PALAEOGEOGRAPHY

JOHN BRADSHAW

REAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

ONSHORE SEDIMENTARY &
PETROLEUM GEOLOGY

RECORD 1990/72

R9007201

Record 1990/72

GEOLOGICAL CROSS-SECTION ACROSS THE

PETREL SUB-BASIN, BONAPARTE BASIN

BY

JOHN BRADSHAW

Bureau of Mineral Resources, Geology and Geophysics &
Australian Petroluem Industry Association

CONTENTS

SUMMARY

The Petrel Sub-basin is a sub-division of the Bonaparte Basin in northwestern Australia. The sub-basin contains in excess of 12 km of Phanerozoic sediment, with a total stratigraphic thickness in the Bonaparte Basin of 17 km.

The structural cross-section is located entirely offshore and has been compiled from both modern and old well data and seismic. It runs from the northern margin along the centre of the basin and up onto the southwestern margin. Two-way time to depth conversions were calculated using the velocity surveys of the wells along the line of the section, being; Flat Top 1, Petrel 1, Penguin 1, Lesueur 1 and Berkley 1.

Several models of Middle Palaeozoic rifting have previously been proposed that differ mainly in the nature of the material flooring the rift. A large diverging gravity high with an associated low occurs along the axis of the basin, and has been suggested to represent a deep axial intrusion and oceanic crust. Gravity modelling suggests that the core of the rift is not composed of oceanic crust as proposed, but confirms that substantial deep intrusions do occur in the centre of the sub-basin.

The northern part of the sub-basin has proven to be gas prone in the post-rift sediments whilst traces of oil have been found in the pre-rift sediments in the south. Locating good reservoirs with adequate seals has been a problem in the southern areas where the older sequence is present at shallow depths. Regional northwest tilting has destroyed many four-way closures and late stage salt tectonics may have perforated pre-existing traps.

INTRODUCTION

DATA SET

BERKLEY 1	(Magnet Metals - 1982)
LESUEUR 1	(Australian Aquitaine Petroleum - 1980)
PENGUIN 1	(Arco Australia - 1972)
PETREL 1,1A,2	(Arco Australia - 1969,70,71)
FLAT TOP 1	(Australian Aquitaine Petroleum - 1970)

ELSIE MARINE SEISMIC SURVEY MM81B
(Magnet Petroleum - 1981 : MM81B-45 to 74)
REVELEY MARINE SEISMIC SURVEY
(Magnet Metals - 1980 : MM80-19 to 37)
T84 SEISMIC SURVEY
(Australian Aquitaine Petroleum - 1984 : T84)
LONDONDERRY RISE SEISMIC SURVEY
(Arco Australia - 1968 : LR)
EMPEROR MARINE SEISMIC SURVEY
(Lennard Oil - 1980 : LE80)
HOWLAND MARINE SEISMIC SURVEY
(Australian Aquitaine Petroleum - 1981 : HD)
PERON ISLAND MARINE SEISMIC SURVEY
(Australian Aquitaine Petroleum - 1972 : PI)

Helby, R., 1974a : A palynological study of the Petrel Formation.
Helby, R., 1974b : A palynological study of the Cambridge Gulf Group (Triassic - Early Jurassic).

SCALE

The cross-section has been drawn at 1:100,000 scale with a vertical to horizontal exaggeration of 1. The total length of the section is 335 km and has a maximum depth of approximately 12 km.

HORIZONS DRAWN

A total of 13 seismic horizons have been drawn on the cross-section:

1) Base Tertiary
2) Cretaceous - Base Turonian - Top Time Slice K8
3) Cretaceous - Base Aptian - Base Time Slice K4
4) Top Jurassic
5) Top Triassic
6) Top Permian
7) Permian - Base Kazanian - Base Time Slice P5
8) Permian - Sakmarian - Base Time Slice P3
9) Top Carboniferous

10) Carboniferous - Namurian - Base Time Slice C5
11) Carboniferous - Visean - Base Time Slice C4
12) Pre-Carboniferous Unconformity
13) Igneous Basement ?

Several additional sequence boundaries were carried on the seismic but were not drawn on the section. This includes a prominent Late Triassic - Early Jurassic unconformity evident between Flat Top 1 and Petrel 1. This boundary could not be accurately portrayed on the cross-section because of the closeness of adjacent horizons when represented at the scale of 1:100,000.

Another sequence boundary occurs between the base P3 and top Carboniferous horizons in the central and northern parts of the basin. It is difficult to correlate this specific boundary to the southern regions because of intervening old vintage data and salt diapirs (sections F-G-H-I). Where it appears to tie into Lesueur 1 there is no evidence of a depositional break on either the seismic or biostratigraphy. However, slightly lower in the Permian to Carboniferous sequence in Lesueur 1 there is a depositional break in the biostratigraphy (Plate 2 - Time depth plots) and there is also a suggestion of an angular unconformity on the seismic (Plate 2 - Seismic section s.p. 440 TWT 1.8'). If a mis-tie has occurred, then the pick on the top Carboniferous in the central and northern areas is too low by about 100-400m, and the horizon drawn as the top Carboniferous in these areas probably equates with the top of Carboniferous time slice C5. However, the preferred alternative is that there is no mis-tie and that there are actually two sequence boundaries in the Carboniferous to Permian sequence. One is evident in the south and ranges in age from the Westphalian to the Asselian, whilst the other is evident in the north and ranges in age from the Sakmarian to the Asselian.

TIME DEPTH PLOTS

Time/depth plots have been drawn for each of the five wells along the section; Berkley 1, Lesueur 1, Penguin 1, Petrel 1 and Flat Top 1 (Plate 2). These plots are not burial history curves, but simply represent the palaeontological dating performed in each well, and show the precise nature of the biostratigraphic control which exists for the cross-section. The boxes drawn on the time/depth curves are the actual depth range of the palaeontological zones assigned in the well.

For Flat Top 1 there is no specific palaeontological report, such that inferences in the geological report have been utilised in drawing the time/depth plots. Problems exist with the dating in Flat Top 1 in that correlations on seismic from Petrel 1 suggest that a thin Triassic interval is present. However, the dating suggests that either a Jurassic or Permian sequence is present, but not Triassic (Time/depth plot - Plate 2). Dating at the base of Penguin 1 was found to be spurious when correlated with horizons drawn both from Flat Top 1 and Lesueur 1. To maintain the integrity of the palaeontological data set, both cases of spurious data have been displayed and utilised in the construction of the time dependant diagrams, albeit with appropriate asides and question marks (Plate 2). The palaeontological data from Petrel 1 and Penguin 1 well completion reports have been supplemented with data from Helby (1974a & b). The basic data from Lesueur 1 (species list) was re-interpreted by a consultant palynologist.

RESULTS

DATING OF HORIZONS

Basement

A distinction has been made as to the nature of the Basement. On the southern flanks of the basin Berkley 1 (section A-B - Plate 1) penetrated Proterozoic igneous basement (T(Nd)=2.1 $\pm$ 0.1 x 10^9 ; T(Sr)=1.34 $\pm$ 0.05 x 10^9). Between Berkley 1 and Lesueur 1 (section A-D - Plate 1) an igneous basement has been assumed. Adjacent to Lesueur 1 the igneous basement is down faulted on a major basin margin fault (section F-G - Plate 1). To the north of Lesueur 1 the character of that basement horizon is lost on old vintage seismic (LR 37 section H-I) and can not be carried into the centre of the basin.

Northeast of Flat Top 1 there is basement with a distinctive magnetic and seismic signature (Flat Top 1 to Q - Plate 1). The depth to magnetic basement in this location agrees with the depth to basement estimated from seismic, thus suggesting that it is igneous basement. However, Flat Top 1 encountered an undated quartzite. It is presumed to be Proterozoic (?), as it is very hard and resulted in a very low drill penetration rate. However, as it is a conglomeratic quartzite with some organic matter, and has not undergone metamorphism, it is possible that it could be Palaeozoic in age. On seismic around Flat Top 1, the Proterozoic (?) basement has an irregular surface with downlap of the Permian sequence onto it, suggesting that it is an erosion surface. No deeper horizons are evident, due either to the nature of the sequence (igneous basement?) and/or to the many multiples on the seismic (PI 3 - section P-Q). On the modern seismic between Flat Top 1 and Petrel 1 (HD 6 - section O-P) there are deeper horizons that also appear to be multiples. Where the modern seismic (HD 6) ties with the older vintage seismic (PI 3) the irregular surface of the basement is lost. No major faulting is evident on either line to suggest that the basement has been faulted out or that a major basin margin fault has been crossed.

