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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

APIRA

AUSTRALIAN PETROLEUM SYSTEMS

THERMAL MODELLING ON THE NORTH WEST SHELF

Volume 1

by

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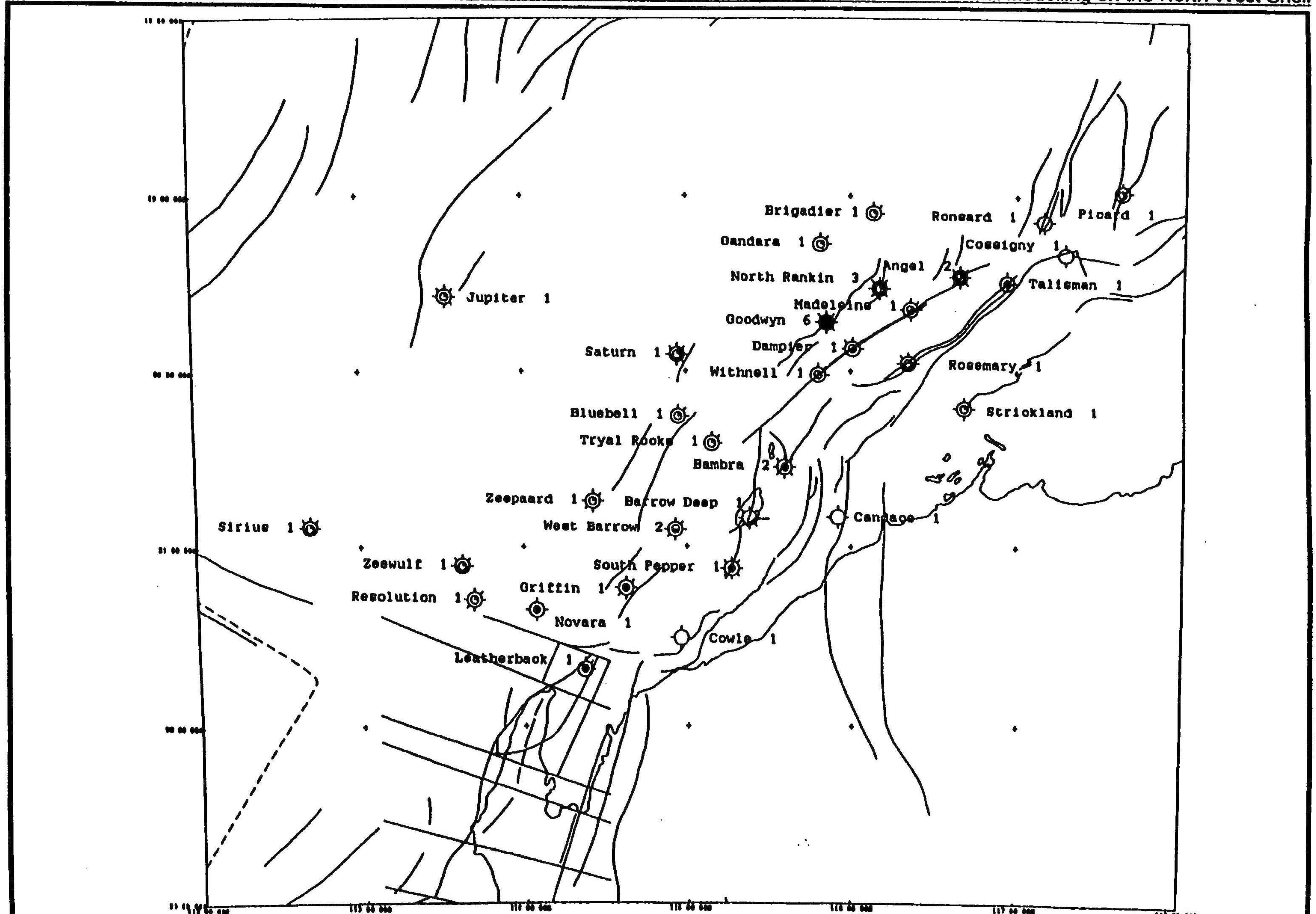

FIGURE 1 LOCATION MAP: WESTERN NORTH WEST SHELF

INTRODUCTION

As part of the AGSO-APIRA Australian Petroleum Systems Project, 48 wells (Appendix 1) from the offshore North West Shelf were studied to provide information on timing and amounts of

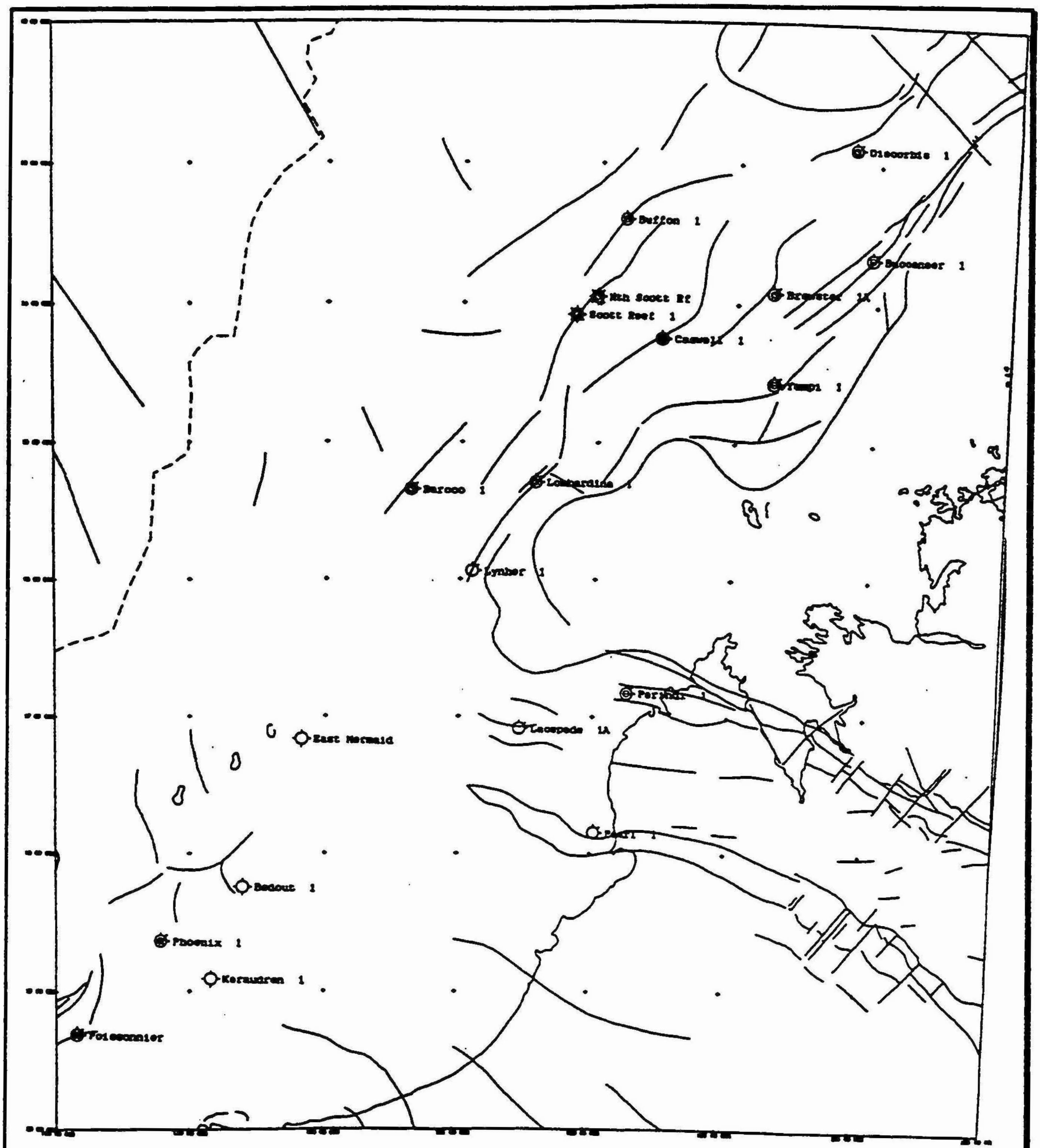

FIGURE 2 LOCATION MAP: NORTHERN NORTH WEST SHELF

hydrocarbons generated and expelled. The study used WinBury v2, a burial and thermal geohistory software package for Windows ™, to model the palaeothermal parameters.

WinBury is a one-dimensional heatflow modelling package which takes well stratigraphic data and maturity as input, and outputs computed palaeotemperature and downhole maturity (using the industry standard algorithm of Burnham & Sweeney, 1992). By forward modelling the palaeowaterdepth (directly linked to palaeo-sea bottom temperature) and palaeoheatflow variables, a best fit may be derived to observed maturity data, implying a valid palaeotemperature model at all levels in the well. This palaeotemperature model is then applied to the kerogen types present in the source rocks (using industry standard algorithms of Tissot and Welte, 1978) to predict when source rocks would generate and expel hydrocarbons.

Output from WinBury may be viewed on a single or multi-well basis. Single well output is described in the Appendix 1. This section describes the input data, modelling procedure and uses the multi-well viewing capabilities of WinBury to discuss the theoretical considerations involved in this study.

To facilitate map output the wells studied have been divided into two areas shown on Figures 1 and 2. These areas are referred to as the Western North West Shelf and the Northern North West Shelf.

INPUT DATA

Global Data

Chronostratigraphy

The time scale of Harland et al (1982) was used for this study. This time scale has been used in the three AGSO-APIRA projects, Palaeogeography of Australia, Phanerozoic History of Australia and Australian Petroleum Systems. Its retention allows easy use of previous results and variations from the most recent time scales (Jones et al. 1996) are minor in the Mesozoic and negligible in the Cainozoic.

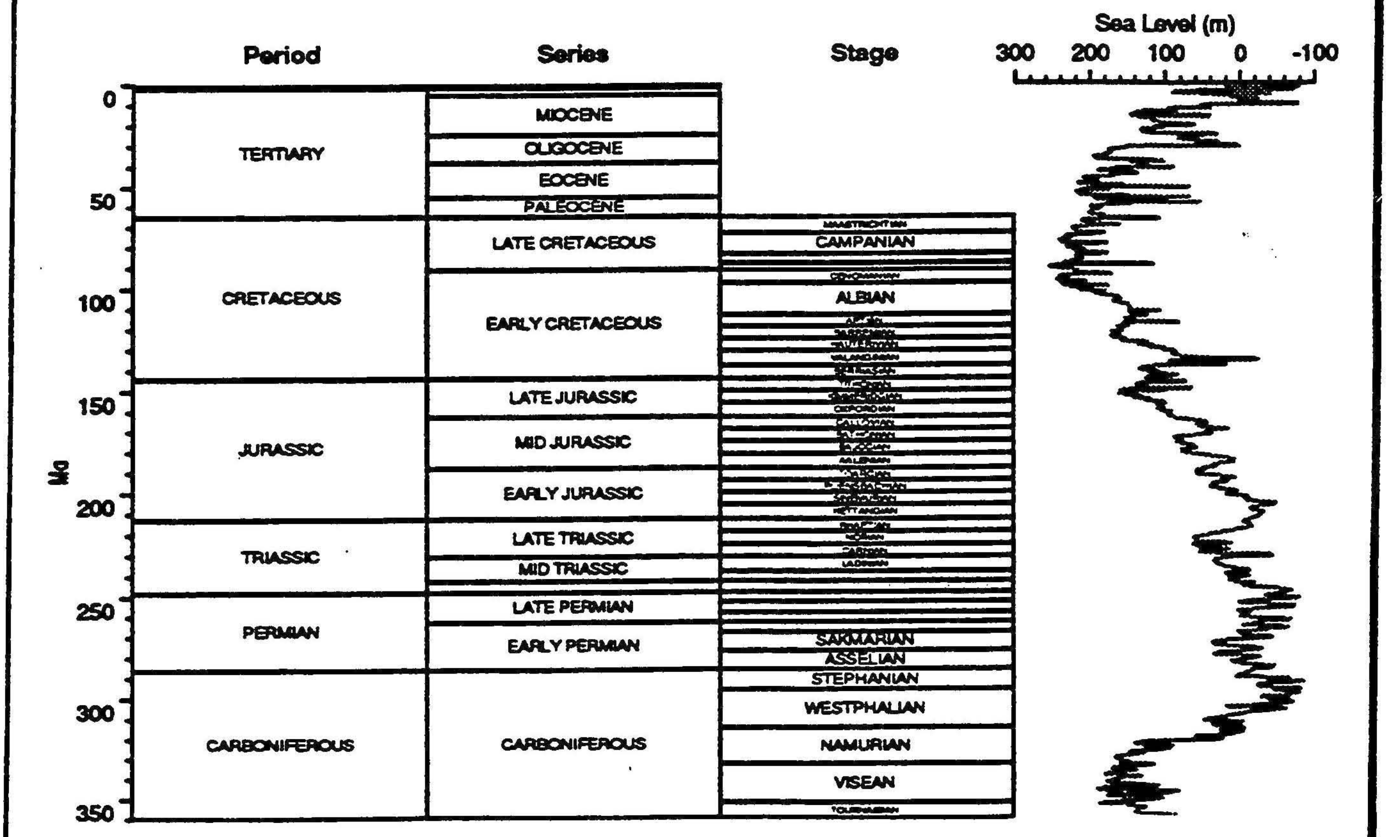

FIGURE 3 CHRONOSTRATIGRAPHY AND SEA LEVEL

Sea Level Curve

The short wavelength sea-level curve of Haq et al (1988) with extensions back to the Permian (developed at AGSO) was used, with all ages stretched to the Harland (1982) time scale (Fig. 3).

