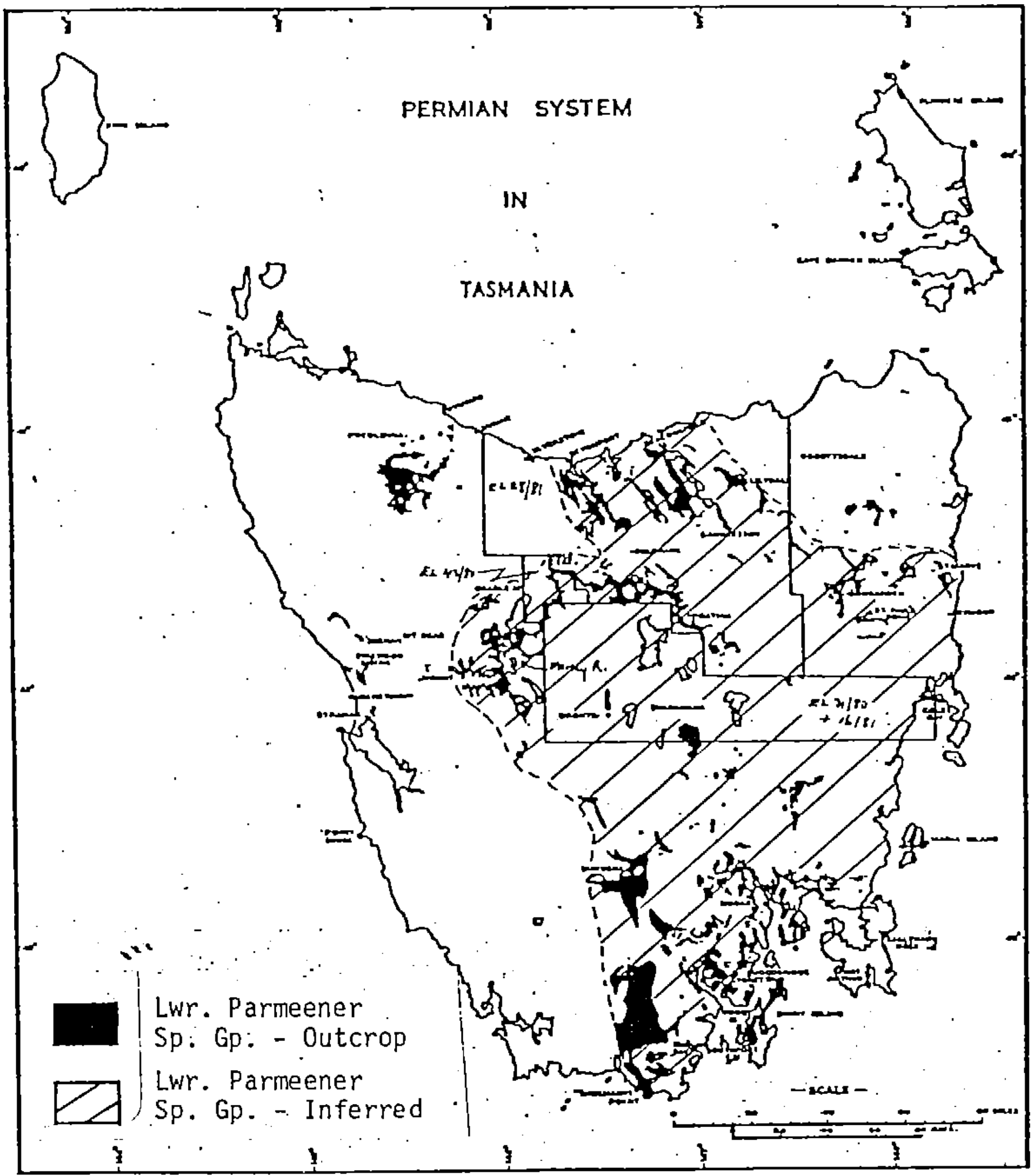


Fig. 3: Distribution of the Lower Parmeener Super Group

5 cm

TABLE 1

PARMEENER SUPER GROUP

Upper Parmeener Super Group (Upper Freshwater Sequence)

| 1:250,000 Map Sheet | Locality | Cygnet Coal Measures (m) | Ross Form'n (m) | Cluan Form'n (m) | Tiers Form'n (m) | Brady Form'n (m) | Total (m) |
|---|---|---|---|---|---|---|---|
| Hobart | - | ND | ND | ND | ND | ND | ND |
| Oatlands | (Poatina | 60 | 200 | 140 | 90 | 165 | 655 |
| | (Great Lake | ND | ND | ND | ND | ND | 580 |
| Launceston | Quamby | ND | ND | ND | ND | ND | 630 |
| Burnie | West.Bluff | ND | ND | ND | ND | ND | 365 |
| Queenstown | Cent. Plat. | ND | ND | ND | ND | ND | ND |
| | | | | | | Average: | 550 |

Lower Parmeener Super Group (Lower Marine, Lower Freshwater and Upper Marine Sequences)

| 1:250,000 Map Sheet | Locality | Lower Marine Sequence | | | | Lower Fresh-Seq. (m) | Upper Marine Seq. (m) | Total (m) |
|---|---|---|---|---|---|---|---|---|
| | | Tillite (m) | Silt/ms (m)* | SS/Silt/LS (m) | Sub Tot. (m) | | | |
| Hobart | Cygnet/ Glenorchy | 300 | 200 | 100 | 600 | 30 | 300 | 930 |
| Oatlands | Poatina/ Friendly Beaches | 105 | 90 | 60 | 255 | 110 | 280 | 645 |
| Launceston | Quamby | ND | ND | ND | 350 | 45 | 265 | 660 |
| Burnie | Wynyard/ West.Bluff | 490 | 135 | 60 | 685 | 36 | 260 | 981 |
| Queenstown | Central Plateau/ Florentine Valley | 45 | ND | ND | ND | ND | ND | ND |
| | Averages: | 235 | 142 | 73 | 472 | 55 | 276 | 804 |

(* Includes the Woody Island Siltstone and "Tasmanite" horizons)

Maximum Thickness preserved: 655 + 981 = 1636m ( ≃ 1.6m).
This contrasts with the figure given by Williams (1979) of 1930m.

The Lower Fresh-water Sequence includes the Mersey and Prelonna Coal Measures, with an average thickness of 30m. Typical lithogies are sandstone, carbonaceous siltstone and coal; oil shale and cannel coal occur near the top of the sequence, adjacent to the Malbina Formation.

The Upper Marine Sequence includes the Cascades Group, the Malbina Formation, Risdon Sandstone, Ferntree Mudstone and Poatina Group. Lithogies range from calcareous siltstone and limestone to siltstone and mudstone, with minor arkosic and glauconitic sandstone.

The environment of deposition was probably similar to that of Lower Marine Sequence, namely medium/shallow water shelf conditions; the climate was cool as indicated by rare glacial dropstones.

The Upper Parmeener Super Group consists of the Upper Freshwater Sequence with a total maximum thickness of approximately 650m (Williams, 1979). It includes the Cygnet Coal Measures, Ross, Cluan, Tiers and Brady Formations.

Lithogies range from quartzose to lithic sandstone, siltstone, carbonaceous to grey/green mudstone, to coal and acid/intermediate volcanics.

The environment of deposition was similar to that for the Lower Freshwater Sequence - continental and freshwater (lacustrine).

Parmeener Super Group localities and thicknesses are shown in Table 1, where it should be noted that the apparent maximum preserved thickness is approximately 1600m.

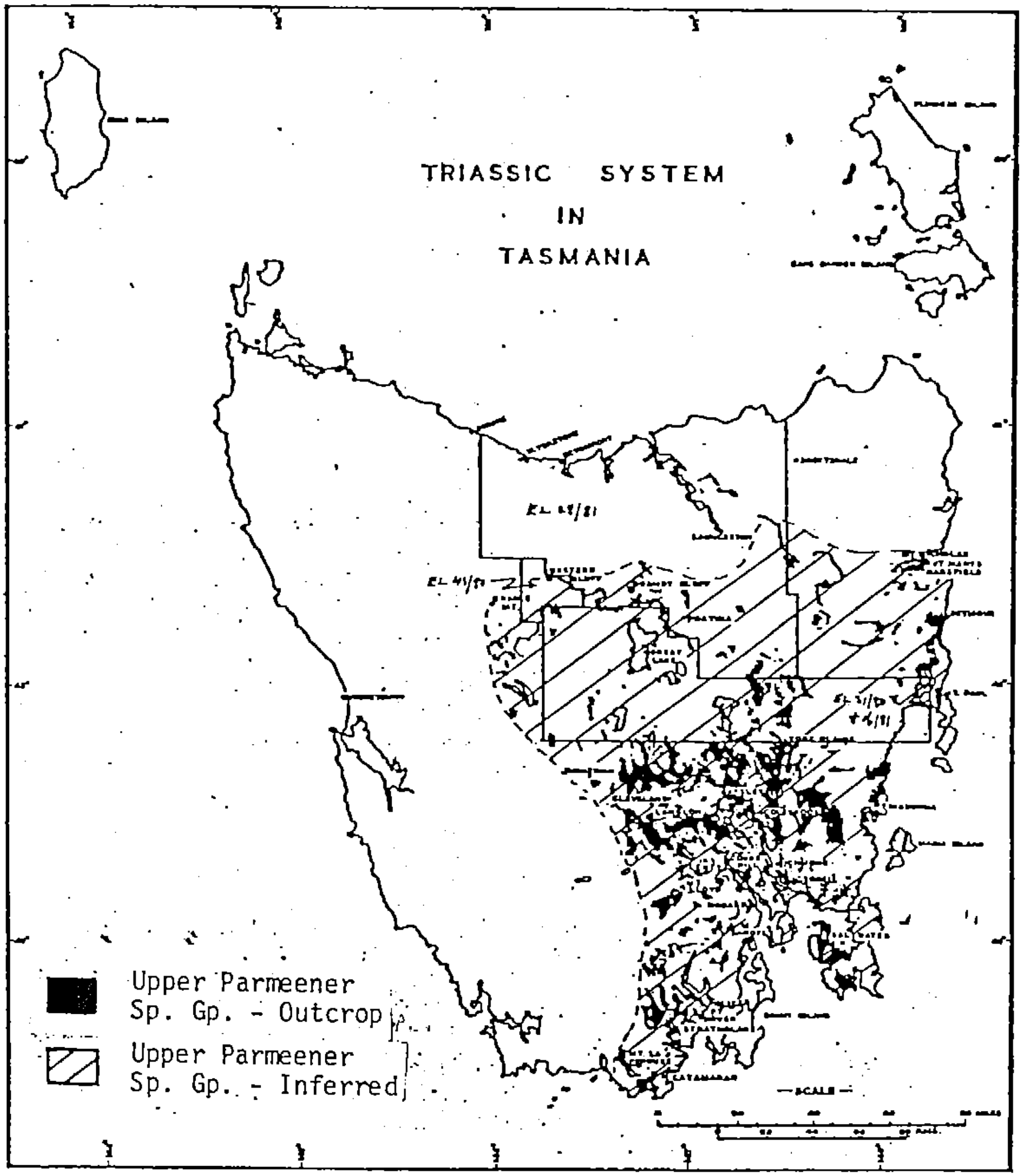
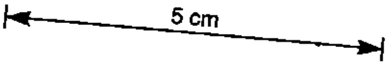