A few minor discontinuities are present on the modern seismic (HD 6) along the basement horizon carried from Flat Top 1 and the old vintage seismic (PI 3). This horizon has been carried into the centre of the basin until it dips beneath the limit of the seismic records south of Petrel 1. In the centre of the basin this horizon may represent a major structural unconformity in pre-Carboniferous sediments as noted around Lesueur 1 on the southern flanks of the basin.

Cambro-Ordovician (?)

There are no well ties to this sequence which is postulated to occur to the immediate north of Lesueur 1 (section F-G - Plate 1). It overlies what may be the down faulted extension of the igneous basement on the southern margin of the basin. Overlying it is the postulated level from which the salt diapirs have emanated. There is no evidence for the age of this salt level along the line of section, other than that it is pre-Carboniferous.

Devonian (?)

A Devonian (?) sequence is postulated beneath the Carboniferous sediments encountered in Lesueur 1 (section F-G), although it is not penetrated in any of the wells along the section. On the seismic around Lesueur 1 (Plate 2) the Devonian (?) has been tilted and eroded, producing a sharp angular unconformity between it and the overlying Carboniferous. This unconformity may be the basement interpreted in the centre of the basin around Penguin 1, and adjacent to Petrel 1.

Carboniferous

A Carboniferous sequence was encountered in Lesueur 1 and was carried all along the section. Three horizons were picked; Visean - base C4, Namurian - base C5 and Top Carboniferous. The Top Carboniferous can be tied out onto the southern and northern margins of the basin, whereas the lower horizons pinch out on the margins of the basin and/or are lost beneath the limit of the seismic records in the centre of the basin. The interpretation of the base C4 and base C5 horizons along the old vintage seismic (section H-I - Plate 1) is ambiguous, such that it is possible that the lower Carboniferous thickens into the centre of the basin rather than being uniform in thickness as shown.

Permian

A Permian sequence is present in all of the five wells along the section. Three horizons have been tied all along the section; Sakmarian - base P3, Kazanian - base P5 and Top Permian. The Permian sequence is truncated and/or pinches out at the very ends of the section on the northern and southern margins, whilst it thickens into the centre of the basin. Dating of the lower part of the Permian in Penguin 1 is believed to be incorrect. This is indicated from accurate ties between Flat Top 1 and Lesueur 1 that show the equivalent levels to mis-tie by over 0.5 seconds with those in Penguin 1. As the dating in Lesueur 1 is modern and appears to be accurate, and the seismic tie from Lesueur 1 to Penguin 1 is not complex, the dating in the lower Permian in Penguin 1 has been ignored. Ties on the Top Permian are however accurate between all wells.

Triassic

A Triassic sequence is present in Petrel 1, Penguin 1 and possibly Lesueur 1. The dating is poor in all wells due to the sparse recovery of microfossils. Seismic suggests that a thin sequence of Triassic may be present in Lesueur 1, although it is not indicated by dating. Only a Top Triassic horizon has been shown on the section, although a Late Triassic to Early Jurassic sequence boundary was correlated between Flat Top 1 and Petrel 1. This sequence boundary may represent an unconformity associated with the red bed sequence of the Malita Formation. It may also correlate with an undated sequence boundary associated with the Permo-Triassic (?) in the Arafura Basin (Cross-section 2 - Bradshaw, 1989). Whilst the Triassic interval thins onto the margins of the basin (and/or is eroded), there is not the appreciable thickening into the centre of the basin as occurs in the Carboniferous or Permian.

Jurassic

A Jurassic sequence occurs in Penguin 1, Petrel 1, Flat Top 1 and perhaps Lesueur 1. Only a Top Jurassic horizon has been tied, although it can be carried to the margins of the basin, before rapidly pinching out. There is some thickening of the sequence into the centre of the basin, although there is extensive erosion along the margins of the basin.

Cretaceous

A Cretaceous sequence occurs in Penguin 1 , Petrel 1, Flat Top 1 and perhaps Lesueur 1. Two horizons have been tied; base Aptian - base K4 and base Turonian - top K8. Seismic over Lesueur 1 suggests that Cretaceous is present although it is not confirmed by dating. The Cretaceous is present on the northern margin of the basin (also on Bathurst and Melville Islands - Hughes (1978); Norvick & Burger (1975)), and thins rapidly onto the southern margin of the basin due to erosion. In the centre of the basin the Cretaceous as a package has a fairly uniform thickness. However, between the base K4 and top K8 time slice horizons, there is marked thinning into the centre of the basin from both the northern and southern margins. There is a complementary thickening into the centre of the basin of the interval from the top K8 to the base Tertiary. The seismic reflectors in the Cretaceous interval are often patchy and discontinuous, making interpretation very difficult. This is undoubtedly related to the depositional break at the top of the lower Cretaceous that is indicated from the biostratigraphy of Petrel 1 and Penguin 1 (Plate 2).

Tertiary

Only a single horizon has been tied for the Tertiary section; base Tertiary. The Tertiary is very thin on the southern margin, is thick in the centre of the basin and thins rapidly onto the northern margin. It is usually not differentiated in the wells although it is present on seismic wherever resolution in the top interval is possible.

TIME AND FACIES DIAGRAMS

Time and facies correlation diagrams were drawn by extrapolating the time/depth plots for each well to produce time space, time slice correlation and time slice - facies diagrams (Plate 2). All three diagrams essentially portray similar data, except that the time space diagram is plotted against time and the time slice correlation and time slice - facies diagrams are plotted against depths using successive datums at the top of the Jurassic, top of the Permian and top of time slice P4 (base Kazanian). The reliability of the extrapolations can be directly assessed by examining the data points on the time depth plots of each well.

Time Space

This diagram shows three major unconformities delineated from the palaeontological data in the wells : Late Carboniferous, Late Triassic to Early Jurassic and Late Jurassic to Early Cretaceous. Becasue of the poor dating in the Jurassic to Triassic intervals it is difficult to accurately date the Late Triassic to Early Jurassic unconformity.

In the Carboniferous there was a transition from paralic to fluvio-lacustrine conditions. In the Permian paralic conditions were followed by a marine incursion and finally a regression occurred with fluvial conditions dominating the late stages. From the Triassic to Jurassic there was a transition from fluvial to paralic conditions. During the Cretaceous both marine and paralic conditions were present.

Time Slice Correlation

Three unconformities are shown with the extrapolated thickness changes in each time slice. Noticeable thickness changes occur from both flanks of the basin to its centre in the Permian sequence. As mentioned above, the dating in Penguin 1 for the Early Permian is believed to be spurious. Thickening also occurs in the Late Jurassic from Penguin 1 to Petrel 1.

Time Slice Facies

Paralic and fluvio-lacustrine sediments were deposited in the Carboniferous, and were eroded prior to deposition of the Permian. During the Permian, deltaic, fluvio-lacustrine and paralic sediments occurred on the flanks of the basin with marine and paralic in the centre. Near the end of the Permian and beginning of the Triassic fluvio-lacustrine and lacustrine facies occurred in the centre of the basin. Some of these sediments (Mt Goodwin Formation) may be more estuarine (paralic) than lacustrine. However, they are a gas prone source rock, have a very sparse fossil content, no glauconite is present and they are absent on the flanks of the basin, thus suggesting only very limited marine connection. Paralic and marine conditions prevailed throughout the remaining Mesozoic and Cenozoic.

STRUCTURAL FEATURES

The Petrel Sub-basin of the Bonaparte Basin is a broad structural depression. The northern and southern flanks of the depression both are faulted and the stratigraphic section thins onto them and has been truncated by regional uplift. The southern flank has a steep normal fault with over 4km of vertical offset (section C-D-E-F-G - Plate 1). The northern flank comprises a series of small normal faults with up to 200m vertical offset that are associated with a regular rise in the level of the basement (section O-P-Q - Plate 1). In the central parts of the basin, there is only minor structural adjustment (section I-J-K-L-M - Plate 1), with few faults in the sequence. Depth to magnetic basement was estimated by Compagnie Generalie de Geophysique (1965) and shows an elongate basinal shape running northwest to southeast (Laws & Brown, 1976 - Fig. 4). The depth estimates can clearly be shown from modern seismic to be inaccurate for determining magnetic basement. Over the Petrel field they estimate 6 km to magnetic basement, whereas seismic indicates that at least 12 km of sediment is present (section O-P - Plate 1).