Lithology Definitions

The following table shows the parameters for each of the nine component matrix types.
Matrix density is in gm/cc, matrix conductivity in cal.gm^{-1} °C^{-1}. The ϕ/Depth factor is the term k in the following expression of porosity versus depth from Falvey & Middleton (1981) :

$$-\frac{1}{\phi_z} = \frac{1}{\phi_0} + kz,$$ where ϕ = porosity and z = depth.

Table 1: Matrix Lithology, Density, Conductivity and Porosity

N O	Matrix Name	Matrix Density	Matrix Conductivity	Initial Porosity	ø/Depth Factor
1	Shale	2.800	4.600	0.700	2.430
2	Sandstone	2.650	12.000	0.400	0.400
3	Chalk	2.750	7.000	0.700	2.430
4	Limestone	2.750	8.000	0.400	1.200
5	Coal	1.550	1.000	0.700	5.000
6	Dolomite	3.800	11.500	0.400	1.200
7	Volcanics	2.760	7.000	0.050	0.500
8	Siltstone	2.800	4.800	0.600	2.000
9	Anhydrite	2.910	13.400	0.450	10.000

Kinetic Definitions

In the kerogen degradation model of Tissot & Welte (1978) the relationship between temperature and the rate of each kerogen bond reaction is given by the Arrhenius equation:

$$dx_n/dt = A_n \exp(-E_n/RT)\, x_n$$

where x_n (mg/gram) is the residual petroleum potential (or *bond frequency*) of bond n, A_n is the *rate constant* (sec^{-1}) for each bond (also called the frequency factor), E_n is the *activation energy* (effectively defining the temperature of the reaction), R is the universal gas constant and T is the absolute temperature (°K).

Table 2: Bond Parameters for Type II Kerogen:

N O	Activation Energy	Rate Constant	Bond Frequency	Reactant	Product
1	49	9.5E+0026	17.500	kerogen	oil
2	50	9.5E+0026	70.000	kerogen	oil
3	50	9.5E+0026	16.000	kerogen	oil
4	51	9.5E+0026	175.000	kerogen	oil
5	51	9.5E+0026	35.000	kerogen	gas, residue
6	52	9.5E+0026	70.000	kerogen	oil
7	52	9.5E+0026	14.000	kerogen	gas, residue
8	53	9.5E+0026	17.500	kerogen	oil
9	54	3.2E+0025	40.000	oil	gas, residue

All source rocks in the study were made up of combinations of the standard Type II and III kerogen types of Tissot & Welte (1978). However, the bond parameters for these standard types used were modified from those of Burnham & Sweeney (1992). These are shown in the adjacent tables.

Table 3: Bond Parameters for Type III Kerogen.

NO	Activation Energy	Rate Constant	Bond Frequency	Reactant Code	Product Code
1	48	5.1E+0026	3.000	kerogen	oil
2	50	5.1E+0026	10.000	kerogen	oil
3	52	5.1E+0026	24.000	kerogen	oil
4	52	5.1E+0026	20.000	kerogen	gas, residue
5	54	5.1E+0026	13.000	kerogen	oil
6	56	5.1E+0026	54.000	kerogen	gas, residue
7	60	5.1E+0026	18.000	kerogen	gas, residue
8	64	5.1E+0026	13.000	kerogen	gas, residue
9	68	5.1E+0026	5.000	kerogen	gas, residue
10	54	3.2E+0025	40.000	oil	gas, residue

Well Header Data

Basic information (Latitude, Longitude, KB, TD, GL) was taken from the PEDIN database. The following items are part of the modelling process.

Surface Temperature

See note below on sea bottom temperature.

Bottom Hole Temperatures (BHT)

Bottom Hole Temperatures were derived from information in well completion reports. Where possible, nearby temperature measurements were combined using the Horner Plot method to derive a stabilised borehole temperature.

Basement Depth.

While this may be the depth to incompactable sediment, it may also be real basement. Very rarely is it compatible with aeromagnetic basement, which may include intrusive volcanic layers. For this study the WinBury default depth of 10km was used.

Well Stratigraphic Data

Stratigraphic Units/Eroded Beds

Time slice tops were derived from STRATDAT. For particular wells, the STRATDAT data was supplemented with time slice picks from the first AGSO-APIRA project, Palaeogeography of Australia (Langford et al, 1995). Erosional events were based on seismic interpretation.

Palaeowater-depth Model

Palaeoenvironment interpretations were derived from the RESFACS database. These usually indicate a range of waterdepths through the deposition of each time slice. The environments have been interpreted from well logs, core cuttings descriptions, palaeontologic data and palaeogeographic descriptions. They have been strictly adhered to in this study. The modelled palaeowater-depth was determined by smoothing the tectonic subsidence curve through time, within