Fig. 4: Distribution of the Upper Parmeener Super Group



## 3:0 COMMENTS ON SOURCE ROCK TYPES

### 3:1 CARBONATE

3:1.1 Pure limestones are able to generate heavy oil with the requisite maturation conditions, and organic matter (OM) content. Impure limestones, containing more clay minerals (to act as Lewis Acid Catalysts) would modify the tendency to produce heavy oil (Hunt, 1979). The Karmberg Limestone contains ≃75-85% $CaCo_3$ while Cashions Creek Limestone contains ≃93% $CaCo_3$, and the Benjamin Limestone ≃ 85-90% $CaCo_3$.

3:1.2 Dark or brown coloured limestone/dolomite is generally a good source rock; most of the Karmberg, and some of the Cashions Creek and Benjamin Limestones are impure and argillaceous. Litho correlates of these units at Lune River (Summons, 1981), are similarly dark brown, with bituminous stylolites, disseminated pyrite, and with interbeds of carbonaceous phosphatic shale/siltstone. Bituminous stylolites are recorded from several localities in the Gordon Limestone (e.g. Railton, Deloraine).

3:1.3 Fine grained carbonate rocks generate more hydrocarbons from the same amount of total organic matter (TOM) than a clastic source rock, because limestones contain sapropelic OM (rich in algal/amorphous kerogen). These kerogen types have the highest H/C ratio, and thus the highest yield of petroleum of all the kerogens (Hunt, 1979).

The Gordon Limestone is essentially fine grained (micrites and calcisiltites) across the state, and this feature is important in maximizing the amount of associated OM within it.

3:1.4 Typical source beds were formed in low energy coastal marine environments, where clays and carbonates were deposited with 0.5-5% OM. The critical factor in preservation of the OM is the existence of toxic, anaerobic conditions. Sapropelic OM, which was formed in marine environments, is able to generate both oil and gas.

The Gordon Limestone was formed under shallow water, marine conditions (as discussed previously), and the frequent occurrence of pyrite in conjunction with the carbonaceous shales implies an anerobic and toxic environment.

3:1.5 A possible parallel of the Karmberg-Cashions Creek Limestones (Florentine Valley) and the Lower Sequence at Lune River exists in the lower part of the Marl Slate of N.E. England (Turner et al, 1978), where the sapropelic facies (laminated siltstone, dolomite and bitumen) is overlain by evaporite facies sediments. Details on the evaporitic nature of the Middle Sequence at Lune River were described by Summons (1981).

3:1.6 Catalytic cracking of hydrocarbons can be induced by salts of V, Mo, Ni (Levorsen, 1966); the black shales in the Gordon Limestone at Lune River are phosphatic, and anomalous in their content of Mo and Ni.

3:1.7 The association of oil brines with hypersaline dolomitizing brines responsible for the formation of the Mississippi Valley Type ore deposits has been noted by several authors, e.g. Hall and Friedman (1963), Hall and Heyl (1968), and Carpenter et al (1974).

Dolomitization of the Gordon Limestone has occurred at several localities, and a mechanism of transport of any oil that may have been generated may be envisaged.

## 3:2 CLASTIC

3:2.1 Catalytic cracking of hydrocarbons is a significant process in the generation of petroleum below $\approx 125^{\circ}C$ (Goldstein, in Hunt, 1979); typical naturally occurring catalysts are smectite clay minerals and zeolites. Levorsen (1966) cites an example of polymerization of propylene at $35^{\circ}C$ in response to natural catalyst bearing rocks.

The Lower Marine Sequence of the Parmeener Super Group is reported to contain altered glass shards in southern Tasmania and the Upper Marine Sequence (Cascades Group) contains beds of bentonite, (Banks, 1962). These occurrences are interpreted as indicating volcanism (possibly that recorded in N.S.W.), during the Permian, and the original presence of zeolitized tuffs may be inferred.

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The original presence of smectite clays in the Lower Marine Sequence is currently unknown, but the concept of smectite/zeolite initiated catalytic decomposition of OM may have been significant in view of the geothermal gradients estimated for the Permian in Tasmania.

3:2.2 Sapropelic OM is formed by decomposition and polymerization of spores and planktonic algae, and may be converted to one of the following with increasing maturation; boghead coal/oil shale, cannel coal, or oil. Sapropelic OM is known to occur in both the Lower and Upper Marine Sequences of the Parmeener Super Group as follows:

(a) The "Tasmanite" oil shale from N. and N.W. Tasmania (Quamby Formation) consists of a single celled alga named Tasmanites Punctatus, which has H/C ratio of ≒ 1.5, and an O/C ratio of ≒ 0.12.

As stated previously, sapropelic organic matter is the most productive generator of oil, because its kerogen constituents (algal, amorphous and herbaceous) can contribute H in the range of H/C from 1.7 - 0.30. Thus the "Tasmanite" oil shale may be viewed as representing the optimum type of source rock OM.

(b) Banks (1962) recorded oil shale and cannel coal from the top of the Mersey Coal Measures; however, it is equally possible that these occurrences of sapropelic OM occur at the base of the overlying Malbina Formation; similar comments (to those made for "Tasmanite" oil shale), apply as to the petroleum prospectiveness of this OM, given the necessary maturation conditions. The presence of cannel coal (world ave. H/C ≒ 1.0, O/C ≒ 0.11) suggests that it has progressed along the maturation pathway from the "Tasmanite" oil shale.

3:2.3 Radioactive elements may aid in the transformation of kerogen to petroleum through the action of alpha particle bombardment (Levorsen, 1966); however, the evidence for the significance and extent of such transformation is conjectural.

Uraniferous black shales occur beneath the Permian Basal Conglomerate (and possibly in the Quamby Formation) at Rossarden.

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## 4:0 GEOTHERMAL HISTORY

The geothermal history of a basin involves an analysis of the time intervals during which the sediments were subjected to various temperatures. It represents the optimum mode of evaluating hydrocarbon generation in a basin, providing reasonable palaeo temperatures can be established.

The three main optical organic metamorphism indices are vitrinite reflectance,palynomorph colour change (Thermal Alteration Index - TAI), and conodont colour change (Colour Alteration Index - CAI). The colour and preservation of palynomorphs is a function of the thermal alteration (Staplin, 1969), but it is only recently that Epstein et al (1977) and Harris (1979) have demonstrated that the conodont colour is similarly temperature dependant. These authors have correlated colour changes with the amount of fixed C in the conodonts and the host sediments; the conodonts darken with increasing temperature as a result of carbonization of the OM in the inter lamellar spaces. Further indications of the potential of using CAI values were summarised by Harris (1979) as follows:-

(a) Conodont colour alteration is progressive, cumulative and irreversible.

(b) The colour alteration is dependant on time and temperature, but is independent of pressure.

(c) An Arrhenius plot of experimental and field data indicate that colour alteration of conodonts ranges from 50-450°C.

(d) Time is of minor importance for CAI values in rocks older than 50 million years.

(e) The 6 CAI values can be correlated with vitrinite reflectance, translucence photometry,and chemical analyses.

## 5:0 PALAEO - GEOTHERMAL GRADIENTS

### 5:1 Gordon Sub Group

Burrett (1978) showed that CAI values in the Gordon Limestone vary considerably across the state, outlining an arcuate trend around the Precambrian blocks of central Tasmania. This arcuate trend follows Cambrian volcanics and lower Palaeozoic synclinoria, which both fringe and overlie the Precambrian blocks (Cradle Mtn., Prince of Wales blocks).