Salt tectonics are evident along the section and elsewhere in the basin. Both localised diapirs and regional doming have affected at least the post-Devonian sequence. The level from which the salt has moved is postulated along section F-G, although no specific dating is possible. If the age of the Lower Palaeozoic sequences along section F-G are correct, the age of the salt is most likely either Ordovician or Silurian.

Time of Deformation

Adjacent to Flat Top 1 (section O-P-Q - Plate 1) minor faults offset the Carboniferous and Lower Permian sequence. There is also a change in thickness between these fault blocks suggesting that structural movement occurred from the Late Carboniferous to the Early Permian. It is possible that the thickness changes could be principally due to pinch-out onto the northern margin. If so then the time of movement on the northern margin faults is Permian. Minor re-adjustments occurred along these faults up into the Lower Cretaceous but show minimal offset of the sequence. Whilst stratigraphic thinning onto the northern margin is clearly evident from the Carboniferous to the Jurassic, the pinch-out of the Cretaceous and Tertiary sequence is very much less in comparison.

Adjacent to Lesueur 1 there is at least 4 km of vertical displacement on a normal fault (section F-G - Plate 1). The history of movement on this fault and in this region is considerably more complex than on the northern margin. Cambro-Ordovician (?) to Lower Carboniferous rocks are present on the downthrown side of the fault (north) but absent on the southern side. A major angular unconformity is evident between the Devonian (?) and the Cambro-Ordovician (?), and between the Devonian (?) and the Carboniferous. The Lower Permian and Upper Carboniferous thicken rapidly from south to north across the fault. Thus movement on the fault has occurred in the Ordovician (?) to Silurian (?) and between the Devonian (?) and Early Carboniferous. Continued movement may have occurred during the

Carboniferous and into the Permian.

Two later events resulted in uplift and erosion of the Permian to Cretaceous section on the flanks of the basin. The first event occurred in the Jurassic, and is probably associated with the Malita Formation. The effect of this event can be seen where the Jurassic pinches out underneath the Cretaceous (section H-I - Plate 1). It resulted in the truncation of the Permian, Triassic and Jurassic sequences on both the southern and northern margins (sections C-D-E-F-G-H-I & P-Q - Plate 1). This event may have (re-)initiated movement of salt diapirs. The precise timing of this event is complicated by the poor dating that occurs over the Jurassic to Triassic interval (Time/depth plots - Plate 2). It is made more difficult by the simultaneous pinch-out of already thin sequences onto the southern margin that are approaching the limit of seismic resolution.

The second event occurred just below the base of the Tertiary and eroded the Cretaceous, Triassic and Permian on the southern margin (section C-D-E-F-G-H-I - Plate 1) and parts of the Upper Cretaceous on the northern margin (section O-P-Q - Plate 1). The age of this event is between the Turonian and the base of the Tertiary.

The time of salt movement may be at least from the Carboniferous onwards (Laws and Brown, 1976). Some salt structures within the basin have deformed the Tertiary (section F-G-H and seismic section - Plates 1 & 2). Dating the time(s) of movement of the salt diapir to the north of Lesueur 1 (section F-G-H - Plate 1) is complicated by its location near the edge of the basin margin. No localised stratigraphic thinning is evident, although more regional pinch-out and erosion are evident across the diapir and onto the southern margin. The diapir deforms horizons within the Tertiary, thus indicating some movement in the Tertiary. The regional uplift that produced erosion of the Palaeozoic and Mesozoic sequences in the Jurassic, could have instigated movement within the diapir as there is no unambiguous evidence of stratigraphic thinning adjacent to the diapir prior to the Jurassic.

RIFT MODELS

Various models of Palaeozoic rifting have been proposed for the Bonaparte Basin, including Veevers (1976), Brown (1979) Gunn (1988) and Mory (in press). Laws (1981) suggested that sinistral movement on the Halls Creek Mobile Zone contributed to the initiation of the basin during the Late Devonian to Early Carboniferous. A major gravity high with associated lows occurs within the Petrel Sub-basin (Gravity map of the Bonaparte Basin - Plate 2), and has been attributed to various causes; 1) salt free ridge in the centre of basin (Laws and Brown, 1976), 2) crustal thinning (Brown, 1979), 3) volcanics in basement and sediment in an old rift system (Anfiloff, 1988) and 4) axial dyke of upper mantle material flanking oceanic crust (Gunn, 1988).

Essential to the understanding of the structural evolution of the basin is an integrated explanation of the gravity, magnetic and seismic profiles, which has been addressed by Gunn (1988). The stages proposed by Gunn (1988) are (see Model for the evolution of the Bonaparte Rift - Plate 2) :

1) Stretching of lithosphere and crustal thinning. Pre-rift depocentre received Middle Devonian to Early Carboniferous sediments.

2) Continued stretching with collapse of central part of the subsiding basin. Rift is floored by tilted blocks of pre-rift sediments. Early Carboniferous rift-fill sediments deposited and pre-rift sediments outside the rift eroded during arching caused by isostatic response to lithospheric thinning.

3) Continued rift widening and crustal thinning initiated intrusion of an axial dyke of upper mantle material which domes the rift-fill and tilted block sequence. Early Carboniferous sediments infill after doming.

4) (a - South) Rift development ceased before crustal splitting, and post-rift sediments deposited during subsidence.

4) (b - North) Crustal splitting occurred along axial dyke. Oceanic crust generated between rift segments and thick sedimentary sequence deposited over oceanic crust. At the termination of crustal splitting a thick sequence of subsidence phase sediments was deposited over the area.

However, no gravity modelling was attempted by Gunn (1988) to test the concepts proposed. Mory (in press) compared the observed gravity with the predicted gravity for the model and cross-sections proposed by Gunn (1988) (see Basin cross-sections - Plate 2). Mory (in press) concluded that:

1) the magnitude of the gravity low in the centre of the basin is not compatible with an area of oceanic crust

2) there is evidence from the gravity modelling of deep intrusions within the centre of the basin

Mory (in press) suggests that crustal thinning occurred in the late Proterozoic or early Phanerozoic which produced the gravity high in the southern area of the basin. In the north, crustal thinning was modified by middle Phanerozoic rifting and subsidence. Two basement highs were produced by this rifting which correspond to the Y-shaped gravity high in the centre of the basin.

COMPARISON TO OTHER CROSS-SECTIONS

Two other cross-sections of the Petrel Sub-basin are shown on Plate 2 (Basin cross-sections : A-B and G-H). They are both from Lee and Gunn (1988). A-B runs northeast to southwest through the Petrel field, and G-H runs northwest to southeast through the Petrel field. These two sections are at different horizontal and vertical scales which complicates comparison between sections and with Plate 1. A-B has a 1:5 vertical exaggeration and G-H has a 1:7.6 vertical exaggeration, whilst

Plate 1 has a 1:1 vertical exaggeration. From Flat Top 1 to Petrel 2 of A-B equates with Section Q-P-O on Plate 1. From Petrel 1A and 2 to halfway towards Barnett 1 on G-H approximately equates with Section O-N-M-L on Plate 1.

The major differences between the sections occurs at depth, below 10 km. As stipulated by Gunn and Lee (1988) and Gunn (1988), these parts of their sections are highly speculative because they are beyond seismic records, and are hence determined by expectations of their assumed model. However, between Flat Top 1 and Petrel 2 several faults of 2 to 4 km vertical throw have been interpreted by Lee and Gunn (1988) which are within the limit of seismic records. Faults of this magnitude are not portrayed on the corresponding section on Plate 1 (section Q-P-O) as they could not be identified on seismic. The overall southwest plunge in the level of "basement" is real in this location, however it is believed to be more of a hinge zone rather than a basin margin with major down to the basin faults. Many of the reflectors on the modern seismic beyond the "basement" level seem to be complicated by multiples, however, there is no significant offset indicated within this interval. The faults may have been interpreted by Lee and Gunn (1988) from the gravity profiles in this region (Gravity map of the Bonaparte Basin - Plate 2), which show a relatively steep gradient. Near Lesueur 1 there is a gravity low, and on seismic there is a corresponding sequence of down faulted pre-rift sediments. Neither of these elements are present between Flat Top 1 and the Petrel field.