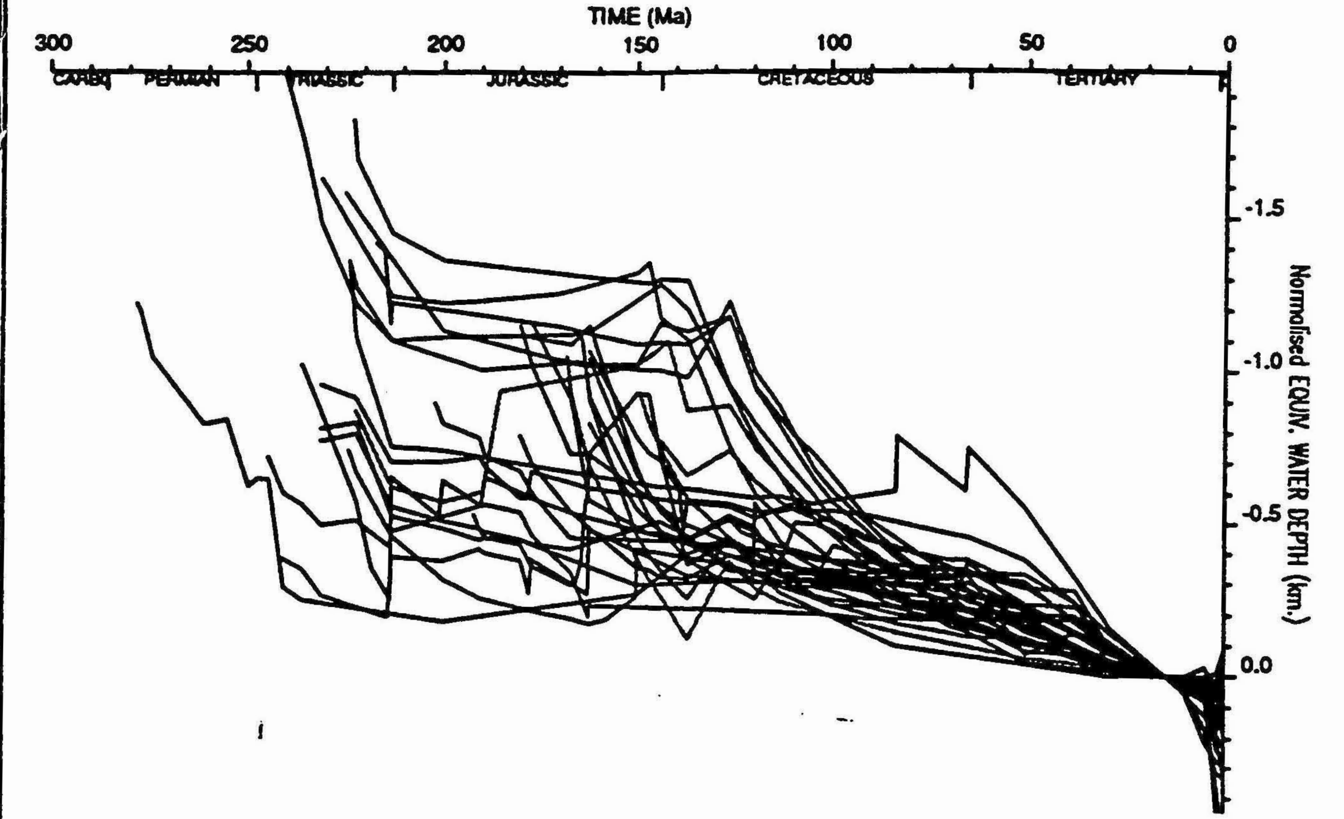

FIGURE 4A(i)
NORMALISED AT 15MA STRIPPED BASEMENT VS TIME, WESTERN NORTH WEST SHELF

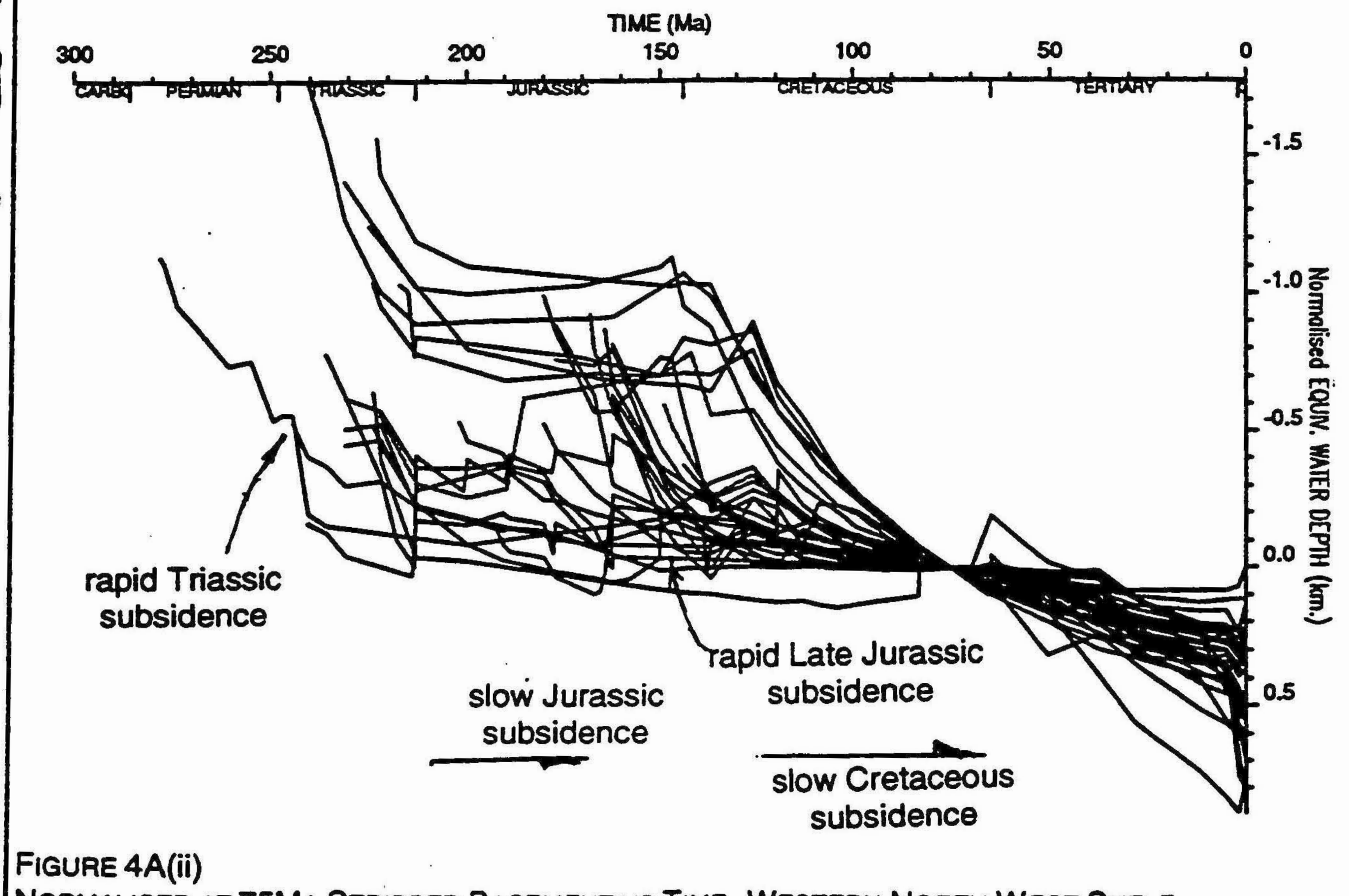

FIGURE 4A(ii)
NORMALISED AT 75MA STRIPPED BASEMENT VS TIME, WESTERN NORTH WEST SHELF

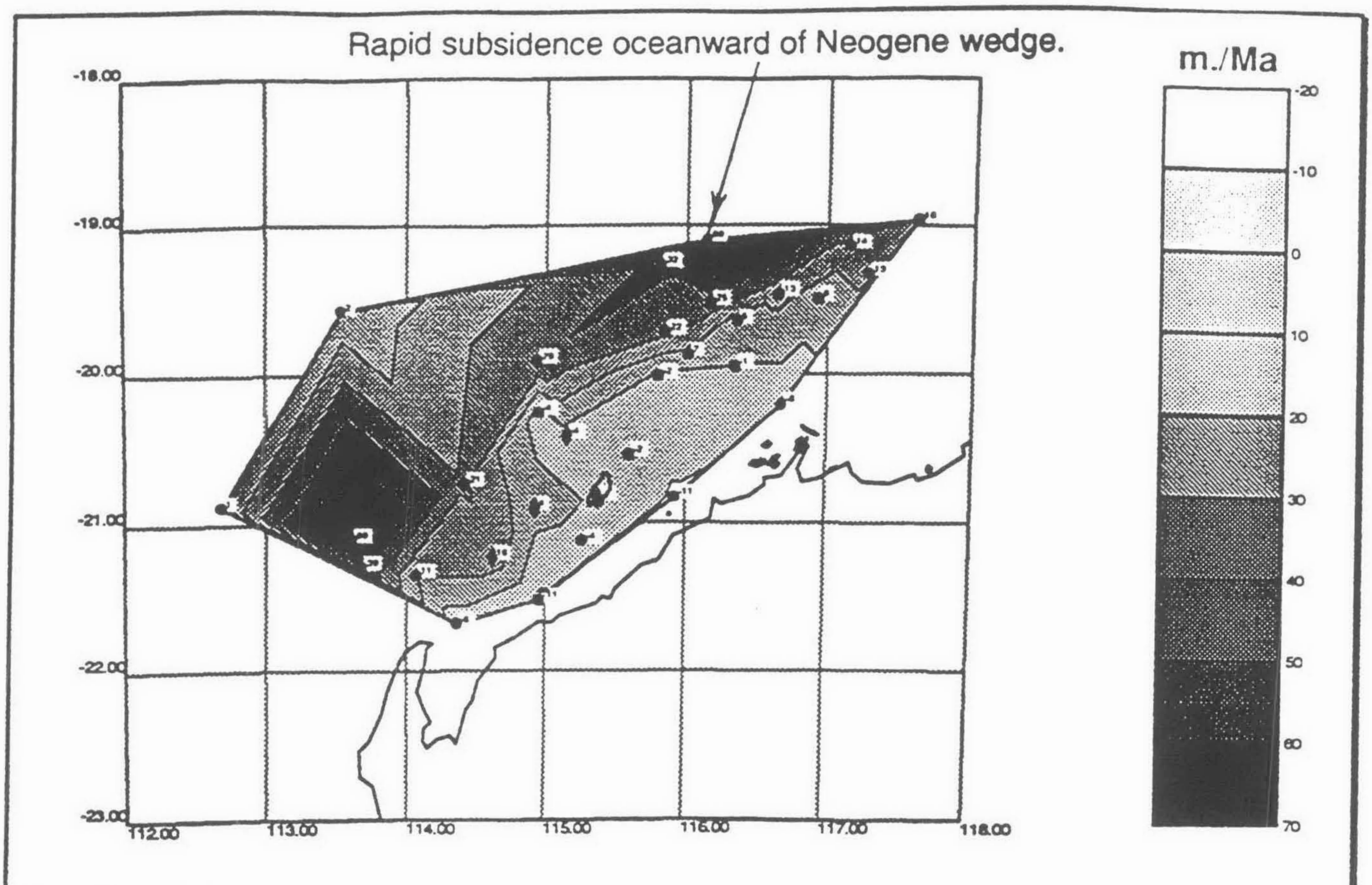

FIGURE 4A(iii)
STRIPPED BASEMENT CHANGE RATE MAP (m/MA) : 8 TO 0 MA, WESTERN NORTH WEST SHELF

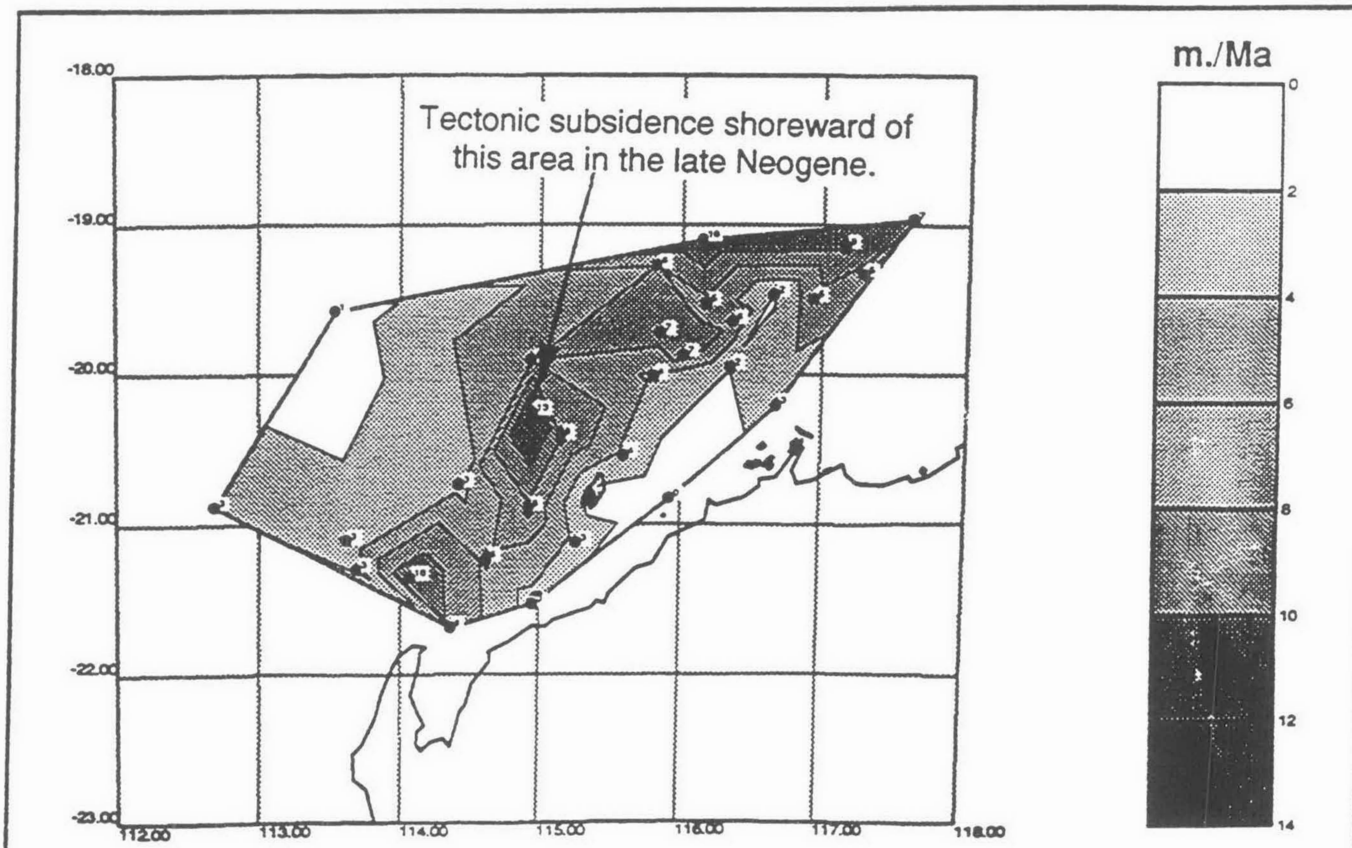

FIGURE 4A(iv)
STRIPPED BASEMENT CHANGE RATE MAP (m/MA) : 35 TO 8 MA, WESTERN NORTH WEST SHELF

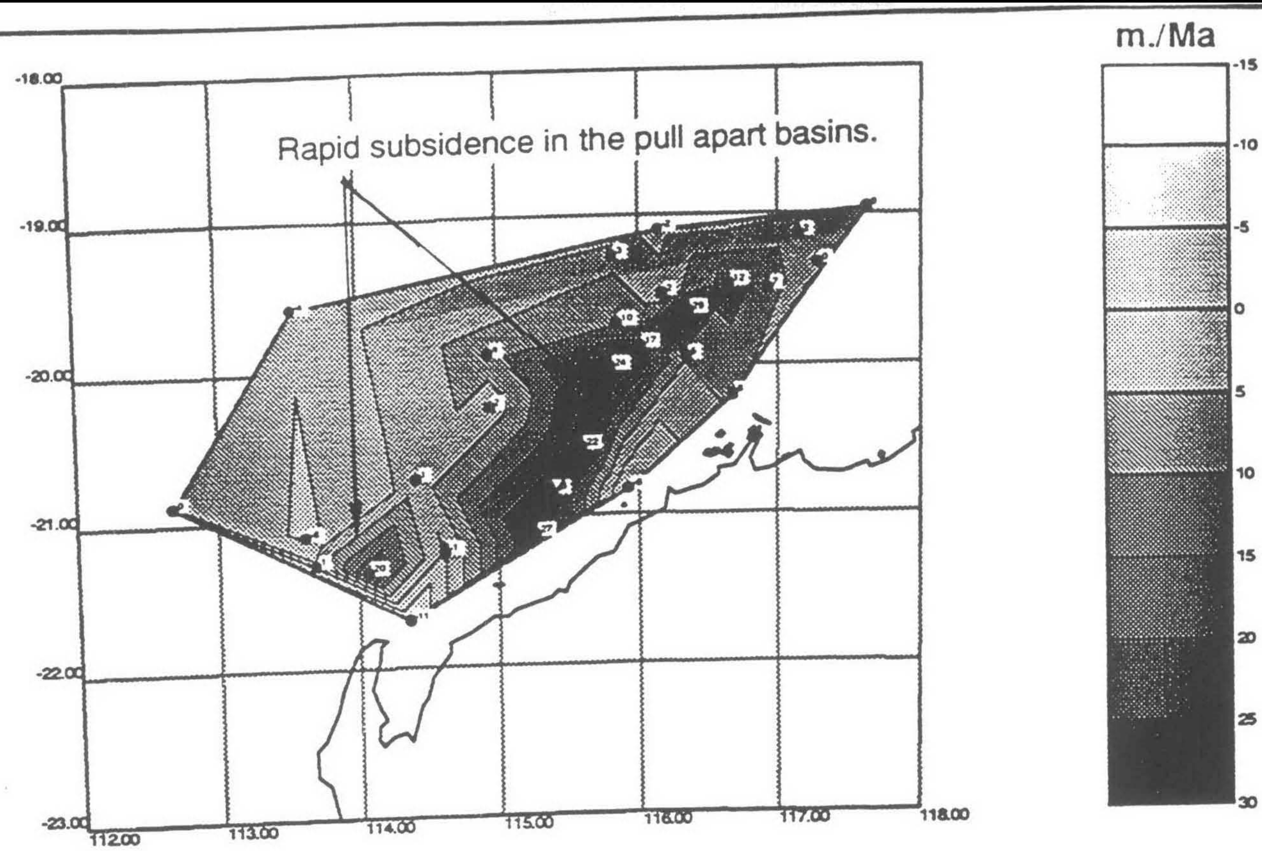

FIGURE 4A(v)
STRIPPED BASEMENT CHANGE RATE MAP (m/MA) :160 TO 140 MA WESTERN NORTH WEST SHELF

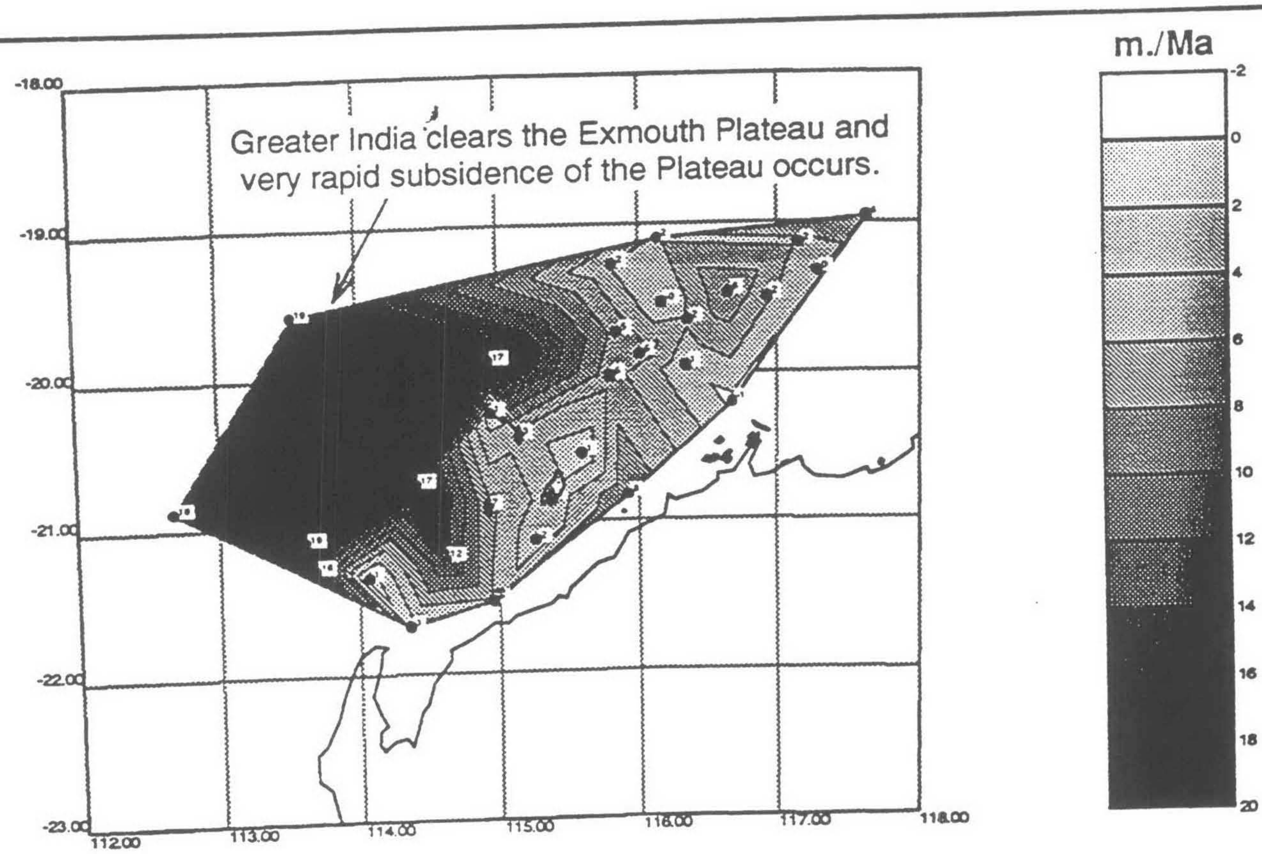

FIGURE 4A(vi)
STRIPPED BASEMENT CHANGE RATE MAP (m/MA) :130 TO 100MA WESTERN NORTH WEST SHELF

the limits imposed by these palaeoenvironmental determinations. This procedure is discussed fully in Appendix 2.

- Western North West Shelf Area (Figure 4 : A series)

Figure 4A(i) shows the stripped basement curves for the western North West Shelf area. The curves have been normalised (offset to zero) at 15 Ma. Figure 4A(ii) shows the stripped basement curves for the western North West Shelf area normalised at 75 Ma to enhance several features.

These curves show two Tertiary tectonic subsidence phases :-

1. Late Tertiary loading. This phase relates to the rapid build-out of the late Neogene carbonate wedge. It causes overly rapid subsidence in wells oceanward of the wedge and slight uplift in wells shoreward of the wedge. This is shown in Figure 4A(iii) which shows the *rate* of tectonic subsidence from 8 Ma to present. The main area of subsidence is oceanward of the Neogene wedge; the main area of tectonic subsidence is landward of it eg. Barrow Island.
2. Early/Mid Tertiary loading. Similarly, the build-out of a Palaeogene to early Neogene carbonate wedge resulted in increased tectonic subsidence. This can be seen on Figure 4A(iv), showing the main area of tectonic subsidence to be shoreward of that applying in the late Neogene.

Tectonic subsidence in the Triassic to Cretaceous is more complex. Figure 4A(ii) shows that, amongst the random trends for many wells, there appear to be three patterns :-

1. Rapid subsidence in the Triassic followed by slow subsidence in the Jurassic.
2. Rapid subsidence in the Late Jurassic followed by slow subsidence through the Cretaceous. Figure 4A(v) shows the rate of tectonic subsidence between 160 to 140 Ma, and indicates that these wells occupy the main pull-apart basin axis trend.