The Cambrian volcanics (which host the major base metal orebodies of Mt. Lyell, Rosebery, etc.), have been interpreted as an island arc adjacent to an east plunging subduction zone (Solomon and Griffiths, 1974), and more recently as a rift valley-caldera structure by Corbett (1979).

The zone of darkest Ordovician conodonts (Flowery Gully, Melrose, Loongana, Everlasting Hills, Olga synclinorium), coincides with a belt of thinned Cambrian crust (represented by the Mt. Read Volcanics, Dundas Group, etc.), and a belt of maximum deformation in Gordon Sub Group localities. The Cambrian geothermal gradient would have been appreciably higher within this region of thinned crust, and assuming this region was not underlain by Precambrian crust, high heat flows would have occurred in post-Cambrian times.

The corallary to this interpretation is that post-Cambrian rocks, floored by Precambrian crust, would have been relatively insulated from the postulated high heat flow values within the Cambrian volcanics.

Table 2 depicts CAI, change ($\Delta$) in temperature, thickness and geothermal gradients ($\beta$ ) for the Gordon Limestone. No gradients appear to have existed across the Gordon Limestone at Flowery Gully, Melrose, Gunns Plains and Everlasting Hills as indicated by the CAI values. The Gordon Limestone in these areas was heated to $\geqslant 300^{\circ}$C, and a consideration of the maximum depth of burial by post-Ordovician rocks implies the presence of abnormally high geothermal gradients. A high, post-Ordovician (probably middle Devonian) heat flow is assumed for W. and N. Tasmania for the following reasons:

(i) In several localities (referred to previously), the "normal" geothermal gradient due to depth of burial (with attendant increase in temperature), does not exist, suggesting that it has been obscured by another source of thermal energy. The lowest CAI values in, and the lowest geothermal gradients across, the Gordon Limestone occur in those areas floored by Precambrian crust; other areas marginal to the Cambrian volcanics (e.g. Mole Creek, Olga River) have intermediate geothermal gradients.

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TABLE 2

## ORDOVICIAN (GORDON SUB GROUP) SAMPLES

| Locality | C.A.I. | | Min. $\Delta$Temp. (°C) | Max. $\Delta$Temp. (°C) | Thickness (km) | | $\beta$ Min. (°C/km) | $\beta$ Max. (°C/km) |
|---|---|---|---|---|---|---|---|---|
| | Base | Top | | | Present | + 35% | | |
| Flowery Gully | 5 | 5 | - | - | 0.47 | 0.72 | - | - |
| Melrose | 5 | 5 | - | - | ?0.25 | ?0.39 | - | - |
| Gunns Plains | 4 | 4 | - | - | 0.90 | 1.39 | - | - |
| Loongana | 5 | 4 | 100 | 210 | 0.65 | 1.00 | 100 | 210 |
| Mole Creek | 5 | 3 | 100 | 290 | 1.30 | 2.00 | 50 | 145 |
| Mole Creek* | 4 | 3 | <80 | 190 | 1.30 | 2.00 | <40 | 95 |
| Bubs Hill | 5 | 3 | 100 | 290 | 0.35 | 0.54 | 185 | 537 |
| Everlasting Hills | 5 | 5 | - | - | 0.25 | 0.39 | - | - |
| Olga River | 5 | 4 | <100 | 210 | 1.50 | 2.31 | <43.3 | 90.9 |
| Florentine Valley | 4 | 2 | 50 | 240 | 1.70 | 2.62 | 19.1 | 91.6 |
| Lune River | 2 | 1 | 20 | 90 | >0.70 | >1.08 | <18.5 | <83.3 |
| Average Mole Creek* and Olga River: | | | | | | | 41.6 | 92.9 |
| Average Florentine Valley & Lune River | | | | | | | 18.8 | 87.4 |

NB:

(i) CAI - *Conodont Colour Alteration Index*

(ii) Thickness recalculated to allow for volume reduction due to pressure solution (diagenetic and tectonic stylolites).

(iii) $\beta$ - Geothermal gradient within Gordon Limestone, before volume reduction (shortening). The $\beta$ values shown here are reproduced as $\beta_o$ values in Table 4.

(iv) CAI data from Burrett (1978), and change in temperature ($\Delta$) from Harris (1979).

(ii) Lower Devonian conodonts, in rocks which were unlikely to have been buried to any appreciable depth, have been metamorphosed (Burrett, 1978).

(iii) The K-Ar ages of late Devonian granite have not been reset by heat induced leaking of Ar; however, the K-Ar ages of late Cambrian granites have been reset to Ordovician ages (McDougall and Leggo, 1965), presumably by Devonian heating.

Thus the best estimates of the "normal" (due to depth of burial alone), geothermal gradient across the Gordon Limestone, are the values indicated for Florentine Valley and Lune River (Table 2), which range from 19°C/km to 87°C/km, with an average of 53°C/km.

The average of the Mole Creek (less altered sample) and Olga River samples indicates a geothermal gradient of 42-93°C/km and an average of 67°C/km. Inclusion of the more altered sample from Mole Creek indicates an average value for the two areas of 77°C/km.

The CAI values for Flowery Gully, Melrose, Gunns Plains and Everlasting Hills indicate heating to > 300°C for the entire Gordon Limestone, which compares with temperatures of ≃ 200°C and ≃ 80°C at the top of the Gordon Limestone, in the Mole Creek/Olga River, and Florentine Valley/Lune River areas respectively.

If it is assumed that the rocks overyling the Gordon Limestone were similar in thickness and thermal conductivity, and that the Gordon Limestone had approximate constant thermal conductivity, then temeprature is proportional to heat flow; accordingly, the CAI data imply that the Devonian heat flow (relative to Florentine Valley/ Lune River), was 150% and 275% higher in the Mole Creek/Olga River and Flowery Gully, etc. areas respectively.

## 5:2 Parmeener Super Group

Harris (1981) examined samples collected by Victor Exploration Pty. Ltd. staff from several localities in the Lower Marine Sequence of the Parmeener Super Group. AMDEL (1981) analysed 10 out of 12 samples collected, and Harris (1981) was only able to find herbaceous kerogen in 5 of the 10 samples, and consequently, could only assign reliable TAI values to half the samples. This data is shown in Table 3, which also depicts change in temperature, thicknesses, and geothermal gradients for the Parmeener Super Group and Jurassic dolerite.

Although it is not possible to construct TAI isograds from the limited number of samples, it is apparent that those samples collected from the N.W. of the state (Bronte, Mersey River)show higher thermal maturity than those elsewhere in the state (Poatina, Quamby Brook, Maydena). Inclusion of the 5 samples devoid of kerogen (and assuming the inferred TAI values are valid), generally enhances the thermal maturity pattern described above, the exception being the Poatina Power Station sample, the true location of which cannot be determined.

This pattern may be a reflection of a relict, high Devonian heat flow as discussed previously.

Similarly to the Gordon Limestone samples, the problem in determining the "normal" geothermal gradient during Permian and subsequent time appears to be one of screening out the effects of high heat flow; accordingly, the best estimate of the "normal" geothermal gradient can be obtained from the Maydena/Styx River area (Sample 12A), which ranges from 28-50°C/km, and has an average of 39°C/km. The Quamby Brook - Poatina areas range from 32-70°C/km (average 57°C/km.).

Although the number of useful (herbaceous kerogen bearing) samples is inadequate to permit statistically reliable conclusions to be made about the thermal history of the Parmeener Super Group, the following observations may be of possible significance:

TABLE 3

## PERMIAN SAMPLES

| Sample | Locality | TAI | Min.Δ Temp (°C) | Max Δ Temp (°C) | Thickness | | | $\beta$ Min. (°C/km) | Max. $\beta$ (°C/km) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | PSGp | Dol. | Total | | |
| 4/6 | Mersey River | (4) | - | - | - | - | - | - | - |
| 5 | Mersey River | 3 | 100 | 155 | 0.86 | 0.50 | 1.36 | 73.5 | 114.0 |
| 7 | Bronte | 3 | 100 | 155 | 1.20 | 0.50 | 1.70 | 58.8 | 91.2 |
| 11 | King William Saddle | (4) | - | - | - | - | - | - | - |
| 12 | Styx River | (4) | 155 | 200 | 1.30 | 0.70 | 2.00 | (77.5) | (100.0) |
| 12A | Styx River | ≃2 | ≃50 | ≃90 | 1.10 | 0.70 | 1.80 | 27.8 | 50.0 |
| 1 | Hobart | - | - | - | - | - | - | - | - |
| 2 | Quamby Brook | 2 | <40 | 100 | 1.29 | 0.50 | 1.79 | <22.3 | 55.9 |
| 3 | Poatina | (4) | 155 | 200 | 1.20 | 0.50 | 1.70 | (91.2) | (117.6) |
| 8 )<br>9 )<br>) | Poatina )27m<br>HEC DDH )<br>5021 )242m | 2)<br>)<br>3) | ≪ 30 | 60 | 0.22 | 0.50 | 0.72 | <41.7 | 83.3 |
| | Average for W. Tasmania (Samples 5,7) | | | | | | | 66.1 | 102.6 |
| | Average for N.E. Tasmania (Samples 2,8,9) | | | | | | | 32.0 | 69.6 |
| | Apparent oil threshold (Maydena, Sample 12A) | | | | | | | 27.8 | 50.0 |
| | Average for S. and N.E. Tas. (Samples 12A, 2, 8, 9) | | | | | | | 30.6 | 63.1 |

NB: (i) TAI - Thermal Alteration Index; values in brackets are estimates only, as the samples did not contain any herbaceous kerogen.