This is a major deficiency in the cross-sections and model of Lee and Gunn (1988) (Plate 2), as without significant down to the basin faulting of pre-rift sediments on the northern margin, the basin assumes an asymmetrial shape rather than having a symmetrical rifted appearance. Thus their tectonic evolution and model of the basin would have to be significantly altered. The sections on Plate 1 are drawn largely from analysis of only the seismic along the line of section. Thus it is possible that evidence for the basin margin faulting depicted between the Petrel field and Flat Top 1 by Lee and Gunn (1988) could exist on other lines further to the southeast. Regardless of this, the evidence for major down to the basin faults between the Petrel field and Flat Top 1 will remain equivocal.

CORRELATION TO ARAFURA BASIN

In the Arafura Basin there is an undated sequence boundary on the southern side of the Arafura Graben that occurs above the top of the Carboniferous (Cross-section 2 - Bradshaw, 1989). The thickness from the top of the Carboniferous to this boundary is 2 to 2.5 km and it was presumed to be Permo-Triassic (?) in age. Overlying this sequence there is another 2.5 to 3 km of sediment that was presumed to be Triassic (?) in age.

In the Petrel Sub-basin there are two possible sequence boundaries that may correlate with the one in the Arafura Graben. The first is associated with the Malita Formation and is Late

Triassic to Early Jurassic in age. It is evident all across the basin, and is particularly prominent on the northern margins of the basin, closest to the Arafura Basin. If these two boundaries do correlate then the Permo-Triassic (?) interval in the Arafura Basin is a correct estimate, but the Triassic (?) interval would need to be modified to Late Triassic to Early Jurassic. The comparative thicknesses for these intervals and the Carboniferous would then be :

	Petrel Sub-basin	Arafura Graben
Carboniferous	2 - 6 km	0.8 - 1.5 km
Permo-Triassic	3 - 6 km	2.5 - 3 km
Late Triassic - Early Jurassic	1 - 1.5 km	2 - 2.5 km

The second sequence boundary in the Petrel Sub-basin that could possibly correlate with the one in the Arafura Graben occurs in the centre of the basin and is Sakmarian to Asselian in age (Lower Permian to top Carboniferous). However, the Carboniferous interval in the Arafura Graben is well dated and totally disagrees with this correlation. Thus the sequence boundary in the Arafura Graben is best correlated with the Late Triassic to Early Jurassic sequence boundary in the Petrel Sub-basin. The conclusion that remains is that the Sakmarian to Asselian sequence boundary identified in the Petrel Sub-basin is not shown by the geometry of seismic reflections in the Arafura Graben, thus making it similar to the Ordovician to Silurian and Early Carboniferous depositional breaks within the Arafura Graben which appear as paraconformities on seismic.

HYDROCARBON PROSPECTIVITY

The many aspects of the hydrocarbon prospectivity of the Petrel Sub-basin have been discussed by Lee and Gunn (1988) and reviewed and reiterated by Gunn (1988) and Gunn and Ly (1989), and have been compiled by Lavering and Ozimic (1989).

The two major discoveries in the basin are Tern and Petrel. Both are gas fields reservoired in the Hyland Bay Formation. Petrel is structurally located on a drape anticline whilst Tern is on a turtle-back anticline. Porosities from the reservoirs in the Hyland Bay Formation in Tern and Petrel average 13 - 17 %, but they have low permeabilities. The reservoir characteristics are believed to be facies dependent, with more favourable porosities in zones where dispersed clays have inhibited quartz diagenesis (Bhatia and others, 1984). Other reservoirs in the basin include sandstones in the Late Carboniferous to Early Permian where average porosities over 22 % occur in the Kulshill Group.

Many of the structures drilled have been related to salt tectonics, being either over or adjacent to diapirs, or on associated turtle-back anticlines. The absence of hydrocarbon shows from almost all of the offshore wells located crestally on diapiric structures (Gunn & Ly, 1989 - Table 1) suggests that there was substantial late stage movement. The absence of shows could be explained by either; 1) formation of a trap after hydrocarbon migration, or 2) fracturing and faulting of the trap during late movement, thus destroying the seal and creating loss of the accumulation. Regional post-rift tilting due to subsidence created a strong northwest dip to the basin, and has been suggested to have destroyed many four-way closures (Gunn and Ly, 1989).

Intra-formational seals occur in the Hyland Bay Formation and the Kulshill Group and possible regional seals are the Mount Goodwin Formation (Tern 1) and the Fossil Head Formation. The north-western part of the basin appears to be gas prone with the only indications of oil in wells in the south (Turtle 1, Barnett 1, Cambridge 1 - drape anticlines; Lacrosse 1 - fault rollover). Geochemical studies indicate that the Permian sediments are dominantly gas/condensate prone with some intervals in the Kulshill Group capable of producing light oil. Both the Jurassic and Triassic are gas prone and the source rock potential of the Carboniferous and Devonian is very low (Gunn and Ly, 1989).

REFERENCES

ANFILOFF, V., 1988 : Polycyclic rifting - an interpretation of gravity and magnetics in the North West Shelf. In : Purcell, P.G., & Purcell, R.R., (Eds), The North West Shelf, Australia, Proceedings of Petroleum Exploration Society of Australia Symposium, Perth, 443-455.

BHATIA, M.R., THOMAS, M., & BOIRIE, J.M., 1984 : Depositional framework and diagenesis of the late Permian gas reservoirs of the Bonaparte Basin: APEA Journal, 24 (1), 299-313.

BRADSHAW, J., 1989 : Cross-section 2 - Arafura Basin : Phanerozoic History of Australia Project 175A : BMR-APIRA.

BROWN, C.M., 1979 : Bonaparte Gulf Basin explanatory notes and stratigraphic correlations : Bureau of Mineral Resources, Australia, Record 1979/52.

COMPAGNIE GENERALE DE GEOPHYSIQUE, 1965 : Timor Sea aeromagnetic survey : Report for Arco Limited and Australian Aquitaine Petroleum Pty Ltd.

GUNN, P.J., 1988, Hydrocarbon discoveries in the Bonaparte Basin. In : Purcell, P.G., & Purcell, R.R., (Eds), The North West Shelf, Australia, Proceedings of Petroleum Exploration Society of Australia Symposium, Perth, 563-9.

GUNN, P.J., & LY, K.C., 1989 : The petroleum prospectivity of the Joseph Bonaparte Gulf area, northwestern Australia : The APEA Journal 29 (1), 509-526.

HELBY, R., 1974a : A palynological study of the Petrel Formation : Report to Arco Australia Ltd. : In Jell, P.A., (Ed), Studies in Australian Mesozoic Palynology: Association of Australasian Palaeontologists, Memoir 4 - Fiche 1-5.

HELBY, R., 1974b : A palynological study of the Cambridge Gulf Group (Triassic - Early Jurassic) : Report to Arco Australia Ltd. : In Jell, P.A., (Ed), Studies in Australian Mesozoic Palynology: Association of Australasian Palaeontologists, Memoir 4 - Fiche 1-5.

HUGHES, R.J., 1978 : The geology and mineral occurences of Bathurst Island and Coburg Peninsula, Northern Territory : Bureau of Mineral Resources, Australia, Bulletin 177.

LAVERING, I.H., & OZIMIC, S., 1989 : Australian Petroleum Accumulations Report 5 Bonaparte Basin, N.T. & W.A. Bureau of Mineral Resources, Geology and Geophyics.

LAWS, R.A., 1981, The petroleum geology of the onshore Bonaparte Basin : APEA Journal, 21 (5), 5-15.

LAWS, R.A., & BROWN, R.S., 1976 : Petroleum geology of the southeastern Bonaparte Gulf Basin, In, Leslie, R.B., Evans, H.J., & Knight, C.I., (Eds), Economic geology of Australia and Papua New Guinea - 3, Petroleum : Australian Institute of Mining and Metallurgy, Monograph 3, 200-208.

LEE, R.J., & GUNN, P.J., 1988 : The Bonaparte Basin. In Petroleum in Australia, the first century. Australian Petroleum Exploration Association, 252-69.

MORY, A.J., (in press) : Geology of the offshore Bonaparte Basin : Geological Survey of Western Australia, Report 29.

NORVICK, M.S., & BURGER, D., 1975 : Palynology of the Cenomanian

of Bathurst Island, Northern Territory, Australia : Bureau of Mineral Resources, Australia, Bulletin 151.
VEEVERS, J.J., 1976 : Early Phanerozoic Events on and alongside the Australasian-Antarctic Platform : Journal of the Geological Society of Australia, 23 (2), 183 - 206.