3. Rapid subsidence in the Early Cretaceous declining gradually through the Cretaceous and Tertiary. Figure 4A(vi) shows the rate of tectonic subsidence between 130 to 100 Ma, and indicates that these wells are predominantly on the Exmouth Plateau. Rapid subsidence here takes place immediately after Greater India clears the end of the Exmouth Plateau.

- Northern North West Shelf Area (Figures 4 : B series)

Figure 4B(i) shows the stripped basement curves for the northern North West Shelf area. The curves have been normalised (offset to zero) at 65 Ma. Figure 4B(ii) shows the stripped basement curves for the northern North West Shelf area normalised at 180 Ma to enhance several features.

The curves show two Tertiary tectonic subsidence phases :-

1. Tertiary loading. During the Tertiary, buildout of a carbonate wedge resulted in increased tectonic subsidence. This event seems to apply in most wells.
2. Late Tertiary Plate Collision. Superimposed on the above process is a phase of increased subsidence in the late Tertiary. This phase probably relates to the collision of the northwest Australian margin with Timor. Plate collision leads to increased tectonic subsidence primarily because of shortening of the crust (cf extension during rifting). Figure 4B(iii) shows that this subsidence is greatest in the north-west as expected.

Pre Tertiary tectonic subsidence is hard to characterise in the wells studied in the northern North West Shelf area. A weak phase of rapid subsidence takes place in the late Jurassic.

Temperature

• Sea bed temperature

Because of the large differences between palaeo-water depths in this project, ranging from near shore at Barrow Island to bathyal on the Exmouth Plateau, both at present and in the past, it is important to consider the link between waterdepth and temperature. Palaeoseabed (or palaeo-surface) temperatures were modelled using specific lookup tables for each area which relate palaeowaterdepth to palaeo-sea bottom temperature. An example lookup table (Table 4 next page) is shown below and defines the connection between age, palaeowaterdepth and palaeo-sea bottom

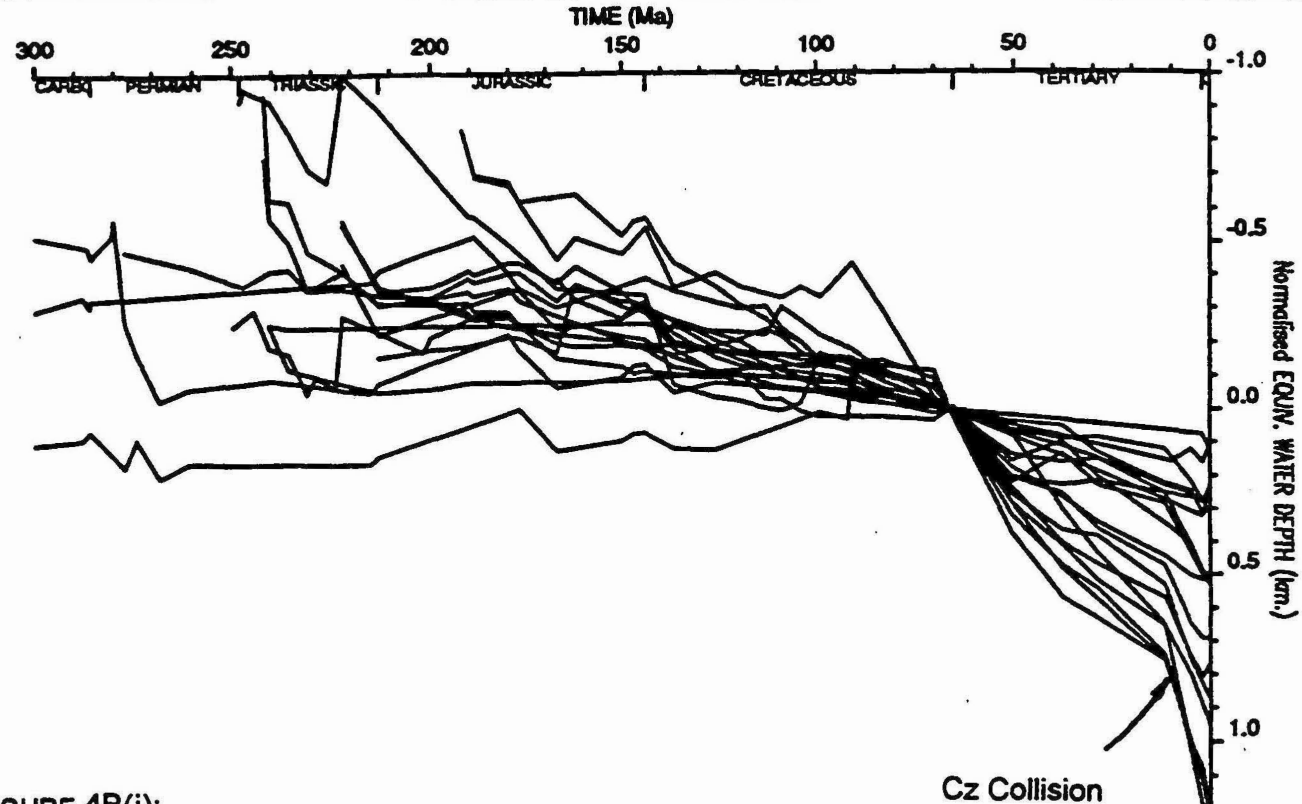

FIGURE 4B(i):
NORMALISED AT 65MA STRIPPED BASEMENT VS TIME, NORTHERN NORTH WEST SHELF

temperature. For further discussion see Appendix 2.