(ii) PSGp - Parmeener Super Group thickness from the top of the Wynyard Tillite, except for sample 12A, for which the thickness was taken from the top of the Woody Island Siltstone correlate.

(iii) Sample 12A is from the Woody Island Siltstone correlate, Maydena.

(iv) Maydena section (above Wynyard Tillite) taken as 630m. (lwr. PSGp), 640m. (upper PSGp) and 700m. (J. dolerite). The section above the Woody Island Siltstone correlate excluded this unit (200m).

(v) $\beta$ - Geothermal gradient, calculated assuming a ground temperature of 10°C. The $\beta$ values shown here are reproduced as $\beta_2$ values in Table 4.

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TABLE 4

## ESTIMATED GEOTHERMAL GRADIENTS (ORDOVICIAN - JURASSIC) - TASMANIA

| Locality | Thickness (k/m) | | | | Ave. Geothermal Gradient (°C/km) | | | |
|---|---|---|---|---|---|---|---|---|
| | Dolerite | PSGp | E.Gp. | Og. | | | | |
| Quamby/Poatina Mole Creek | 0.5 | 1.3 | <1.0 | 1.3 | 51 | >52 | <68-69 | 57-67 |
| Olga River | (0.5) | (1.5) | 2.0 | 1.5 | (75) | (59) | 67 | (61) |
| Maydena/ Florentine Valley | 0.7 | 1.6 | 2.0 | 1.7 | 39 | 21 | 55 | 31 |
| Lune River | 0.5 | 1.6 | (-) | >0.7 | 39 | 19 | < 51 | < 27 |
| | | | | Average for Sthn. Tasmania: | 39 | 20 | 53 | 29 |

NB: (i) PSGp - Parmeener Super Group (Including Wynyard Tillite).

(ii) E. Gp. - Eldon Group (Silurian - Devonian).

(iii) Og - Gordon Sub Group (Ordovician)

(iv) Geothermal gradients, $\beta$ =

$\beta_2$ = Average geothermal gradient across dolerite + PSGp to the top of the Wynyard Tillite.

$\beta_1$ = Average geothermal gradient across dolerite, PSGp (total) and E.Gp.

$\beta_o$ = Average geothermal gradient across Og (Original thickness).

$\beta_T$ = Average geothermal gradient from dolerite to the base of Og (present thickness).

(v) The original thicknesses of dolerite and PSGp in the Olga Synclinorium are unknown, and are assumed to have been similar to the Bronte data, with 300m. of Wynyard Tillite. Similarly, the $\beta_2$ value was taken as the Bronte value; accordingly, the $\beta_1$, $\beta_o$, and $\beta_T$ values for the Olga River, are only very approximate, although the $\beta_1$ and $\beta_T$ figures are notably similar to those for the Quamby/ Poatina/Mole Creek area.

(i) The geothermal gradient across the Gordon Limestone in the Mole Creek/Olga River areas was ≃ 26% higher than the gradient in the Florentine Valley/Lune River areas.

(ii) The geothermal gradient in the Mesozoic in the Quamby Brook/Poatina areas was ≃ 30% higher than the gradient at Maydena.

All palaeo-geothermal data is shown in Table 4, which was compiled from Tables 1, 2 and 3, and from Figure 1.

## 6:0 MODERN GEOTHERMAL GRADIENTS

Surface heat flow (Q) is measured in units of W/m$^2$, and related to thermal conductivity ($\lambda$ , in units of W/m/$^o$C) and the geothermal gradient ($\beta$ , in units of $^o$C/m) by the expression $Q = \lambda\beta$.

Currently, Tasmania has an abnormally high heat flow which is approximately twice the world average of 60mW/m$^2$. Evidence for this comes from the work of Newstead and Beck (1953), Jaeger and Sass (1963), Wronski (1977), Lilley, Sloane and Sass (1977), Cull (1979), Cull and Denham (1979), and Nicholas, Rixon and Haupt (1980).

Lilley et al (1977) produced a heat flow map for Australia, and reported the following Q values (in mW/m$^2$) for Tasmania:

Rosebery (Cambrian schist) = 120
Glenorchy (Parmeener Super Group - Cambrian Volcanics) = 87
Storeys Creek (Mathinna Group Sediments) = 150
Central Plateau (dolerite) = 75 - 100

There are no known measurements of heat flow in granitic rocks in the state.

Cull (1979) assigned eastern Tasmania to the Eastern Australian Heat Province, while Cull and Denham (1979) observed that the heat flow anomalies in Tasmania were apparently unrelated to surficial deposits of uranium; they reported the heat flow in Tasmania to range from 85-110mW/m$^2$.

The majority of the geothermal gradients measured in Tasmania are in excess of 30°C/km (D.C. Green, pers. comm.). Nicholas et al (1980) produced an uncorrected geothermal map of Australia, and reported the measurements of geothermal gradients from 5 Bass Basin oil wells, which averaged 35°C/km.

However, corrections for mud circulation effects (cooling) in the holes were not applied (+10, +14%, D.C. Green, pers.comm.), nor were corrections for climatic controls, as discussed by Cull (1979). Cull observed that variations in the geothermal gradient were caused by surface warming following the retreat of the Pleistocene glaciers in Southern Australia, and estimated positive corrections of 10-25% for all geothermal data obtained from depths of $<$ 300m.

Assuming that the Bass Basin oil well measurements were made at depths $>$ 300m., the only correction to be made to the data is that for mud circulation, i.e., the geothermal gradient in Bass Basin is approx. 35+10% to 35 +14%°C/km, which is approximately 40°C/km. Thus the present geothermal gradient for Tasmania would appear to range from 30-40°C/km.

The generally higher heat contents of granite rocks is a function of the concentration of naturally radioactive elements (K, U, Th) which are concentrated in the upper portion of the earth's crust, and contribute $\geqslant$ 50% of the heat flow measured at the surface.

In a recent gamma ray survey of granite rocks in Tasmania conducted by the Geological Survey of Tasmania and the B.M.R., by Collins, Wyatt and Yeates (1981, in press), the granites were found to be areas of high heat productivity with $U \leqslant 25$ppm, and $Th \leqslant 50$ppm. These values are clearly elevated from the world averages for granite of $U \simeq 5$ppm and $Th \simeq 17$ppm (Levorsen, 1974).

The high heat flow in the Tasmanian crust is probably due to two factors:-

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(i) The abundance of granitic rocks, as indicated by gravity surveys (Leaman, Richardson and Shirley, 1980), with apparently anomalous levels of U and Th as discussed above.

(ii) The combinations of thin crust overlying abnormally hot, conductive mantle. Electric conductivity anomalies in Bass Strait and northern Tasmania were reported by Lilley (1976). Sutherland (1981) postulated that northward migration of Australian continental plate has controlled volcanism in Queensland, New South Wales, Victoria and Tasmania, from the start of the Tertiary period 55 million years ago (i.e. the Gondwanaland break up). He suggests that volcanism has occurred as the Australian plate passed over a fixed mantle magma source ("hot spot"), and that the present heat flow anomalies are due to magmatism (crust/mantle), and extension of the crustal plate.

Further discussion on the high heat flow in Tasmania is made in the Appendix.

## 7:0 POTENTIAL OIL SOURCE ROCKS

### 7:1 GORDON SUB GROUP

The Gordom Limestone is fine grained, often dark coloured, impure/ argillaceous, and frequently has bituminous stylolites. The most likely source rocks would be the Karmberg and Cashions Creek Limestones (or their correlates), particularly the algae rich Cashions Creek limestone. Beds of pyritic, carbonaceous shale/siltstone imply the requisite toxic, anaerobic conditions existed for the preservation of organic matter.

The type and amount of OM is not known, but it can be predicted as being sapropelic.

Although pure limestones have a higher threshold temperature for petroleum generation than clastic source rocks, the impure nature of the Gordon Limestone, and the Mo, Ni bearing carbonaceous phosphatic shales would offset this effect.

The geothermal history of the Gordon Limestone varies considerably across the state; lowest geothermal gradients occurred in the south, and highest in the west and north west. The low values are believed to be representative of the normal geothermal gradient in those regions underlain by Precambrian crust.

The effect of these Ordovician geothermal gradients in terms of generation of hydrocarbons has to be viewed in context of the total sequences in given areas, as shown in Figure 1.

The optimum generation of petroleum from Gordon Limestone potential source rocks would have occurred in Southern Tasmania (based on present data - the thermal history of the inferred Gordon Limestone in eastern Tasmania is currently highly speculative.

Using the 60-150$^{o}$C temperature interval to represent the interval of oil generation, and 150-200$^{o}$C to represent the interval of gas generation (from Hunt,1979), the following observations can be made:-

7:1.1 Florentine Valley - Oil would have been generated from the Benjamin and possibly the Cashions Creek Limestones, and gas from the Karmberg Limestone.

7:1.2 Lune River - Oil would have been generated from the basal portion of the Middle Sequence, and all of the Lower Sequence (which includes an algae rich litho correlate of the Cashions Creek Limestone).

7:1.3 Mole Creek - Mainly gas, with very minor oil, would have been generated from the upper half of the sequence. Other areas of Gordon Limestone in the state appear to have been very hot, and any organic matter present wouldhave been metamorphosed to pyrobitumen; however, minor gas occurrences may be present.