PETREL SUB-BASIN -STRUCTURAL CROSS-SECTION

JOHN BRADSHAW

PLATE 1

Drafted by	John Vizy
Version 1	July,1989

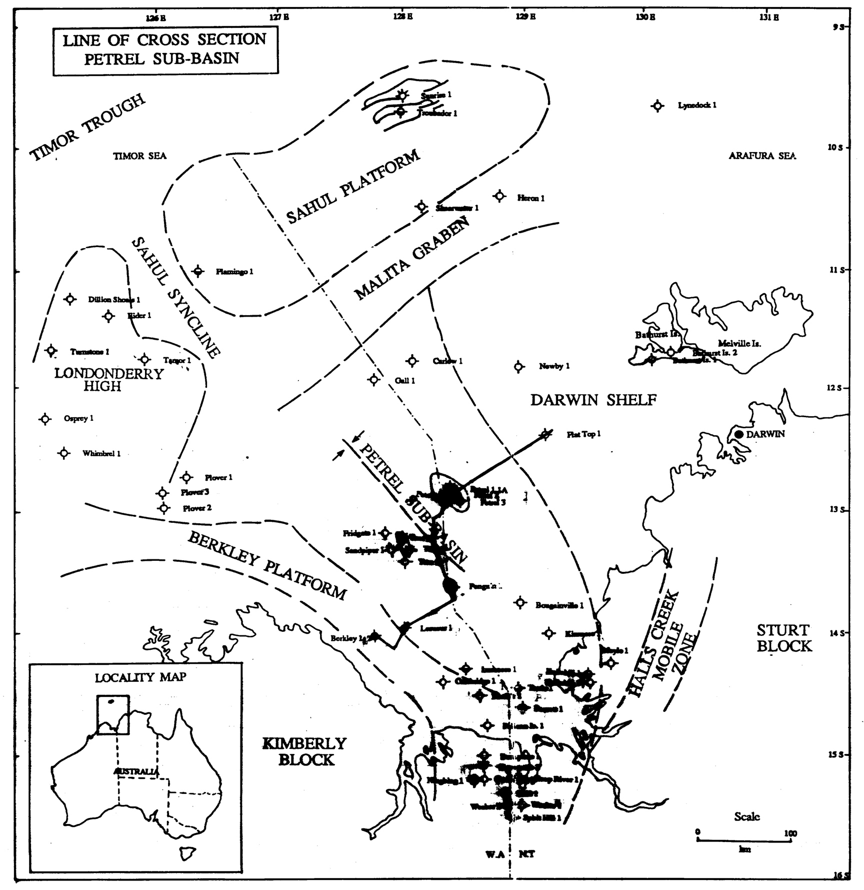
(Palaeogeographic Maps Project -Phase 2)

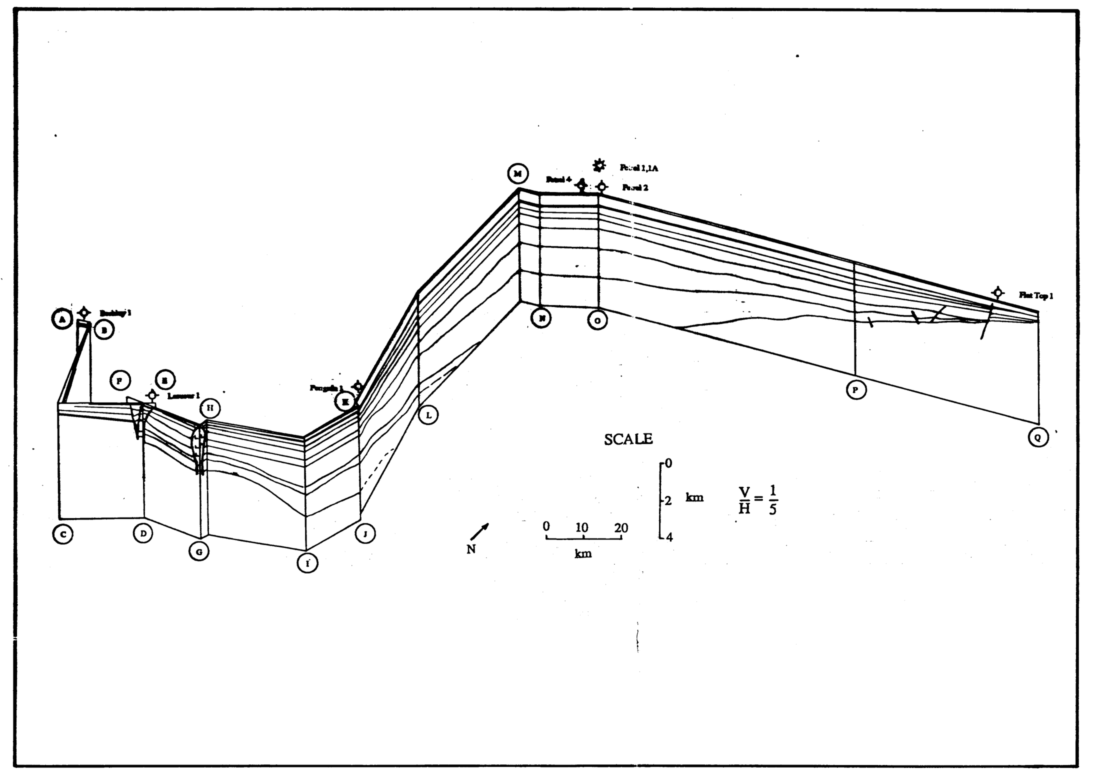
Phanerozoic History of Australia
Project 175A