• Heatflow

Figures 5 A & B shows the present day heatflow calculated by WinBury from :-

- surface temperatures,
- thermal conductivities derived from input lithologies
- and BHT's.

• Palaeoheatflow model

Sea floor spreading studies (Gillis et al 1992 & Ogg et al 1992) indicate that ocean floor spreading off the North West Shelf commenced at two different times :

1. Argoland Breakup commenced at about 160 Ma
2. Gascoyne-Cuvier Breakup commenced at about 140 Ma.

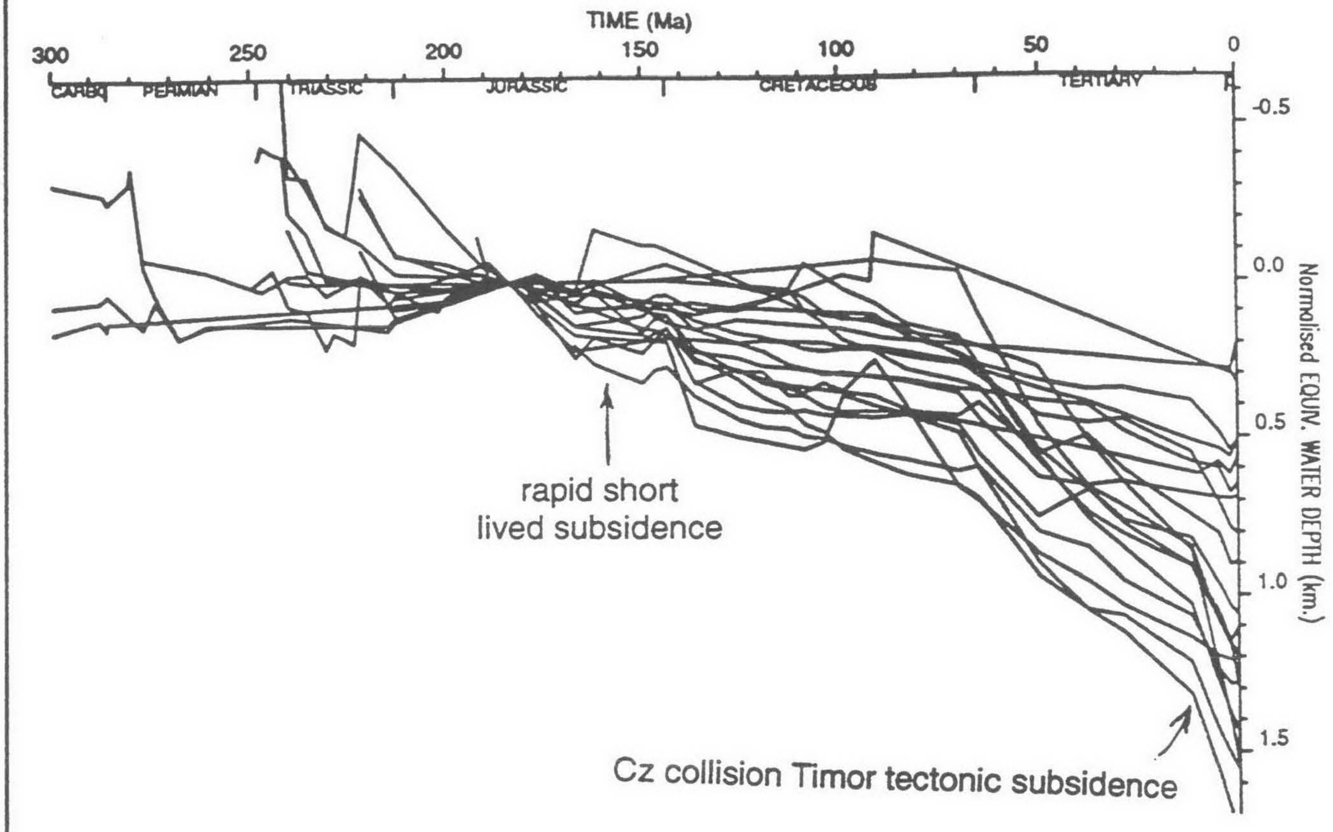

FIGURE 4B(ii)
NORMALISED AT 180MA STRIPPED BASEMENT VS TIME, NORTHERN NORTH WEST SHELF

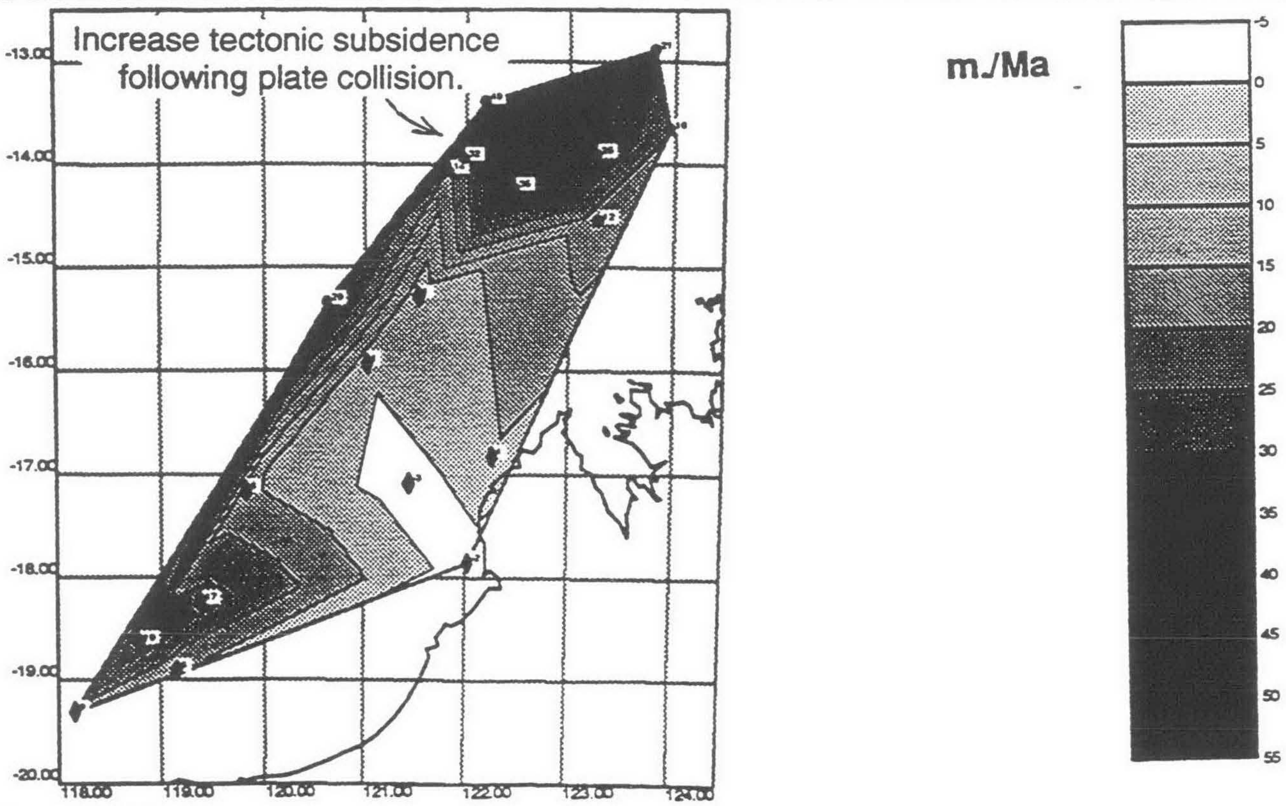

FIGURE 4B(iii)
STRIPPED BASEMENT CHANGE RATE MAP (m/MA) : 15 TO 0 MA, NORTHERN NORTH WEST SHELF

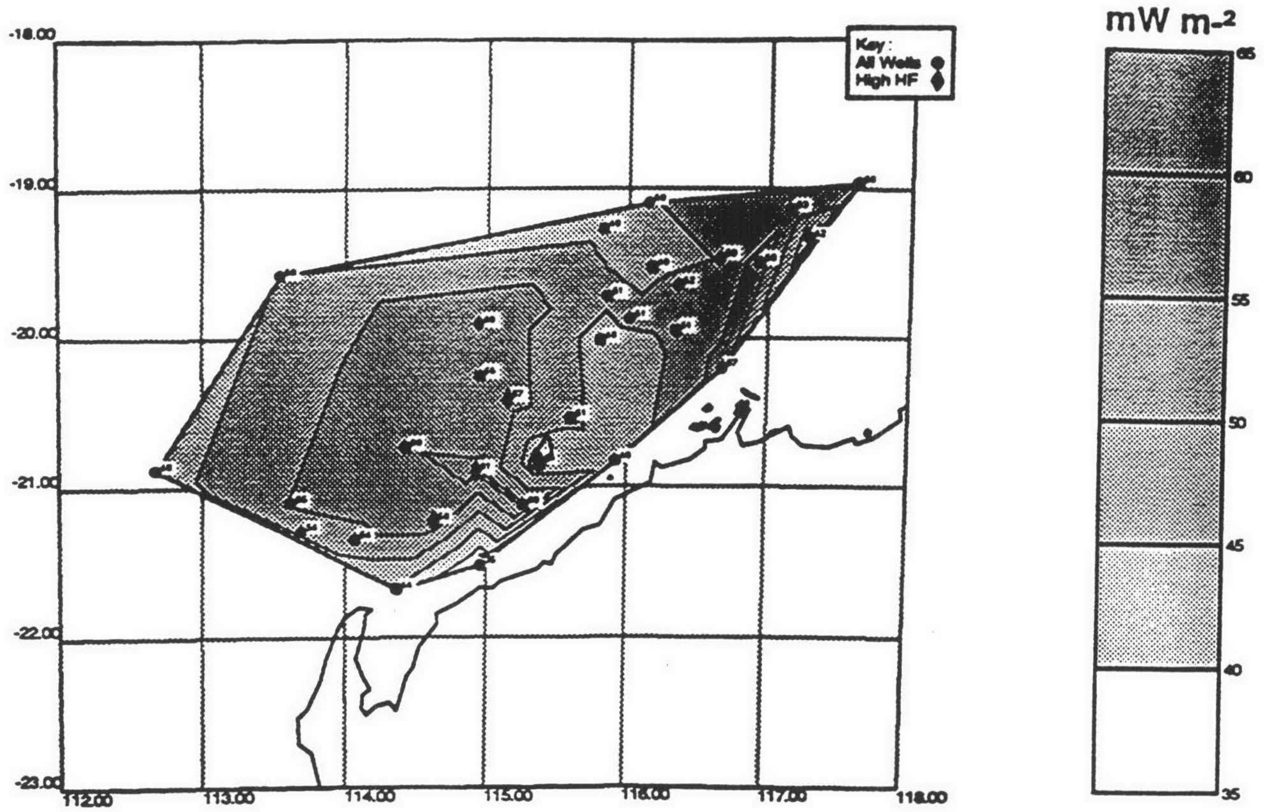

FIGURE 5A
HEATFLOW MAP (MWM^{-2}) AT 0 MA, WESTERN NORTH WEST SHELF

Present day heat flows from surface temperatures , thermal conductivities (lithologies) and BHT's