## 7:2 PARMEENER SUPER GROUP

### 7:2.1 Lower Marine Sequence

This sequence is one of fine grained, dark coloured (often carbonaceous), pyritic clastics, with minor sandstone and limestone; it is variably fossiliferous, and toxic, anaerobic conditions are implied by the pyritic, carbonaceous nature of the sediments (i.e. preservation of organic matter). The nature and amount of OM is not known with a high level of statistical significance, but of 12 samples analysed by AMDEL (1981) and examined by Harris (1981):-

(i) The clastic samples (11) contained an average of 0.74% TOC, and the only carbonate sample contained 0.44%TOC.

(ii) The clastic samples contain sapropelic kerogen in the range 30-95%, averaging 58%; coaly kerogen averages 40%, which is in contrast to the comments made by Harris (1981).

(iii) The clastic samples contain EOM in the range 44-192 mg/gTOC, averaging 96 mg/gTOC.

(iv) Only half the clastic samples contained herbaceous kerogen, so that only half the samples have reliable TAI values.

Clastic source rocks generally require > 0.4% TOC (Hunt, 1979) and carbonate source rocks require > 0.2% TOC (Ruth and Cooper, 1976). Extractable organic matter (EOM) in source rocks should be > 150mg/g TOC (Tissot et al, 1974) or > 200 mg/g TOC (Ruth and Cooper, 1976), although the latter authors observed that a significant quantity of EOM is insufficient by itself to identify a source rock.

Liquid hydrocarbons have recently been discovered by M.C. Forster and R. Hine in the Woody Island siltstone Formation correlate at Maydena. A single sample from this locality contained 1.19% TOC, 80% sapropelic kerogen, and 192 mg/g TOC of EOM; the sample was assigned by TAI value of 4 by Harris (1981), but did not contain herbaceous kerogen.

Liquid hydrocarbons have also recently been located (M.C. Forster, pers.comm.) at Poatina and at the head of the Mersey River; the Poatina sample contained 0.62% TOC, 70% sapropelic kerogen, 122 mg/g TOC of EOM, and has a TAI value of 4; the Mersey River samples average 0.85% TOC, 58% sapropelic kerogen, 91 mg/g TOC of EOM, and have TAI values of 3 and 4.

However, all these TAI values of 4 are not based on palynomorph colours, and are enigmatic in view of the apparent source nature of the rocks. Alternatively, if the TAI values are reliable, it suggests the rocks sampled are reservoirs, although the other source rock parameters (TOC, EOM, etc.) indicate them to be a source rocks (particularly the Woody Island Siltstone Correlate at Maydena). The Mersey River sample with the TAI value of 3 seems a plausible indication of a source rock from which petroleum has been produced. Oxidation and irradiation of palynomorphs may also complicate the interpretation of TAI values.

Oil shale ("Tasmanite") occurs in the north of the state near the base of the Quamby Formation; oil shale is also known at Rossarden (probably the Quamby Formation). The inter relationships between the "Tasmanite" oil shale, other oil shales and the petroleum occurrences, in the Lower Marine Sequence are not known at present, and a knowledge of such relations appears imperative to the understanding of the hydrocarbon potential.

NB: TOC: Total Organic Carbon

### 7:2.2 Upper Marine Sequence

This sequence is one of limestone, mudstone, siltstone and sandstone; on present knowledge, the sequence as a whole would not appear as prospective for source rocks as the Lower Marine Sequence. Potential source rocks appear restricted to the carbonaceous mudstones and the impure limestones.

Oil shale and cannel coal occur at the interface of the Mersey Coal Measures and the Malbina Formation. No analytical data is available for these concentrations of ?sapropelic organic matter; however, the presence of cannel coal suggests a higher level of maturation than the "Tasmanite" oil shale.

The significance of this occurrence of sapropelic OM apparently much younger than the Woody Island Siltstone Formation - "Tasmanite" oil shale horizon has yet to be thoroughly evaluated.

The geothermal history of the Parmeener Super Group (similarly to the Gordon Limestone) varies considerably across the state; lowest geothermal gradients occur at Quamby Brook, Poatina and Maydena, and highest values occur in the Bronte and Mersey River areas. Similarly to the Gordon Limestone, the minimum geothermal gradients are believed to represent the "normal" values while the higher gradients may reflect a relict high Devonian heat flow.

The effect these geothermal gradients had on the generation of hydrocarbons can be elucidated from Figure 1. Values range from 39$^{o}$C/km (Poatina, Maydena) to 62$^{o}$C/km (Poatina) and 84$^{o}$C/km (average for Bronte and Mersey River). Using the data in Table 3, it is apparent that most of the occurrences of the Lower Marine Sequence have undergone the requisite maturation histories for petroleum generation. This observation may explain the "petroliferous odour" noted in the Mersey River, Poatina and Maydena localities, the apparent exceptions being the Bronte, King William Saddle and Poatina drill hole No. 5021 localities. The apparent lack of liquid hydrocarbons in these areas may be the result of the ratio of sapropelic to humic kerogen, or the result of the samples being overmature.

Hunt (1979) observed that the yield of hydrocarbons per volume of sediments is higher in basins of high heat flow. The oil present in the Woody Island Siltstone Formation Correlate at Maydena appears to have been generated in the temperature interval 80-90°C.

An interesting feature of the geothermal gradients shown in Figure 1 concerns the gradient across the Wynyard Tillite and the Eldon Group, which is very slightly positive to markedly negative; this may be due to the following:

(i) A high thermal conductivity of the sandstone rich Eldon Group, or,

(ii) A positive geothermal gradient across the Eldon Group which was cancelled by a negative gradient across the Wynyard Tillite, or,

(iii) An inflated figure for the thickness of the Eldon Group in the Florentine Valley area, and conversely a deflated figure for the thickness of Eldon Group in the Lune River area. If this interpretation is correct, it would modify the hypothesis advanced concerning hydrocarbon generation (potential) in the Gordon Limestone at Lune River.

## 8:0 POTENTIAL OIL RESERVOIR ROCKS

### 8:1 Gordon Sub Group

As mentioned previously, the Gordon Limestone is generally fine grained (micritic), a feature which would have assisted diagnetic calcite cementation so that the present intergranular porosity would be ≪ 2%. As the micrite facies of the Gordon Limestone seldom contain < 2% of acid insoluble residue (AIR), some compaction would have occurred.

Impure limestone (eg. Karmberg) with an estimated composition of ≪ 85% $CaCo_3$ and 5-10% AIR (clay minerals, chert) would experience fluid losses through compaction, thus enabling primary migration mechanisms to operate. Other evidence of inferred migration mechanisms comes from those sections of Gordon Limestone which have been dolomitised. Potential reservoirs in the Gordon Limestone appear limited to coral reefs, and those areas of secondary (granular) dolomite. Coral gardens were common from Blackriveran to Cincinnattian time, but no authentic bioherms have yet been found.

The presence of an Ordovician continental slope has been inferred east of Flowery Gully, where Mathinna Group rocks overlie Gordon Limestone; more recently (C.F. Burrett, pers.comm.) the discovery of a deep water facies of the Gordon Limestone at Surprise Bay, has led to the recognition of a continental slope in the south of the state.

The base of the Gordon Limestone is strongly diachronous, and the Ordovician sea is inferred to have advanced over the Tyennan Geanticline in a generally westward direction. C.F. Currett (pers.comm.) postulates that the coralline facies at the top of the Benjamin Limestone in the florentine Valley was a back reef, with a yet to be discovered fore reef to the east; M.R. Banks (pers.comm.) believes the Ordovician sea contained several islands (e.g. Vale of Rasselas, Glenorchy). Thus a model may be envisaged whereby the Ordovician continental slope extended south from Flowery Gully along what is now the Tamar Fracture System (itself activated in Carboniferous time) and south west to Surprise Bay.

Deposition of Gordon Limestone west of this line would have been under shallow water platform conditions, possibly with fore reefs which would have migrated west (landward) in the westward transgressing sea.

Secondary dolomites are known from several places in the Gordon Limestone; at Lune River secondary dolomite was formed by the action of hypersaline brines which originated in supratidal facies limestone during diagenesis; this dolomite is porous and vuggy, but no details of its intergranular porosity are known.

### 8:2 Eldon Group

This group consists of alternating sequences of sandstone and siltstone with minor limestone; it has a high sand : shale ratio and should be viewed as hosting potential reservoirs. No data on its intergranular porosity is available at present.

### 8:3 Parmeener Super Group

Mention has already been made of the smectitic nature of some of the clays in this group; the dehydration of smectite to illite provides extra pore water for migration mechanisms. Possible reservoir rocks include:-

(i) Lower Marine Sequence - Darlington Limestone and the basal conglomerates.

(ii) Lower Freshwater Sequence - Mersey Coal Measures.

(iii) Upper Marine Sequence - Malbina Formation, Risdon Sandstone.

(iv) Upper Freshwater Sequence - Cygnet Coal Measures, Ross Sandstone.

No data on intergranular porosites is known; the Woody Island Siltstone correlate at Maydena may be a reservoir as a function of its microfracture porosity.

# APPENDIX

## GEOTHERMAL ENERGY

The use of geothermal energy is relatively modern, and it differs from conventional energy sources (fossil fuels, uranium) in that it may be directly utilized without prior combustion or fission.

Three types of geothermal systems are commercially operative or feasible, namely vapour dominated systems, and liquid dominated systems of both high and low enthalpy (natural circulation).

Extraction of geothermal energy from hot, dry granite is currently being investigated at Fenton Hill, New Mexico, U.S.A.; the technique used involves drilling to depths where the temperature is >160°C, and then creating an artificial fracture system through which water is circulated, and the thermal energy recovered by heat exchangers, or by using the steam produced as a result of the method.