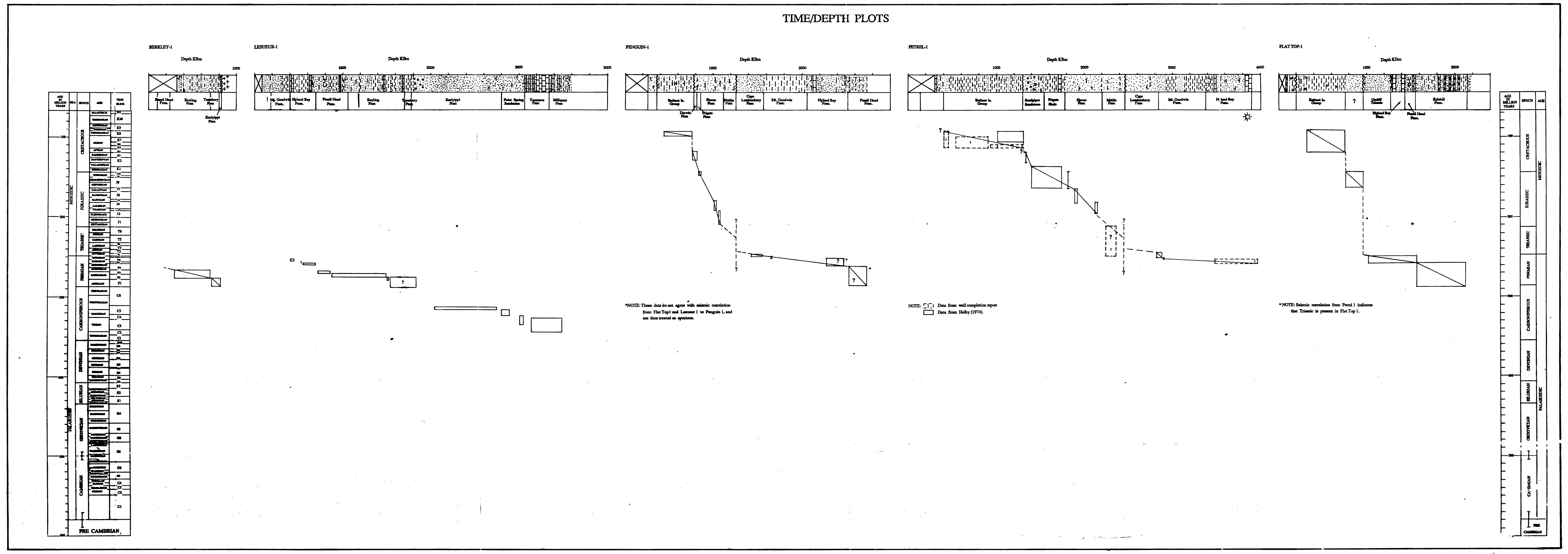
PLATE 2

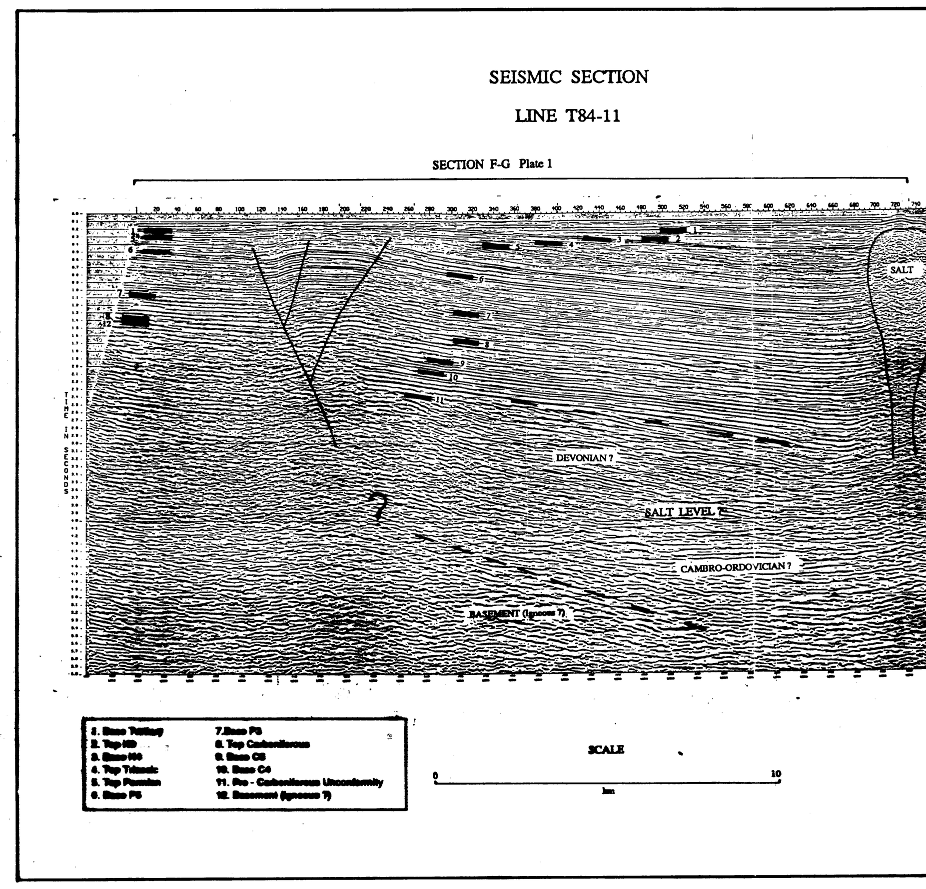
PETREL SUB-BASIN-BIOSTRATIGRAPHY, TECTONICS & GEOPHYSICS.

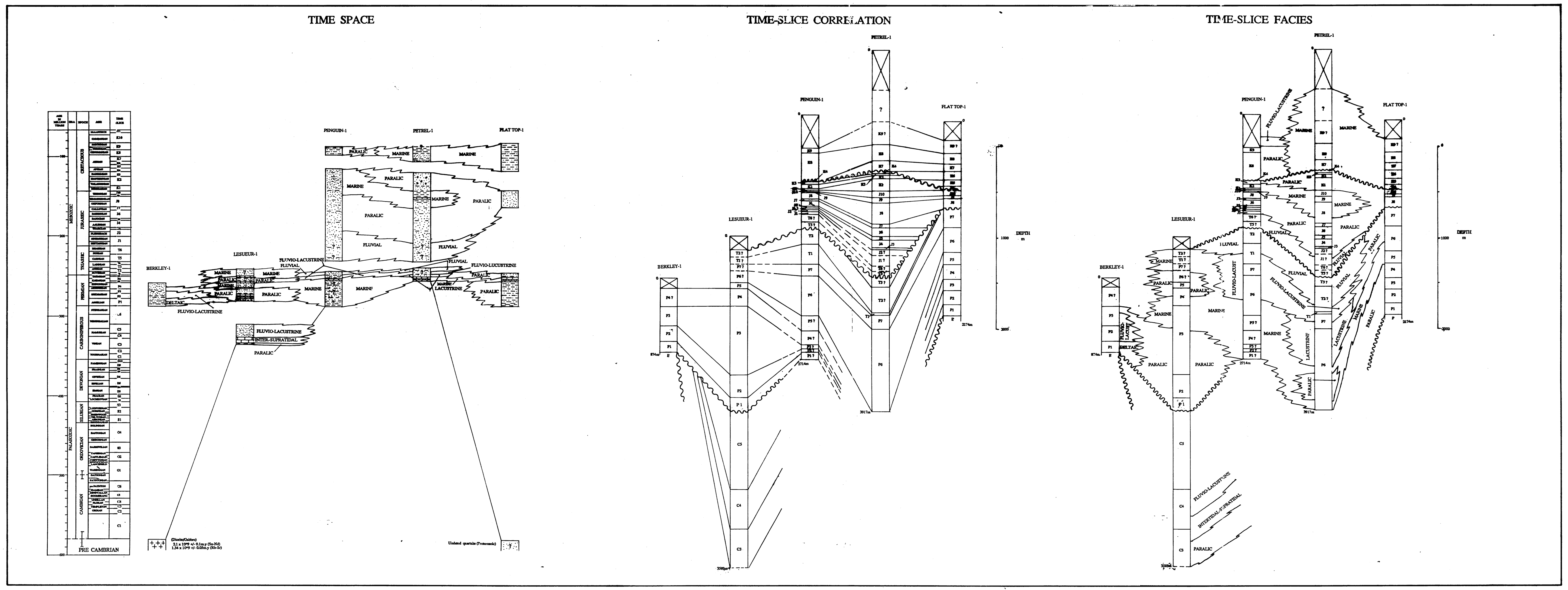
JOHN BRADSHAW

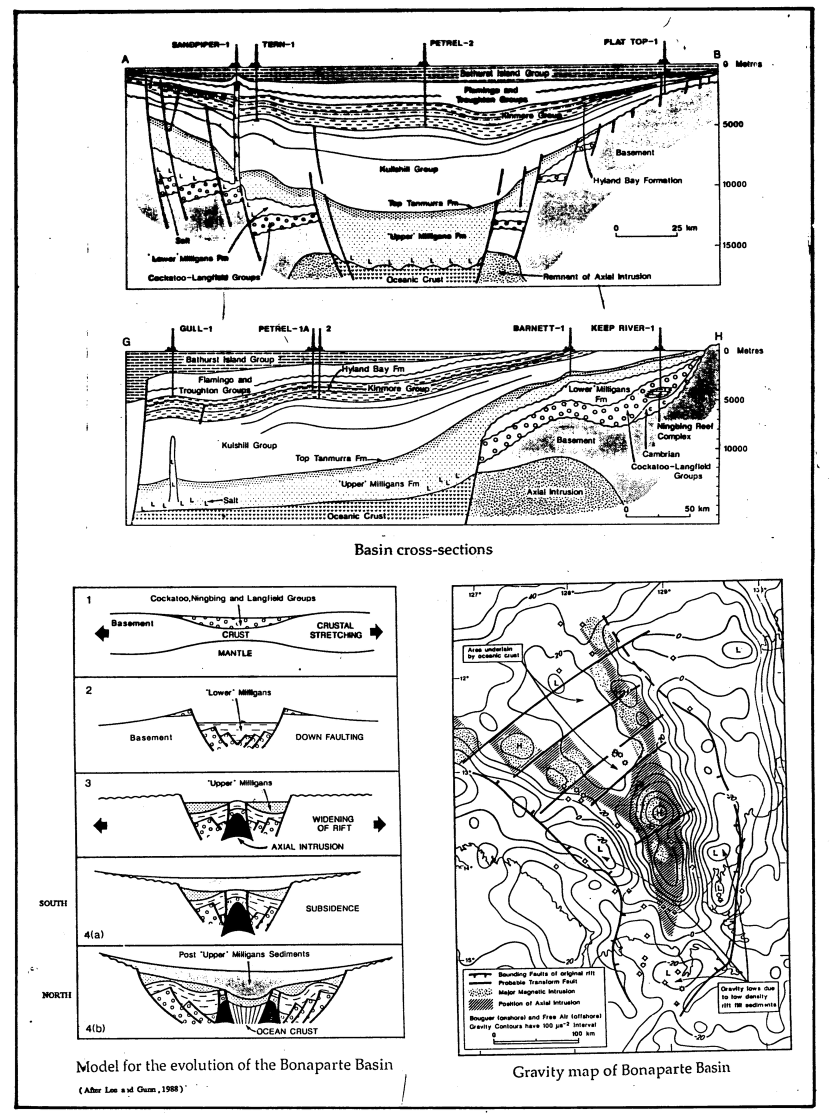












Drafted by	John Vizy
Version 1	July,1989

(Palaeogeographic Maps Project -Phase 2)