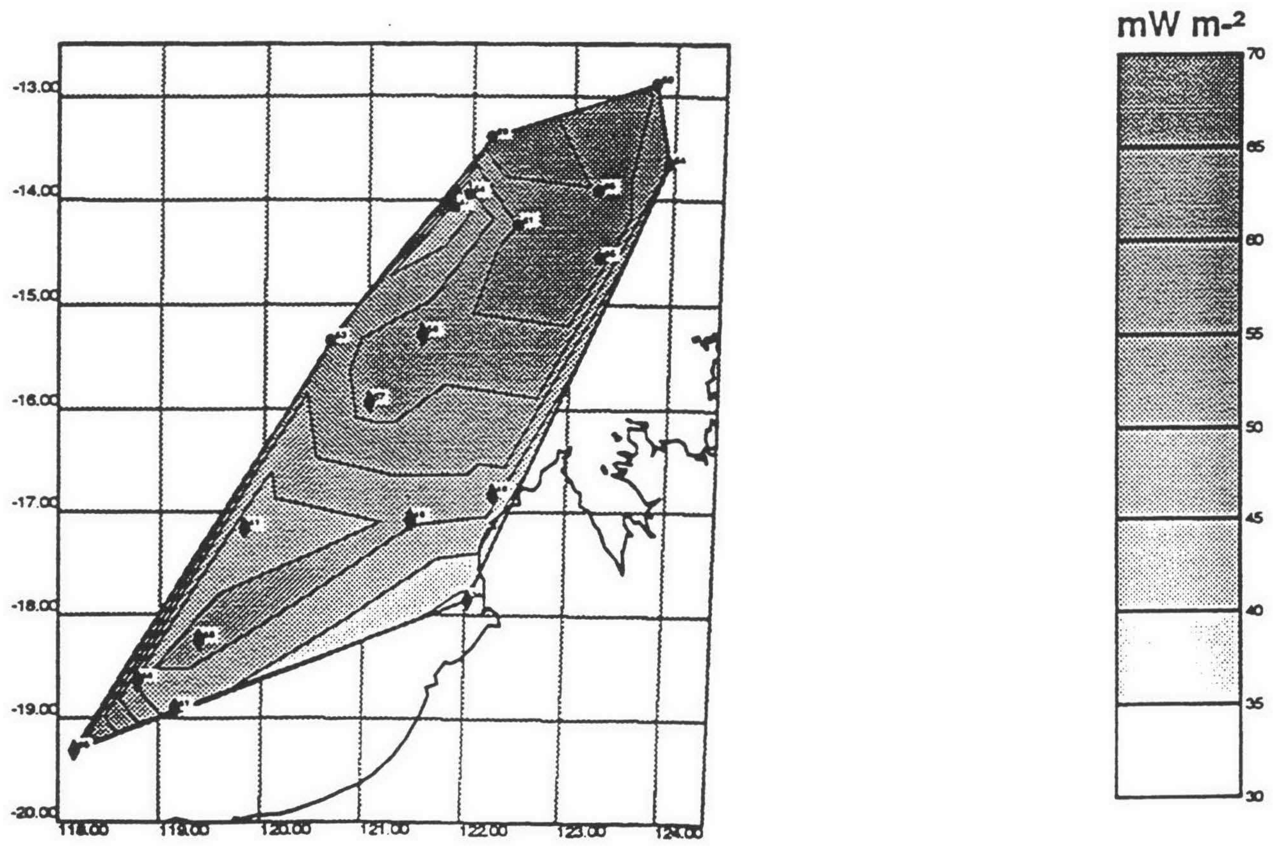

FIGURE 5B
HEATFLOW MAP (mWm^{-2}) AT 0 MA, NORTHERN NORTH WEST SHELF

It is clear from the previous discussion that these break-up events have affected the tectonic subsidence patterns in the area. Each breakup event should be associated with higher heatflows in the continental crust on either side of the incipient ridge. High heatflow values were modelled prior to the thermal cooldown phase in the mid Cretaceous, with heatflows declining according to the bell shaped curve typical of rift/drift margins (McKenzie, 1981). In the area of the pull-apart basins (Exmouth, Barrow and Dampier Sub-basins) very high breakup palaeoheatflows have been modelled (> 100 mWm^{-2}). In at least one well (Dampier 1) fission track analysis could be used to verify or constrain this model as it predicts higher palaeotemperatures in the mid-Cretaceous than at present.

Table 4: Temperature (ºC) Variation with Waterdepth/elevation through Geological Time.

Age (Ma)	1 km Elevation	Shore Line	40 m.	100 m.	200 m.	500 m.	1000m.	2000 m.
0	18	24	20	17	15	10	4	3
24	17	23	20	17	15	10	4	3
50	19	25	23	17	15	10	4	3
65	14	19	17	15	13	10	4	3
90	14	20	17	15	13	10	4	3
135	14	20	17	15	13	10	4	3

Palaeoheatflows have been modelled higher near the main rift axes at the time of commencement of ocean floor spreading, declining to values between 40 and 50 mWm^{-2} during the Late Cretaceous and Early Tertiary. In many areas these values (40 and 50 mWm^{-2}) are below the present day calculated heatflow, which must have risen during the last 10 to 1 Ma. According to the low observed maturity in these wells, which are often at maximum burial, present day temperatures cannot have been in existence for very long. This has been noted by previous authors (Alexander et al., 1990; Botten & Wulff, 1990).

When combined with the erosional model from seismic interpretation only slight modifications to the general heatflow model were required to fit observed maturity data in most wells. This is in contrast to the conclusions and data of FAMM studies (Wilkins et al., 1992; Wilkins et al., 1994) which asserted that much of the Ro data available on the North West Shelf is unmodellable without recent heat flow rises. They dismiss recent heatflow rises as a possible mechanism as "there is no obvious evidence for any event that could cause a rapid increase in heatflux ... during the last 0.1 Ma" (Wilkins et al., 1994, p 426). However in an area in which kerogen rich depocentres have moved down into the oil and gas maturity zone in the late Tertiary, heatflow rises due to migration of hot fluids would be expected in the nearby structural highs. Migration would take place along reservoir and fault pathways and, if prolonged such that steady state heatflow conditions were attained (> 300,000 yrs), would have the appearance of a rise in basal heatflow. As such, these effects should easily be modelled using one-dimensional (steady state) heatflow tools. The models presented here (Appendix 1) show that such rises are not all as recent as 0.1 Ma, with some extending back to the mid Tertiary in the Dampier/Barrow basin areas. In the Timor Sea area combined maturity, fission track and fluid inclusion studies have found that such migration has occurred and has influenced background temperatures (O'Brien et al, 1996). Of course all exploration wells will suffer from this effect since they are drilled on structural highs or potential reservoirs, it is expected that they would act as heat sumps by channelling hot fluids towards them. Therefore, present day heatflow in these wells should be higher than in the surrounding structural lows. In areas that have been continuously buried for the recent past, this effect will increase through time, implying that a recent rise in heatflow will be the norm.

Figures 6 A & B show heatflow vs time for all wells. Figures 7 A & B show the palaeoheatflow at 150 Ma.