A similar program of research is being undertaken on granites in Cornwall, U.K., which have heat productivities of similar and lesser magnitude to the five areas of hot dry geothermal energy outlined by Collins et al (1981, in press) in Tasmania.

The Tasmanian Government has approved the drilling of a geothermal test hole at Coles Bay, but is unable to provide finance for the program.

It is apparent that in an increasingly energy short world alternative energy forms will assume greater significance. On present indications, the geothermal energy available in Tasmania is comparable and possibly superior to that elsewhere, and its future utilization should be given serious consideration.

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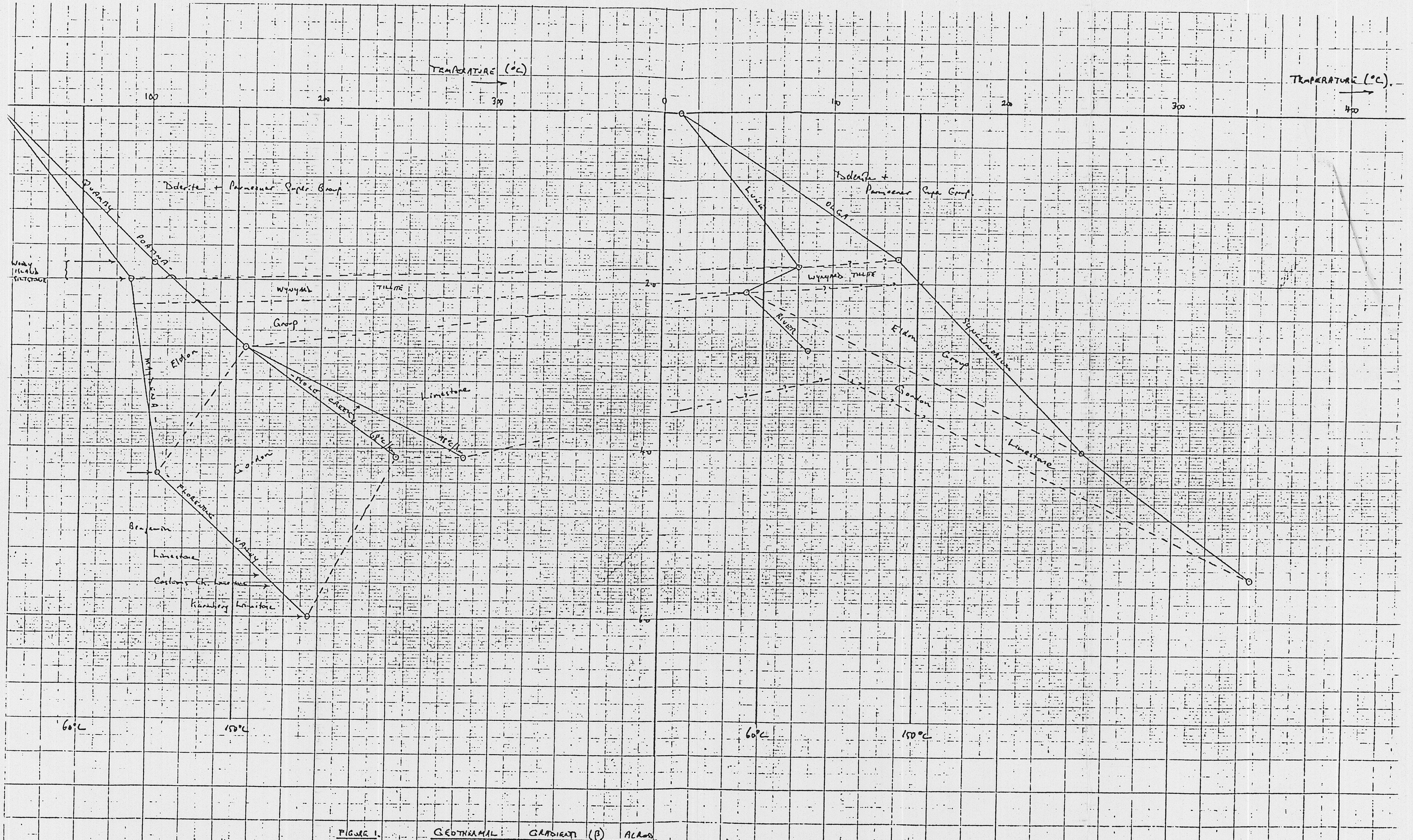

FIGURE 1. GEOTHERMAL GRADIENTS (β) ACROSS DOLERITE - PARMEENER SUPERGROUP - ELDON GROUP - GORDON SUB GROUP TASMANIA.

T.R. SUMMONS.
AUGUST 1981.

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Appendix Z

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PETROLEUM CONSULTING SERVICES

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# AN EVALUATION
# OF THE OIL AND GAS POTENTIAL
# OF TASMANIA

PREPARED FOR

CONGA OIL PTY LTD

BY

QUESTA AUSTRALIA PTY LTD

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FOR DISCUSSION PURPOSES
ONLY

Report 092- 45
May 1992

## INTRODUCTION

The presence of commercial volumes of oil and gas in the subsurface in Tasmania is entirely conjectural, with many of the prerequisite elements which constitute a valid hydrocarbon province not fully verified. Many observers and geoscientists remain skeptical about the possibility of significant volumes of hydrocarbons being found in Tasmania. Perhaps the skepticism is warranted, particularly in light of the abundance of volcanic and other igneous rocks distributed throughout the stratigraphic sequence across much of Tasmania. The subsurface geology of Tasmania is largely an unknown entity. Until recently, only a very limited amount of work had been conducted which addresses the petroleum potential of the State. A few shallow boreholes have been drilled at sites of reported seepages and a few kilometers of seismic data has been acquired.

The first serious and methodical investigations into the petroleum potential of Tasmania were initiated by Conga Oil in the 1980's. financed entirely by their own resources. Work carried out by Conga Oil in the past few years has led to some very encouraging results, providing a considerable degree of optimism that 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.

The elements or criteria 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 an efficient, impermeable seal

4) A trapping mechanism formed by folding and /or faulting of rock sequences or involving lateral changes in rock composition ( porosity and permeability variences)

5) Heating of preserved organic material to temperatures at which hydrocarbons are generated and expelled from source rocks. Generally about 1500 - 2000 meters of sediment overburden is required to generate the required temperatures. Trap mechanisms must be in place before conditions for hydrocarbon generation are achieved

6) A conduit to provide reservoirs access to hydrocarbons migrating from maturing source rocks. Conduit may be established by permeable reservoir rocks being adjacent to source rocks. Faults may also assist.

7) Preservation of hydrocarbon accumulation from excessive temperature and maintaining of trap integrity

8) Sufficient pressure within reservoir 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 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 Conga 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 certain parts of the Conga Oil Licence area.

The difficulty now lies in identifying specific locations in which all of the elements are 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 exhaustively analysed. Specific target objectives must be defined and good quality seismic obtained to pin point optimum drilling locations over valid and robust targets with generous hydrocarbon drainage areas. There is a lot of work ahead but the reward could be considerable.

## PREVIOUS EXPLORATION FOR PETROLEUM IN TASMANIA

The first onshore petroleum seepage in Tasmania was recorded more than 115 years ago. Over 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, exploration inspired by the numerous reports of oil seepages across the State and the occurrences of bitumens on the west coast of Tasmania. To date 13 companies including Conga Oil Pty Ltd have actively explored for petroleum in the island State. A total of 127 exploration licences have been held and some 40, shallow, boreholes drilled. Almost all of the wells were drilled solely on the basis of petroleum seeps without any real knowledge of subsurface structure and stratigraphy. Not one company has evaluated the Pre 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. Many wells entered near - surface Jurassic dolerite intrusions and terminated within them. Until recently, there were no valid methods to predict where the dolerites are relatively thin. In spite of all of the above, small volumes of oil and/or gas were recovered in several of the drill holes.

Around the world, oil strandings and seeps have led to the discovery of many significant oil fields. 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 not observed in petroleum exploration in Tasmania in the past. Today, in light of a new understanding, several major international oil exploration companies are showing an interest in the hydrocarbon potential of onshore Tasmania.

## 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. Earliest PreCambrian sediments were severly deformed and intruded with granites during the Penguin Orogeny which occurred about 725 - 750 million years ago. Terrestrial sediments and shallow marine, predominently quartzose sandstones and dolomites, deeper marine mudstones and turbidites and basalts were deposited across the deformed surface during late PreCambrian 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 Mt. Read Volcanics, a mineral rich island arc complex, and the Dundas Group, which comprises conglomerates and finer grained clastics of a predominently volcanic origin, deposited in a back arc setting. Local interruptions of conglomerates suggest intermittent uplift of the basin margins. Tensional tectonics gave rise to horst and graben development.

The Ordovician is represented by the Denison Group and overlying it, the Gordon Group. The Denison Group comprises a sequence of predominently clastic sediments which were deposited in a full spectrum of depostional environents 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 platform margin buildups to deep water (>200m) carbonate 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 not abrupt and considerable interfingering 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 dedolomitized. 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 Ordovician time, clastic material advanced rapidly across the carbonate platform, and the Gordon Group carbonates were comformably overlain by predominently shallow marine siliciclastics 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 State, basinal grapholitic turbidite deposits were deposited (Mathinna Beds). Uplift of western Tasmania was possibly associated with the Benambrian Orogeny.