Phanerozoic History of Australia
Project 175A

PETREL SUB - BASIN PLATE 3

LINE T84-11

S.P. 1 TO 865

AUSTRALIAN AQUITAINE PETROLEUM
T84 SEISMIC SURVEY
PERMIT WA-18P

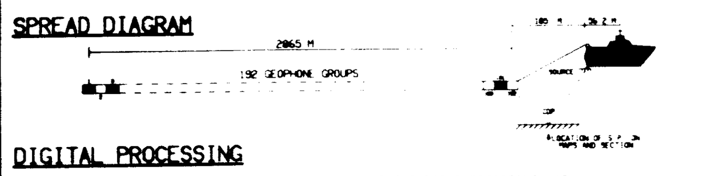
60 DEGREES → DIRECTION SHOT →

FILTERED SCALED STACK

FIELD DATA

DATA SHOT BY	GSI PARTY 2931 M V EUGENE MCDERMOTT II
DATE SHOT	APRIL 1984
RECORDING INSTRUMENTS	TRACE SEQUENTIAL RECORDER (TSR)
RECORDING FILTERS	HIGH-CUT FILTER AND SLOPE 128 HZ @ 72 DB/OCTAVE LOW-CUT FILTER AND SLOPE 8 HZ @ 18 DB/OCTAVE
RECORDING POLARITY	A NEGATIVE NUMBER ON TAPE IS A PRESSURE DECREASE
DIGITAL TAPE FORMAT	SEG B 6250 BPI PHASE ENCODED
RECORD LENGTH / SAMPLE RATE	6 0 SECONDS AT 2 MILLISECOND SAMPLE RATE
ENERGY SOURCE	4075 CU IN AIRGUN ARRAY OPERATING AT 2000 PSI
GUN DELAY	51 2 MILLISECONDS
SOURCE DEPTH	7 METRES AVERAGE
SOURCE TO ANTENNA DISTANCE	56 2 METRES
SHOTPOINT INTERVAL	30 METRES 1 POP PER SHOTPOINT
SHOTPOINT ANNOTATION	SHOTPOINTS ANNOTATED AT CDP POSITION
STREAMER LENGTH	2880 METRES 192 GROUPS 15 METRE GROUP INTERVAL
STREAMER TYPE	G S I MULTIPLEXOR STREAMER
STREAMER DEPTH	11 METRES AVERAGE
HYDROPHONES	80 PER GROUP
COVERAGE	48 FOLD 192 TRACE
PRIMARY NAVIGATION SYSTEM	SYLEDIS
BACKUP NAVIGATION SYSTEM	SAT/SONAR

SPREAD DIAGRAM



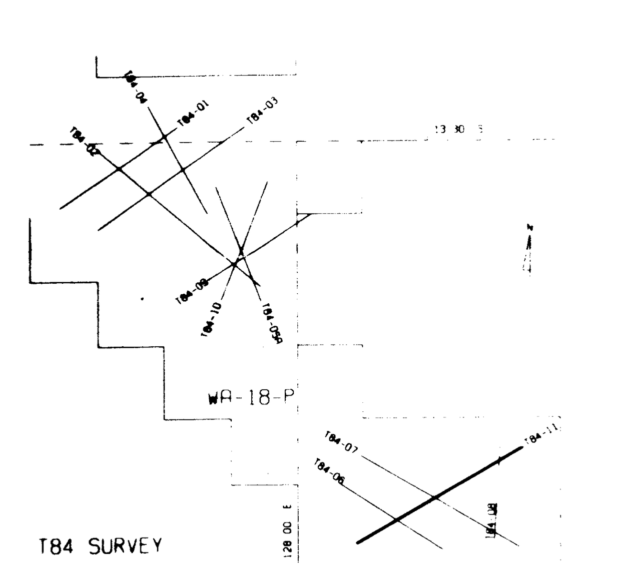
DIGITAL PROCESSING

POLARITY CONVENTION	THE POLARITY OF THE FIELD RECORDING WAS MAINTAINED THROUGHOUT THE PROCESSING AND DISPLAY
PROCESSING RECORD LENGTH	6 0 SECONDS
RESAMPLE	MINIMUM PHASE RESAMPLE FROM 2 TO 4 MSEC
PROCESSING SAMPLE PERIOD	4 MILLISECONDS
STATIC CORRECTIONS	SHOT AND STREAMER STATIC 11 MSEC AVERAGE AIRGUN DELAY 51 2 MSEC
ADJACENT TRACE SUM	ADJACENT FIELD TRACES SUMMED 2 ON 1
AMPLITUDE RECOVERY (TAR)	5 0 DB PER SECOND FROM 0 TO 4 0 SECONDS SPHERICAL DIVERGENCE CORRECTIONS APPLIED
PRE DECONVOLUTION MUTE	RAMP LENGTH 96 MSECS OFFSETS(METRES) 204 549 3069 START TIMES(MSECS) 0 500 2500
DECONVOLUTION	2 X 252 MSEC ACTIVE FILTER LENGTH GAP [illegible] MSEC OFFSETS(METRES) 204 549 3069 START TIMES(MSECS) 0 500 2500 END TIMES(MSECS) 6000 6000 6000
VELOCITY ANALYSIS	USING 9 DEPTH POINT [illegible] FUNCTION VELSCAN ANALYSES LOCATED ONE EVERY 3 KILOMETRES
NORMAL MOVEOUT CORRECTION	USING ANNOTATED VELOCITIES
FIRST BREAK SUPPRESSION	RAMP LENGTH 96 MSECS OFFSETS(METRES) 204 549 3069 START TIMES(MSECS) 0 430 2550
COMMON DEPTH POINT STACK	48 FOLD CDP STACK
ADJACENT TRACE MIX	2 ON 1
TIME VARIANT FILTERING	FREQUENCY(HZ) TIME MSEC 20 80 0 8 80 1800 8 60 3000 8 30 5000
TIME VARIANT SCALING	DIGITAL GAIN CONTROL SCALING USING 500 MSEC GATES START TIME [illegible] 100 MSEC

DISPLAY

HORIZONTAL SCALE	7 69 TR/CM 33 33 TR/KM
VERTICAL SCALE	3 75 IN SEC
POLARITY	NORMAL
TRACE TYPE BIAS	WTVAR 5 0 PERCENT
DATUM	SEA LEVEL
DISPLAY UNIT	0 677333 CM