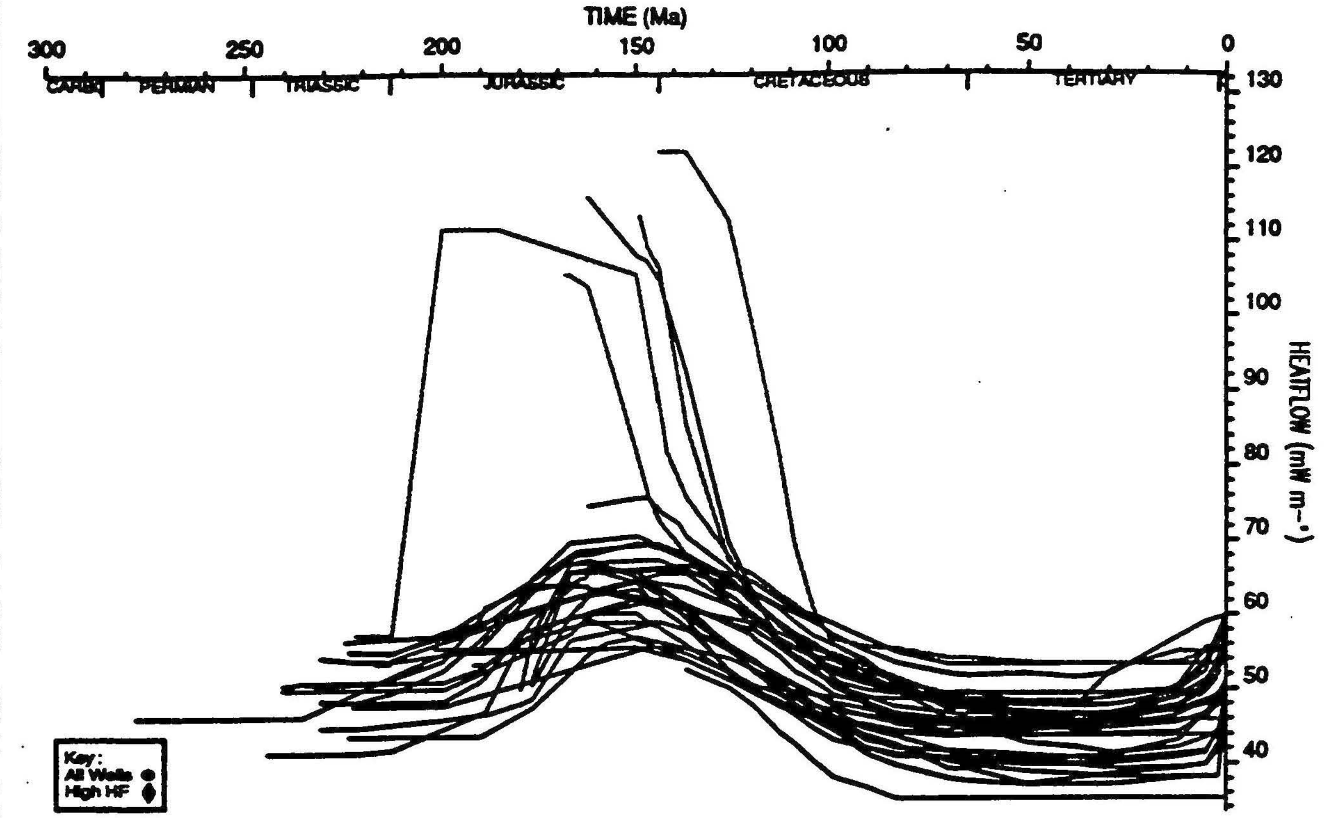

FIGURE 6A HEATFLOW VS TIME, WESTERN NORTH WEST SHELF

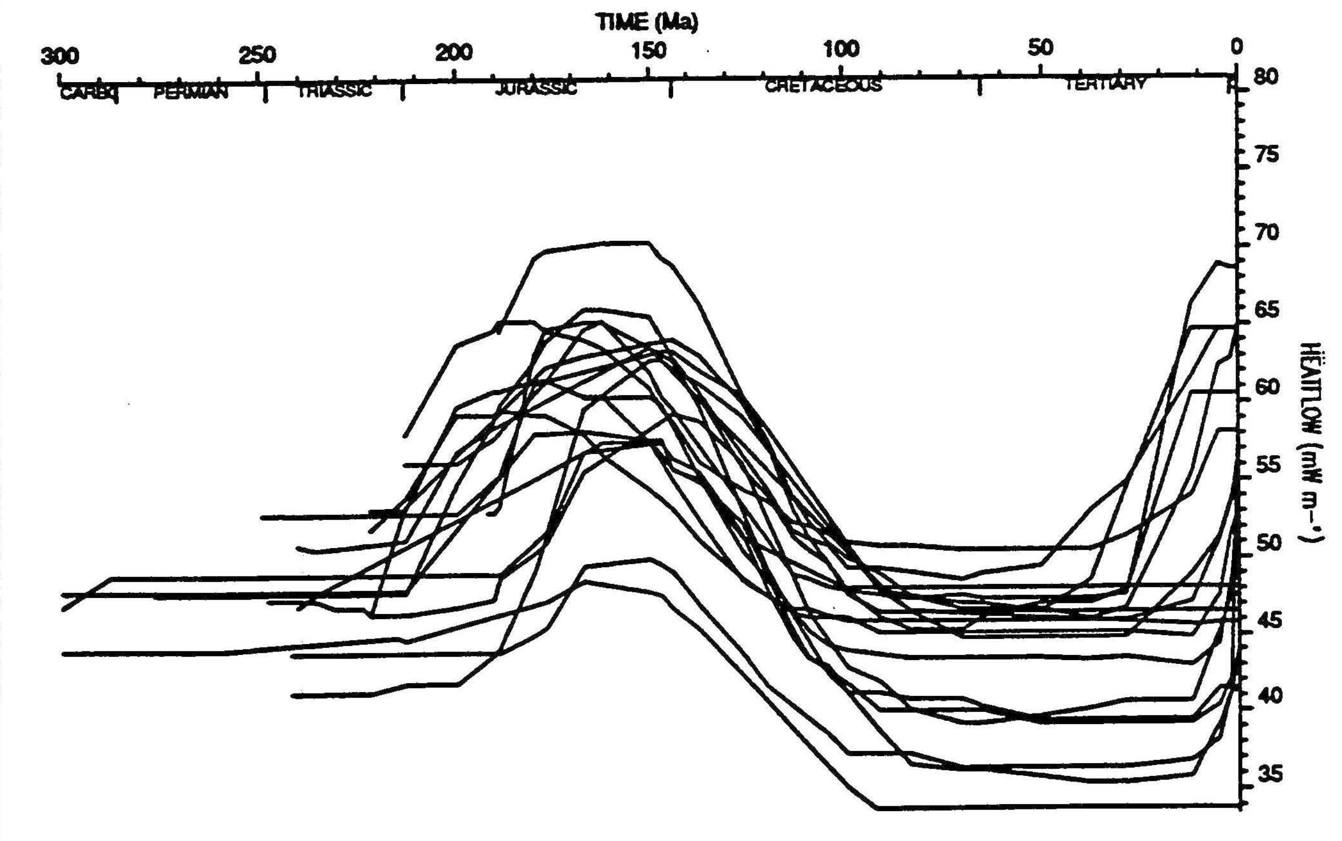

FIGURE 6B HEATFLOW VS TIME, NORTHERN NORTH WEST SHELF

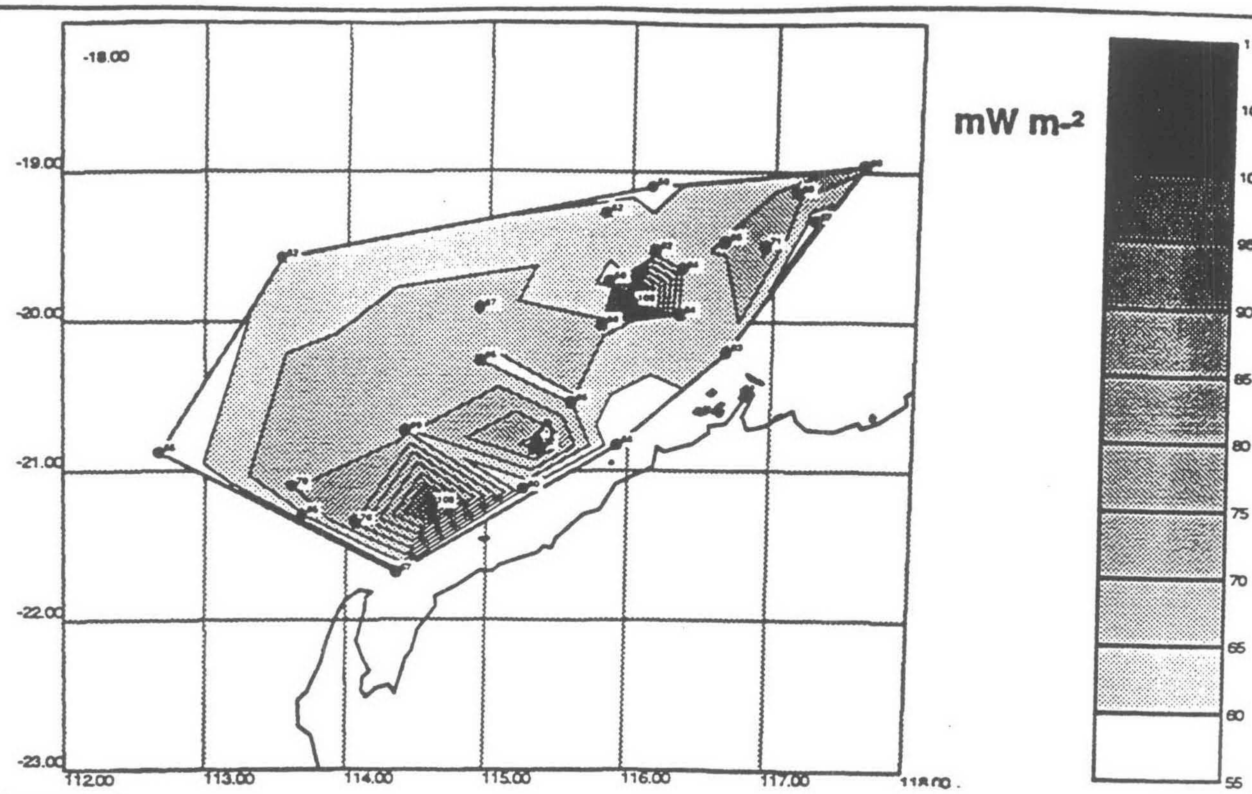

FIGURE 7A
PALAEO HEATFLOW MAP (mWm^{-2}) AT 150 MA, WESTERN NORTH WEST SHELF.
(Uses the pull apart Dampier 1 model and shows the pull apart basins).

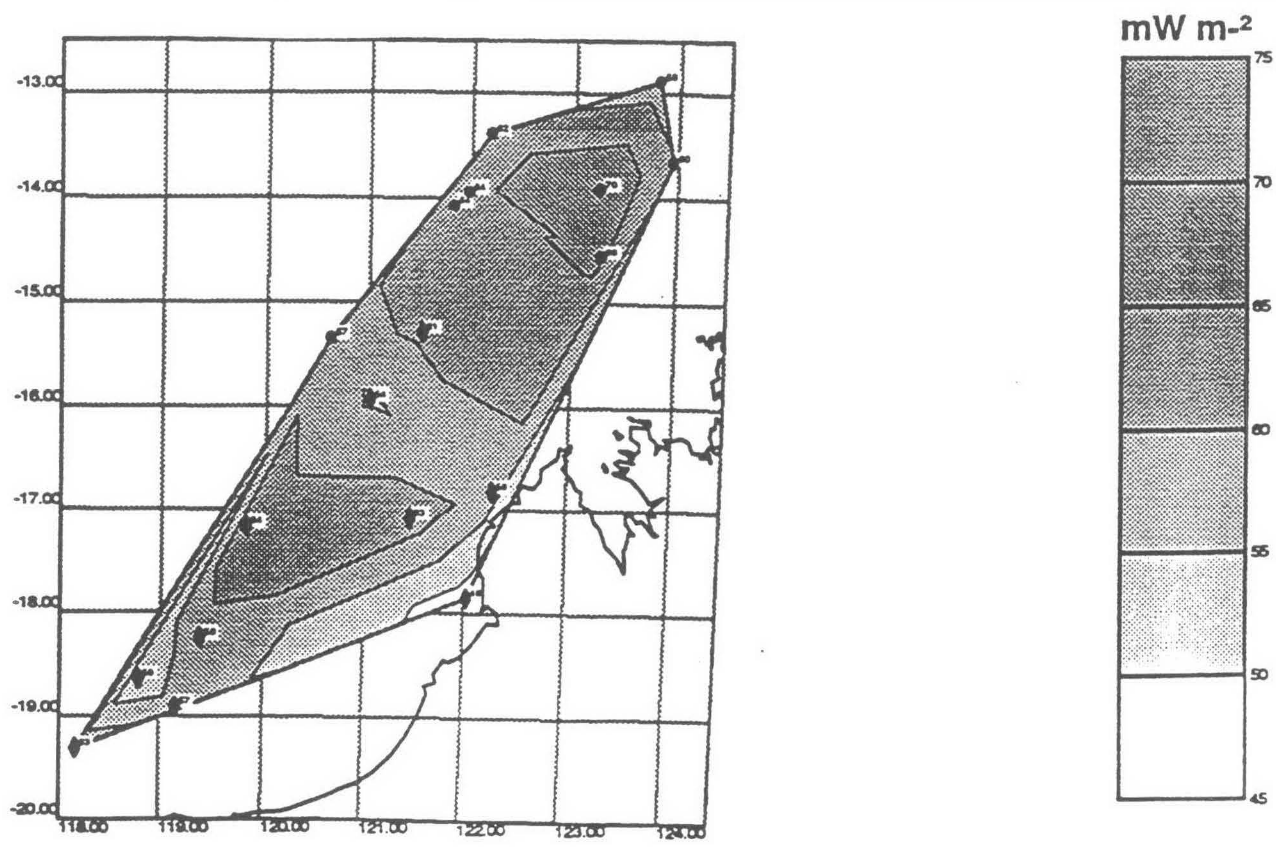

FIGURE 7B
PALAEO HEATFLOW MAP (mWm^{-2}) AT 150MA, NORTHERN NORTH WEST SHELF

Lithology Data

Lithologies were interpreted specifically for this study by Marita Bradshaw, based on wireline log interpretation, core and cuttings descriptions, and lithological descriptions found in the APS module reports. Each time slice is modelled as a combination of up to 5 matrix types from the global lithology definition table (see Table 1).

Observed data

Maturity Data

Maturity data, mostly vitrinite reflectance (Ro), were derived from the ORGCHEM database. The data vary widely in quality as evidenced by large scatter on some wells.

Wilkins et al (1994) from a study of fluorescence alteration of vitrinite found that the thermal alteration of many vitrinites on the North West Shelf suffers from suppression due to water content. Their equivalent vitrinite reflectance (EVR) data led them to conclude that the heatflow has remained constant throughout time in the Carnarvon Basin, a conclusion which is geologically unrealistic. Unfortunately they do not present any data to show the surface temperature models used in their analyses so their conclusions cannot be independently checked. It has been noted above that the large differences in sea-bottom temperature (in time and space) on the North West Shelf cannot be ignored (Table 4). Also, many of their plots show that EVR does not increase monotonically downhole (loc. cit, Figs 3-12). Any such inversions of a maturity indicator, must either imply that the maturity indicator is dependant on at least some non-thermal parameters or that hot-fluids have affected parts of the well section.

Despite the doubts these studies have cast on measured vitrinite reflectance (MVR) analyses, this study shows that the bulk of the MVR data can be modelled using the prime variable parameters of sea bottom temperature and palaeoheatflow.

Fission Track Data

No fission track data was used for this study. In a few wells which were affected by intrusive volcanics, such data may constrain the temperature and duration of the associated heating event (Reekmann et al., 1984). However since most of these events occurred during the Permian, Triassic and Early Jurassic they will have little influence on hydrocarbons that could be preserved today.

Kerogen Data (see Table 5)

Broad palaeoenvironmental facies analysis and consideration of observed HI data was used to define the ratios of Type II and III present in each source rock time slice. The TOC for each unit was based on averages of measured data.

Table 5 Input Data for the Source Rock Model.