Lower Devonian and older rocks were extensively deformed during the Tabberabberan Orogeny. Approximately northwest to north northwest trending folding occurred 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. Conodont colour alteration indices (CAI) indicate that Lower Palaeozoic sediments were heated to about 300$^0$C adjacent to intrusions in the western part of the State. In central and southern Tasmania, Lower Palaeozoic sediments were heated to an estimated 150$^0$C, even though distant from the granitoid masses. This major heating event is significant to the development of petroleum in Tasmania.

During the Late Carboniferous and Permian, glacial deposits (Lower Parmeener Super Group) were deposited unconformably on the newly deformed, 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 Super-Group includes the Tasmanite Oil Shale, a glaciolacustrine sequence which has an extremely high organic content. Triassic rocks are represented by up to 600 meters 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 Supergroup commonly consists of granule conglomerate and coarse sandstone. The upper parts of the sequence are commonly represented by up to 200 metres of clean sandstone. Dark grey shale horizons and subordinate coal measures occur throughout the sequence. Almost everywhere in Tasmania, rocks of the Parmeener Supergroup are subhorizontal.

Extensive sills of dolerites fed by narrow feeder dykes were intruded during Middle Jurassic time. 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 Gondwana supercontinent. While thick (up to 8000 metres) accumulations of alluvial fan, fluviatle and volcanic sediment were deposited in newly formed Bass, Otway and Sorell 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 graben were formed as an extensional regime was set up as Antartica fully separated from Australia. Up to a kilometre of mainly terrestrial sediments was deposited in the graben. 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 was centred more on the Gippsland Basin to the north.

## KNOWN PETROLEUM OCCURENCES

In 1871 , surface tar was reported from Prime Seal Island. This was the first report of petroleum recorded in Tasmania. Since that time, more than 200 reports of possible onshore, liquid petroleum and natural gas seepages and flows and bitumen occurences 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 have been preserved in museums and libraries further validating early reports. Unfortunately, there are only written, unconfirmed reports of seepages in the interior of the State with no preserved samples.

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 occurence of either considerable 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 1969 but then Tasmania has not experienced a major earth tremor since 1958. Figure shows the distribution of reported seeps in Tasmania (from Bendall 1990). Northeast - southwest trends in seep distribution are evident from 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 35 boreholes have been drilled in Tasmania with Petroleum objectives. Wells have been very shallow, the deepest being no more than 400 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 recovered from a depth of 27 metres at Johnson's well on Bruni Island in the south of Tasmania and a small quantity of gas was reportedly 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. Core bled oil from the Tasmanites Oil Shale interval from the Ross 2 borehole, drilled to 480 metres in 1985 by the Department of Mines and a gas flow was reported by a competent geoscientist, while drilling through the Quamby Mudstone at Douglas River. Oil has almost definitely been generated and it looks like low volume seepage has been occuring 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 kilometers to the west.

There have been numerous reports of oil and gas seepages in Tasmania. Most of these reports remain unconfirmed except in the written record. Some coastal bitumens have been preserved in museums and geochemical analyses, although perhaps somewhat inconclusive, indicate an origin from offshore Tasmanian basins. They do not appear to be related to Tasmania's onshore basin.

There have been a large number of reports of seepages from the interior of Tasmania. The sightings appear to have coincided with periods of major earthquake activity. There has not been a major earthquake since about 1958 and consequently reports of seepages in recent years have been minimal. Most of the early sightings were not confirmed by knowledgable 'experts' and certainly not by geochemical analysis and bacterial action has destroyed any evidence of the original seepages. Their actual presence could therefore be discredited today by those wishing to discourage petroleum exploration in Tasmania. 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 magnetics interpretations. These lineaments are interpreted as deep seated thrust faults and there is therefore good reason to believe the seepages originated from subsurface hydrocarbon accumulations. This remains to be verified.

## 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 occurences across the State. The original explorers of New River (circa 1915 - 1925) identified the Gordon Limestone as the primary source of the abundant oil seeps and tars and similarities were drawn between the Gordon Limestone and time equivalent, prolific oil producing limestones in the U.S.A. It has been presumed by most investigators that oil generated and revealed as seeps was derived from the Permian oil shales. Although organically very rich and often oil saturatd themselves, these rocks were not, however, considered to have ever been sufficiently buried to achieve temperatures sufficent for significant hydrocarbon generation to occur.

Today, as a result of considerable work initiated primarily by Conga Oil and 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 Parmeener Group have each generated significant volumes of both oil and gas. Other potential source rocks include Precambrian shales and dolomites.

The Gordon Limestone was formed under shallow water, marine conditions. The fine grained limestones, dark grapholitic shales and evaporite sequences which comprise the Group should all provide excellent, oil prone source potential. The frequent occurences 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. The Cashions Creek Limestone appears to be particularly rich in oil prone, algal matter.

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 Johnson's well on Bruni Island (and in addition with samples of bitumen from the Tasmanian Coast). Analyses indicate that neither the oil from Bruni Island nor the coastal bitumens were generated from the Tasmanites Oil Shale.

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 provided some evidence for their former presence.

Although the Ordovician limestone has been identified as the primary 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 authoritive conclusions and judgements to be made. Considerable more investigation must be initiated. It is quite possible that the Gordon Group comprises organically rich prone source rocks across a major part of Tasmania.

The Parameener 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 Parmaneer Supergroup but that which has been completed indicates the unit is highly variable both in lateral and vertical sense with 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 predominently inertinite (neither oil nor gas prone). Sampling within the Parameener Supergroup has been very limited to date (17 samples from Douglas River, Ross River and Turnbridge borehole No. 2, analysed by BMR) and samples on hand may not be representative of the unit as a whole. Neverthelesss, results are very encouraging.

It appears the Tasmanites Oil Shale, a glacio-lacustrine sequence of organically rich shales, provides the best potential source interval in Tasmania. The oil shale had been mined at      from 1910 to 1932. Artificial distillation resulted in the recovery of 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 <u>Tasmanites</u> <u>punctatus</u>. 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 Shale appears to be sporadically developed across Tasmania and considerable work will have to be undertaken to determine its geographical distribution. It is particularly prominent in the north of the State near the base of the Quamby Formation. Nevertheless, it has been identified in numerous outcroppings and drill holes and is probably of a greater geographic distribution than many workers may think.

Banks (1968) described oil shale and cannel coal from the top of the Mersey Coal Measures. These potential source rocks have similar characteristics to the Tasmanites Oil Shale.

A rock sample of lower Permian mudstone from Poatina, Tasmania, and thought to be stratigraphically related tp 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 hydrocarbons were indigenous to the rocks from which they were extracted. Thin, oil shale intervals are commonly present with the Quamby Mudstone sequence. A borehole drilled beside the Douglas River Bridge as part of the Tasmanian Department of Mines coal assessment programme flowed gas during penetration of formation (Leaman - pers comm) Free oil was subsequently identified by Domak in the cored interval of the Quamby Mudstone. Geochemical analysis indicated the formation to be 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.

Only one sample of the Proelenna Coal has been analysed geochemically and this was found to have extractable hydrocarbons, to be organically mature and to have similar geochemical biomarkers to tar occurences at Bridgewater and South Bruni Island.

## 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. The very few reports which address the hydrocarbon prospectivity (or rather non-prospectivity) of Tasmania, 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 Parneeer Supergroup sediments were considered to be nowhere sufficiently mature for the generation of significant volumes of oil and/or gas. The high organic content of the Tasmanites Oil Shale was well known but explorationists considered the unit was everywhere insufficiently mature for the generation and release of significant quantities of hydrocarbons.

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 of data 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 Middle Devonian to Early Carboniferous Tabberabberan Orogeny. These researchers believed that hydrocarbon generation from the Early Palaeozoic and PreCambrian 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 action. The particularly high basin temperatures were interpreted from conodent alteration index (CAI) values from Early to Middle Palaeozoic marine carbonate rocks of western and west central Tasmania. Low vitrinite reflectance values from unconformable overlying Parmeener Supergroup sediments suggested that the major heat input into the pre Carboniferous sequence occurred before Parmeener Supergroup depositon.

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 (Figure ). Regional metamorphism in western and northwestern Tasmania is interpreted to have been in excess of 300°C and was due to high heat flow rather than to depth of burial. Low CAI values however, in the south west and central Tasmania suggest that if Gordon Group carbonate rocks are present at depth, and there is strong evidence that they are, they are currently within the oil and gas windows. Maturation Modelling suggests that hydrocarbons would not be expelled from these more basinward sediments (at least from the upper parts of the Gordon Group) until after a considerable and protective Parmeener 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 in Canberra, The Tasmanian Department of Mines, Amdel Core Laboratories and others have demonstrated that sediments within the Tasmania Basin are in the oil window, with Vitrinite Reflectance value ranging from 0.7% (lower oil window) at the edge of the basin to 1.35% (upper oil window) at the centre of the basin. The Methyl Phenarthrene Index (MPI) measured from the aromatic fractions of hydrocarbons extracted from Permain 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 high heat flow which is up to twice the world average of 60 $mW/M^2$. Present geothermal gradients onshore Tasmania are 30 - 40°C/km (Summons 1981) and there is strong evidence that geothermal gradients were higher in the past. Recent zircon and apatite fission track data (Hills - Bidal 1991 Dec) confirms a Cretaceous heating event which is predicted from Maturation Modelling and Conodont colour alteration indices indicate a significant, Devonian heating event.