DISPLAY GAIN

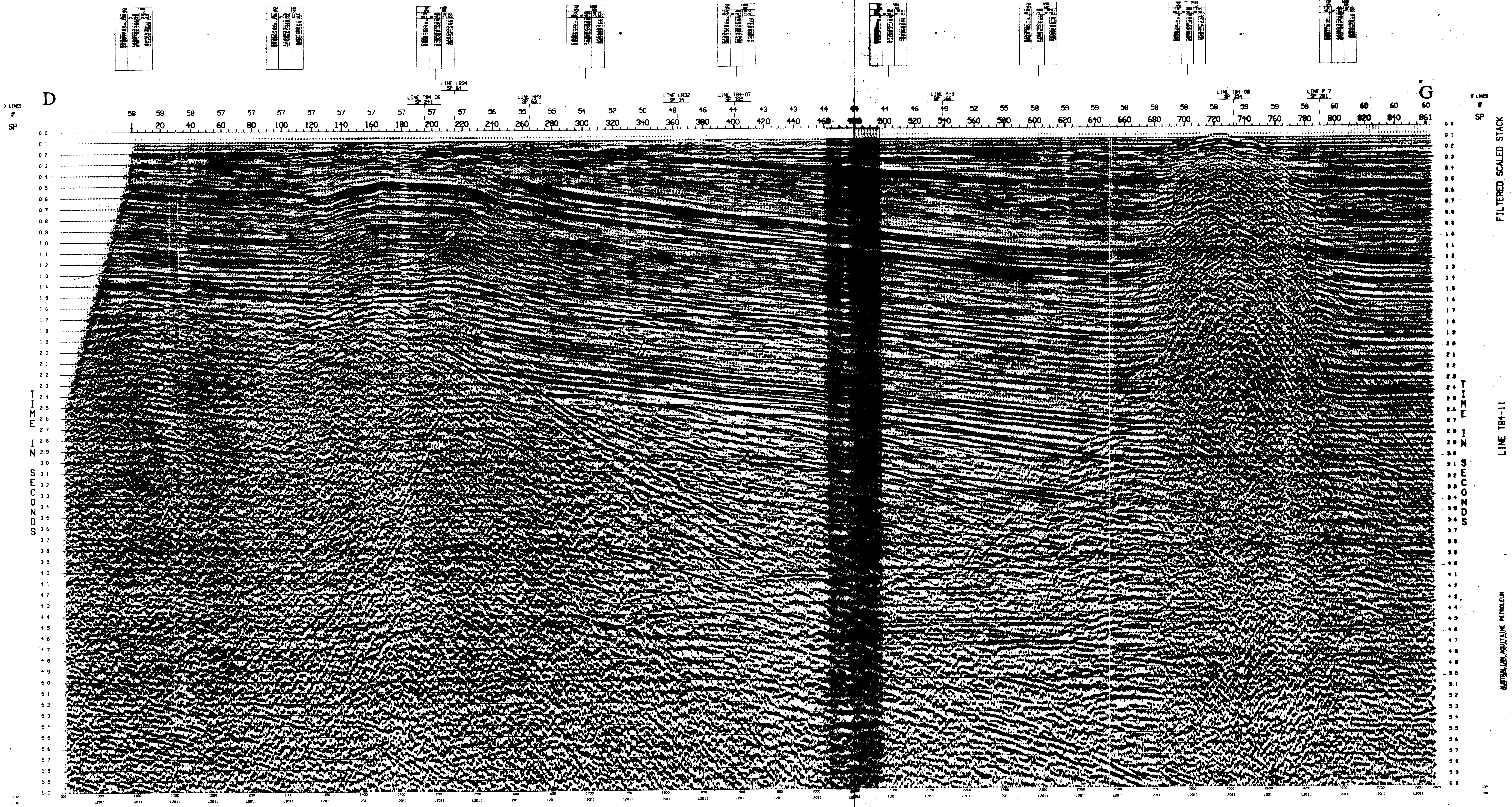


25 AUG 1984

PARTY 6860

GEOPHYSICAL SERVICE INTERNATIONAL
(A DIVISION OF TEXAS INSTRUMENTS LTD)

PROCESSING CHECKED BY -



R9007204

PETREL SUB - BASIN PLATE 4

LINE T84-11
S.P. 1 TO 865

AUSTRALIAN AQUITAINE PETROLEUM
T84 SEISMIC SURVEY
PERMIT WA-18P

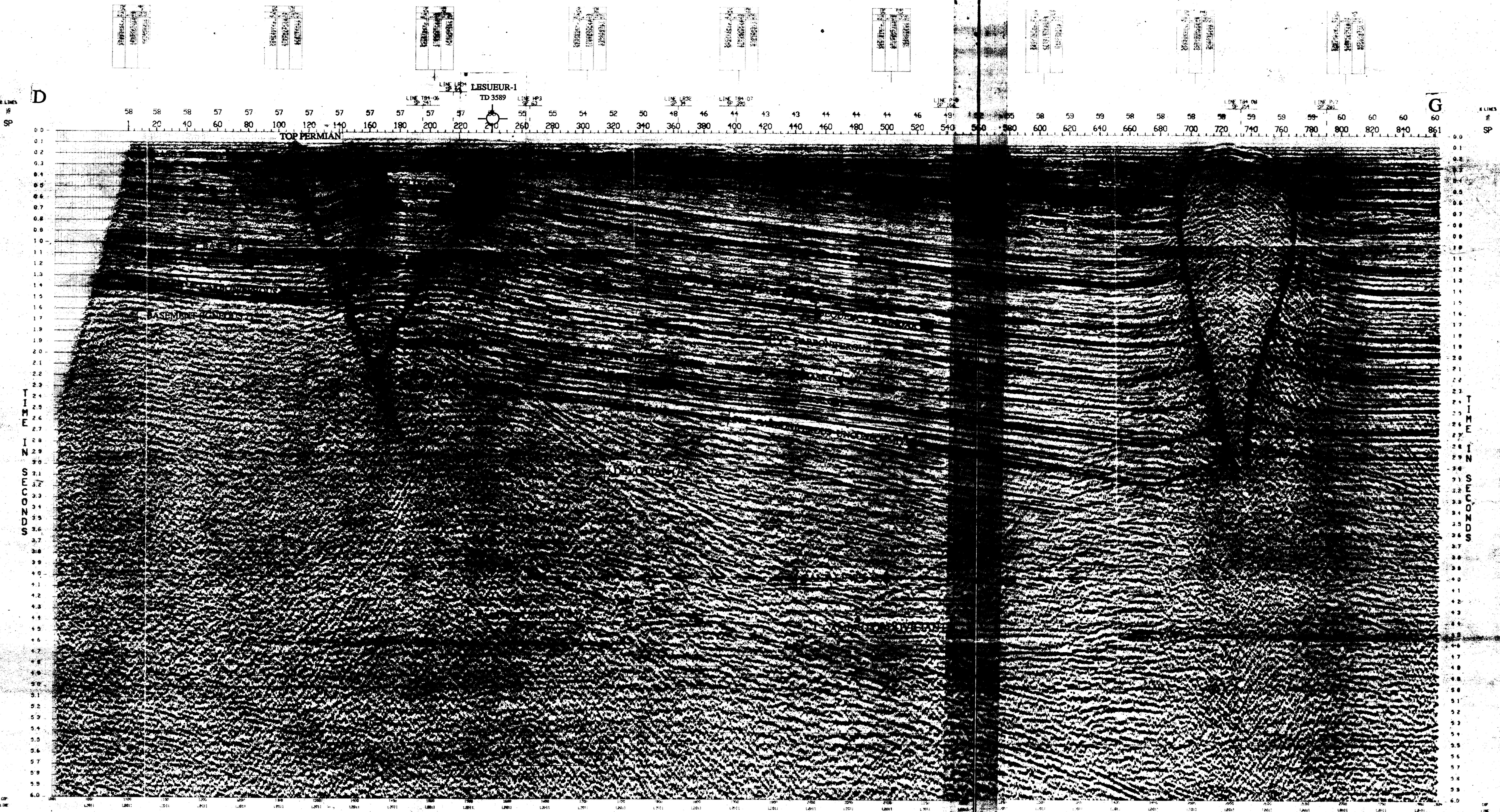
FILTERED SCALED STACK

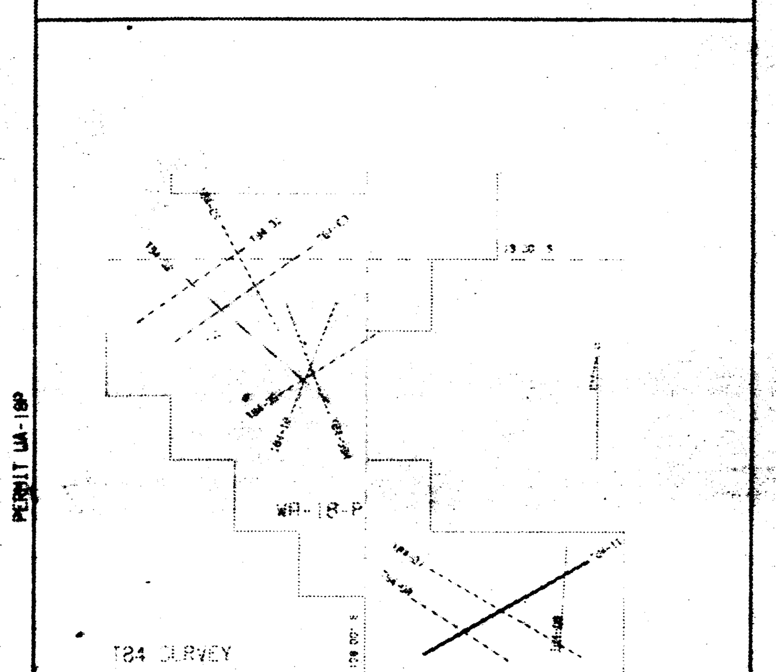
FIELD DATA

SPREAD DIAGRAM

DIGITAL PROCESSING

DISPLAY





GEOPHYSICAL SERVICE INTERNATIONAL
(A DIVISION OF TEXAS INSTRUMENTS LTD)

PROCESSING CHECKED BY

R9007205

PETREL SUB - BASIN PLATE 5

PETREL SUB - BASIN PLATE 6