Gravity and magnetics data indicate greater thicknesses of sedimentary sequence than previous thought in grabens and other basin depressions and a post Parmeener Supergroup cover of in excess of 2 kilometres is interpreted in the central basin area.

All of the geochemical evidence to date indicates that within Tasmania there is a full range of maturation levels, from early mature to extremely over mature (post wet gas preservation), for Ordovician and older sediments. Parmeener Supergroup sediments 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 definite 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 Permeener Super Group.

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 meters) and geographically extensive, sedimentary sequence in which well developed reservoirs shoud be present.

Coral 'gardens' appear to have been common across much of Tasmania during Upper Ordovician time, but to date no authentic bioherms have been identified. C.F. Currett (Cummings T.G. 1981) postulates that the coralline facies at the top of the Benjamin Limestone in the Florentine Valley was a back reef with a yet to be discovered fore reef to the east. Forereef development would be anticipated and these 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 recrystallized (at Lune River at least) and have high porosity where the limestone was exposed during the Tabberabberan 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 has been reported.

Until very recently, it was believed that reservoir conditions within the Permian sequence were virtually non-existant. Several potential reservoir intervals, are however, present.

Due to the structural complexity of much of onshore Tasmania, abrupt stratigraphic changes and a considerable post Triassic cover in places, and because there is insufficient seismic and well data to be able to correlate the stratigraphy in the subsurface, a seemingly infinite number of formation names have been assigned to the Parmeener Supergroup sequence, making it difficult to describe. Nevertheless, several sandstone and conglomerate intervals have been identified, providing the Supergroup with very real reservoir potential.

The Liffey Sandstone seems to stand out as an important reservoir objective. The unit is the first semiregional coarse clastic unit (?reservoir) above the Tasmanites Oil Shale. It is also directly associated with the Preolenna Coal Measure. Effective porosities as measured by Amdel Laboratories in 1981 range from 10.66 - 11.00 percent. Sandstones which constitute the Malbina Formation, the Ross Sandstone and the Risdon Sandstone should also be considered as potential reservoirs although 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 conglomerates provide further potential.

Mudstones generally provide source rock or seal potential but the Quamby Mudstone seemingly offers considerabe reservoir potential. The formation includes the organically very rich Tasmanites Oil Shale and, independent of the oil shale, could prove itself to be an effective source rock in places. Where seen in outcrop, the formation is highly fractured. The fracturing may have been induced by pressure unloading reusulting from uplift and erosion accompanying Tertiary Orogeny, or alternatively the formation may have been highly water saturated prior to uplift and the fracturing could therefore be related to shrinkage from dewatering. Fractures were observed, however, in at least one bore hole (BHP 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 low.

If there is sufficient fracture development within the unit and outcrop exposures suggest there is, the matrix, if hydrocarbon saturated, would be expected to contribute significant volumes of hydrocarbon into the fracture network. There are at least some important similarities between the Quamby Mudstone and the fractured reservoirs of the Spraberry Trend in West Texas oil production and other fractured reservoirs.

## SEALS

Intraformational seals are abundant within both the Lower Palaeozoic (Gordon Group) and Upper Palaeozoic (Parmeener 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, their being no effective vertical seals to hold any significant accumulations. The concern appears to be largely unwarranted.

The thought process which generates the concern implies either that Pre Permian rocks constitute one extensive and thick reservoir or that all potential reservoirs have been breached, both possibilities being very unlikely. The breaching of Devonian generated anticlines has been documented in outcrop. 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 meters of shale, siltstone and mudstone (Bell Shale) has been recognised at the top of the Eldon Group near the mouth of the Gordon River (Baillie 1989). 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 have been reached until after Permian deposition had commenced.

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

## STRUCTURE

Pre Parmeener rocks are concealed across more than half of Tasmania and the described source and reservoir rocks of the Gordon Limestone Group are rarely exposed where the Parmeener cover is absent. Precambrian rocks are exposed in the west and Ordovician and 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 cover. Over much of the State however, the geology of the pre Permo-Carboniferous sequence is unknown. Geological mapping by the Department of Mines indicates Ordovician to Devonian sediments to be present under a relatively thick Parmeener and Tertiary cover, in central Australia.

Very little seismic data is available as onshore record sections have been generally poor. High velocity surface problems coupled with near surface Jurassic dolerites have made it very difficult to obtain good seismic data. Aquisition and processing problems associated with such difficult conditions are now being assessed.

Good seismic data has, however, been obtained in some locations with clear reflections being observed over many seconds of record. At rare localities, excellent records to two-way times of 11 seconds (mantle levels) have been obtained. Most records, however, appear blind for times in excess of 300 - 900 ms or below the base Parmeener unconformity.

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

Preliminary and in places detailed gravity and magnetics analyses and interpretations have been made by D.L. 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 delinated 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 stacks. 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 have overprinted pre-existing west facing early Cambrian 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 outcrop of the Gordon Group in the Picton River area.

Tasmania appears to be a typical fold-thrust province. Several minor and large scale thrusts are stacked and the entire overthrust system has been folded and intruded and in places reactivated.

## PLAY CONCEPTS

As there are numerous and varied potential reservoir objectives and source rocks ranging in age from Precambrian to Permian - 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 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 Tertiary earth movements.

Specific prospect definition will not, however, be possible until more knowledge about the subsurface stratigraphy of Tasmania is obtained and until better, more definite structural control is obtained. With the exception of the seeps themselves, there is insufficient geological information at this time to initiate a wildcat drilling programme. The origin of the hydrocarbons seen as seepages at fault exposures is unknown. Hydrocarbons may be migrating some considerable distances 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 magnetics results. Stratigraphic drilling should considerably reduce the risk of purely "wildcat" drilling in the future.

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

Mackintosh 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 bore hole was drilled. Upon drilling through a mudstone into a sandstone at 30 metres, the well 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 oil traces with an apparent Ordovician signature identified.

Conga Oil plan to drill a stratigraphic well east of the original borehole. The hole will be drilled to a depth of at least 700 metres and will penetrate the entire Parmeener Supergroup interval and may possibly, depending upon shows, maturation indications etc, be continued to intersect considerble Lower Palaeozoic section. As several stacked thrust sheets are interpreted to be present in the Bruny Island area, a very thick sequence of Upper 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 particlular the Quamby Mudstone - Tasmanite Oil Shale) quality and maturity and on reservoir distribution and quality.

Conga intends to follow up the stratigraphic drilling with a conventional petroleum exploration well. Conga have already acquired 260 kilometres of marine seismic data near Bruny Island and in Storm Bay. 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 problable that additional seismic will be acquired offshore and possibly onshore, Bruny Island.

Conga also plans to drill a stratigraphic borehole to further evaluate a flow of gas reported by Dr. D. Leaman while a bore hole was being drilled through the Quamby Mudstone in a coal assessment well at the Douglas River bridge. Two seams of Tasmanite 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.

Conga also intends to drill a stratigraphic evaluation well, 20 kilometres to the west of the Ross Number 2 borehole, to evaluate source (in particular the Tasmanite Oil Shale) maturity and quality and reservoir potential at that location. The Ross Number 2 well was drilled in 1985 by the Department of Mines to a depth of 480 metres. Core recovered from the hole bled oil upon cutting and a Tasmanite horizon was identified at 410 metres.

There is considerable evidence to suggest that the most prospective part of Tasmania for oil and gas will be the west central part of the State. The evidence comprises gravity and magnetics data and extrapolations of surface geology. There is, however, absolutely no subsurface information on this part of the State. No boreholes have been drilled, even to shallow horizons. Conga intend to drill several stratigraphic wells in west central Tasmania to evaluate the hydrocarbon potential of this very exciting area. An abundance of seeps provides considerable 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 magnetics interpretations and possibly seismic data will provide considerable insight as to where these accumulations might be positioned. Results of the stratigraphic drilling may prove to be negative but Questa is confident results will be encouraging and 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 by a lack of subsurface velocity knowledge.

Conga plan to drill 35 boreholes within the next five years. Most of these will be drilled purely to gain stratigraphic, structural and geochemical information. At least three wells will be conventional wildcat oil wells with the objectives of intersecting hydrocarbon accumulations of commercial proportion.

## NEAR- SURFACE DOLERITES

Near surface dolerite intrusions and feeder dykes have perhaps more than anything else discouraged oil and gas exploration in Tasmania. "Several thousand cubic miles of magma formed a nearly continuous body through the Permian and Triassic sediments over almost all of the island". Up to three dolerite sills have been recognised within the Parmeener Supergroup srquence, the lowest being located near the pre-Permian unconformity.

The Jurassic dolerites refect considerable seismic energy from upper surfaces leaving only 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 problems. Seismic processing problems are being assessed. It is simply a matter of not being able to see (seismically) through the dolerite bodies which may be as thick as 50 metres. The problem can be overcome although expensive processing (and acquisition) is required.

Expert gravity/magnetics interpretation can resolve where the dolerites are absent or thin 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 porphries occur at Port Cygnet and are thought to be of Cretaceous age. Tertiary basalt flows are common throughout Tasmania but are confined to river valleys.

The abundance of igneous intrusions and volcanic sediments throughout the stratigrapic 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 proportions. 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.

## 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 Shale is of particularly good source rock quality and there is very good evidence that the unit lies within the oil window across much of Tasmania. Considerable work remains to be carried out on reservoir distribution and quality but several potential, porous reservoirs have alredy 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 period of peak oil and gas generation.

Numerous 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 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 sole objective of finding a commercial hydrocarbon accumulation, bore holes 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 bore holes.