BASIN &Well	Top (m)	Base (m)	Source Rock	Environ	HC Show y/n	% OM Type I	II	III	% TOC MEAN	% TOC RANGE	% TOC No. samples	V_R	HI	HI Max
BEAGLE														
Bedout 1	2476.0	2671.0	J2	CDD/IDB	n		15	85	12.4	1 - 56.3	41	0.60	139	
East Mermaid 1	3443.7	3738.4	J4	CDDU	n		30	70	4.2	2.6 - 8.4	8	0.60	169	
Keraudren 1	3200.0	3844.0	Tr2	CDDL	n			100	1.3	0.2 - 4.9	14	0.70	112	
Lacepede 1A	1319.8	1998.0	J6-4	LDFM	n			100	9.3	0.2 -65.8	27	0.60	103	
Pearl 1	1153.0	1853.0	Crb5	CDD	n			100	1.5					
Perindi 1	828.0	1022.0	P3-2	MS/CDD	y		30	70	2.9	0.1 -37.1	20	1.27	49	
Perindi 1	860.0	863.0	P3	MS	n		100		37.1		1	?	?	
Phoenix 1	3298.0	4880.0	Tr2-4	CDD	y			100	1.4	0 - 6.0	105	0.60	118	
Phoenix 1	2913.0	3298.0	Tr 5	CDIS	n		30	70	1.6	0.1 - 22.9	30	0.60	228	

BASIN &Well	Top (m)	Base (m)	Source Rock	Environ	HC Show y/n	% OM Type I	II	III	% TOC MEAN	% TOC RANGE	% TOC No. samples	V_R	HI	HI Max
Picard 1	3449.0	3883.2	J2	CDDP	y		30	70	2.7	0.2 - 6.6	32	?	?	
Picard 1	2316.5	3449.0	J3-6	CDD	y			100	2.5	0.6 - 5.9	21	0.70	104	
Poissonnier 1	1031.0	1124.0	J4	CDD	n			100	11.5	1.2 - 64.9	12	0.50	52	
Poissonnier 1	1616.0	1840.0	Tr2	CDDP	y		20	80	0.9	0.4 - 1.9	12	0.50	?	
Ronsard 1	2294.0	2848.0	J2-4	CDDL	n		10	90	2.0	0.7 - 3.1	8	0.50	97	
BARROW														
Barrow Deep 1	2178.0	3500.0	J8	MBA	G4/C4		100		2.6	0.8 - 3.7	33	0.80	?	
Barrow Deep 1	3500.0	4252.0	J7	MBA	L1/G2		100		1.6	1.0 - 2.6	46	1.20	?	
Barrow Deep 1	4252.0	4650.0	J6	MBA	G1		100		1.5	0.9 - 3	28	1.90	?	
Candace 1	1760.0	1844.0	P5	CSFL			20	80	1.9	0.4 - 4.9	16		61	131
Candace 1	1844.0	1912.0	P4	MS				100	2.1	1.1 - 4.9	15		39	92
Candace 1	1912.0	2015.0	P2	MS			50	50	1.6	0.4 - 6.1	28		53	260
Griffin 1	2681.0	2864.0	K1	CDDP	L5		70	30	0.7	0.4 - 1.2	6	0.50	382	
Griffin 1	2864.0	3400.0	Tr6	MVS/LDF			50	50	0.9	0.4 - 2.4	18	0.80	267	388
Resolution 1	3240.0	3760.0	J8	MBA	L1		100		2.3	1.1 - 3.4	21	0.60		
Resolution 1	3760.0	3884.0	tR6	CDDP	G1/L1		30	70	2.5	1.6 - 3.2	8	1.46		
Tryal Rocks 1	2042.0	2508.0	K3	MBA	L1		100		2.2	2.2	1	0.90	226	
Tryal Rocks 1	2508.0	3047.0	K2	MBA	G1/L1		100		2.3	1.9 - 2.6	11	0.90	179	226
Tryal Rocks 1	3047.0	3409.0	K1	MBA	G1/L1		70	30	2.0	1.5 - 2.3	6	0.80	122	177
West Barrow 2	2479.0	2608.0	K2	CDD			30	70	2.2	1.8 - 2.7	2	0.60	142	150
West Barrow 2	2398.0	2479.0	K3	MS	L3		40	60	1.8	0.8 - 2.5	5	0.60	195	207
Zeepaard 1	3982.0	4210.0	Tr5	LDFM	G2			100	2.3	1.2 - 5.1	4			
Zeepaard 1	3041.0	3925.0	K1	MBA	G1		70	30	1.2	0.7 - 1.7	14			
Zeewulf 1	3091.0	3265.0	Tr6	CDD/MS	C3			100	1.5	0.6 - 2.4	7	0.50	88	
Zeewulf 1	2672.0	3086.0	K1	MS	L1		20	80	1.0	0.3 - 1.6	10	0.50	68	98
DAMPIER														
Angel 2	3158.3	3968.5	J6	CDP	L2		20	80	2.21	0.3 - 63	123	0.60	130	986
Angel 2	3968.5	4396.7	J5	CDDP	L2		10	90	2.53	0.7 - 4.5	60	0.75	147	228
Cossigny 1	1796.5	2051.3	J6	CDDL	L1			100	4.30	1 - 18.3	7	-	111	219
Cossigny 1	2051.3	2225.0	J5	CDDL	L1			100	6.50	0.8 - 32.1	6	-	98	264
Cossigny 1	2740.0	3203.4	Tr2	LDFM	L1			100	0.60	0.1 - 1.1	11	0.40	75	127
Dampier 1	2598.4	2929.1	K1	MBA	L1		100		1.67	0.3 - 3.7	31	0.55	84	184
Dampier 1	2929.1	3272.0	J10	MBA	L2		100		1.00	0.2 - 2.2	28	0.50	67	93
Dampier 1	3272.0	3703.3	J9	MBA	L2		100		1.58	0.4 - 3.1	38	0.64	74	130
Dampier 1	3703.3	4141.6	J8	MBA	L3		100		2.13	1.6 - 3.3	38	0.71	77	182
Saturn 1	3052.0	3278.0	J1	CDDP			20	80	0.70	0.5 - 9	10	0.53	-	
Saturn 1	3278.0	3536.0	Tr6	CDD	GC3		10	90	0.80	0.6 - 1.2	4	0.61	-	
Saturn 1	3536.0	4000.0	Tr5	LDFM	G1			100	1.80	1.2 - 15.6	9	0.61	-	
Talisman 1	2160.0	2628.0	J6	CDD	L1		20	80	1.40	0.1 - 19.3	29	-	244	403
Withnell 1	2658.0	3016.0	K1	MBA			100		1.70	0.8 - 3.7	19		146	303
Withnell 1	3166.0	3750.0	J9	MBA			100		1.40	0.4 - 2.5	54		141	308
Withnell 1	3750.0	4650.0	J10	MBA			100		2.90	0.3 - 4.6	59		93	465
BROWSE														
Barcoo 1	3268.0	3508.0	K5	MS	L1		100		2.80	1.4 - 4.70	3	0.47	222	312
Brewster 1A	3398.0	3578.0	K3	MS			100		1.51	1.51	1	1.17	152	152
Brewster 1A	3578.0	3875.0	K2	MS			100		2.15	1.92 - 2.37	2	1.18	56	86
Brewster 1A	4306.0	4446.0	J8	CDDL	G1		20	80	1.23	.85 - 1.51	3	1.73	38	188

BASIN & Well	Top (m)	Base (m)	Source Rock	Environ	HC Show y/n	% OM Type I	II	III	% TOC MEAN	% TOC RANGE	% TOC No. samples	V_R	HI	HI Max.
Brewster 1A	4446.0	4703.0	J4-5	CDD	L1/G1		20	80	1.95	1.46 - 2.44	2	2.05	39	153
Buccaneer 1	3102.0	3200.0	J8	CDDL	L3		80	20	1.87	.24 - 3.51	2	0.56	269	269
Buffon 1	3520.0	3682.0	K7-6	MS	G1		100		1.00	.71- 1.71	5	0.86	60	72
Buffon 1	4730.0	4787.0	J1	CDE	L1		80	20	0.61	0.61	1	-	-	
Caswell 1	3570.0	3725.0	K5-6	MS	L2		100		1.00	.5 - 1.60	5	1.00	208	260
Caswell 1	3725.0	4097.0	K4-2	MS			100		1.70	.6 - 2.60	9	1.00	97	131
Discorbis 1	3890.0	4070.0	K1-2	MS	L1		100		1.20	.6 - 2.10	30	0.50	198	350
Discorbis 1	4070.0	4112.0	J8	MS	L1		100		1.05	.86 - 1.48	5	0.58	145	192
Discorbis 1	4112.0	4194.0	Tr3	MS	L1		100		0.50	.36 - .720	11	0.60	45	[illegible]
Lombardina 1	1668.0	1970.0	K4	MS			100		1.65	.72 - 2.32			148	237
Lombardina 1	1970.0	2080.0	K3	MS			100		2.40	2.40	1		118	[illegible]
Lombardina 1	2080.0	2308.0	K2	MS			100		2.55	1.87 - 2.85		1.12	146	207
Lombardina 1	2308.0	2433.0	J10-K1	MS			100		1.00	1.4 - 2.40	5	1.30	129	143
Lombardina 1	2701.0	2775.0	J2	CDP			20	80	1.21	.77 - 1.64		0.78		[illegible]
Lombardina 1	2775.0	2855.0	J1	CDP			20	80	1.11	1.81 - .220		1.20	105	138
Lynher 1	1262.0	1335.0	K1	MS	G1		100		2.31	1.48 - 2.57	4	0.41	74	92
Lynher 1	1453.0	1482.0	J7	CDD	G1		20	80	4.78	2.85 - 7.00	4	0.44	104	163
Lynher 1	1482.0	1527.2	J6	CDP	G1		20	80	2.49	1.61 - 3.36	2		122	140
Lynher 1	1527.2	1549.7	J5	CDP	G1		20	80	3.27	1.29 - 29.8	6	0.47	267	409
Lynher 1	1549.7	1670.8	J4	LDF	G1			100	6.58	2.52 - 40.7	4	0.49	93	93
Lynher 1	1691.0	1990.0	J2	CDDP	G1		100		2.01	.49 - 3.02	17	0.53	85	129
N Scott Reef 1	4220.0	4326.0	J1	CDE	GC5			100	1.50	1 - 3.00	3	-	43	69
N Scott Reef 1	4326.0	4763.9	Tr6	CDE				100	0.50	.2 - 3.90	19	-	39	91
Scott Reef 1	3821.0	4040.0	K5	MS			100		1.15	.75 - 1.44	11	0.80	68	134
Scott Reef 1	4098.0	4210.0	k3	MS	G1		100		1.11	.97 - 1.34	4	0.90	6	6
Scott Reef 1	4210.0	4272.0	K2	MS	G1		100		1.03	.96 - 1.37	4	0.65	55	73
Scott Reef 1	4289.0	4355.0	J6	CDP	G5/C5		80	20	0.95	.41 - 1.35	8	0.68	50	74
Scott Reef 1	4355.0	4730.0	Tr6	MVS	G5/C5		100		0.50	.35 - 1.46	19	1.24	63	63
Yampi 1	2187.0	2342.0	K3	CDP			20	80	1.87	1.51 - 2.23	6	0.48	77	78
Yampi 1	2342.0	2560.0	K2	MS			20	80	1.96	1.01 - 2.96	7	0.53	82	83
Yampi 1	2825.0	2908.0	K1	CDP			20	80	2.11	.64 - 2.42	7	0.53	100	100
Yampi 1	2908.0	3106.0	J10	CDDP			20	80	1.52	.32 - 1.83	8	0.55	78	79
Yampi 1	3127.0	3242.0	J8	CDP	L3		20	80	1.33	.64 - 3.40	15	0.71	150	198
OUTER EXMOUTH														
Brigadier 1	4150.0	4292.0	Tr5	CDDL	G1/L1			100	2.00	0.0 - 6.5	16	0.60	89	119
Jupiter 1	3600.0	4050.0	Tr4	CDDL	G1			100	4.30	3.0 - 6.3	4	0.74		
Jupiter 1	4200.0	4500.0	Tr3	CDDL				100	3.40	3.0 - 4.2	3	0.85		
Jupiter 1	4500.0	4946.0	Tr3	CDDL	G1			100	2.40	2.1 - 2.8	3	1.30		

RESULTS

The main results of the study are provided as source rock expulsion diagrams for each time slice as presented on the time slice diagrams. Appendix 1 shows the graphic results of the single well analyses, including discussion of the palaeothermal model, the fit of predicted to observed maturity and the timing of source rock expulsion in each well.

CONCLUSIONS

Some of the key findings are listed below.

* There are two phases of hydrocarbon generation in Barrow Sub-basin - one in the Early Cretaceous the other in the Late Cainozoic;
* while in the Dampier Sub-basin there is one phase in the Late Cainozoic. Thus, in these two similar and adjacent depocentres the petroleum systems operate quiet differently.
* The thermal modelling requires a revision of the earlier interpretation presented for the Browse Basin (Wilmot et al, 1993). The Early Cretaceous has now been shown to be a viable source rock generating hydrocarbons in the Late Cainozoic at the time of trap formation. Previously, the prospectivity of the basin was downgraded because the Late Jurassic, the main source interval on the North West Shelf, was poorly developed in the Browse and generated in the Cretaceous prior to the major phase of trap formation.
* Despite earlier studies to the contrary, this study has found that the bulk of the available observed vitrinite reflectance data for the North West Shelf can be simply modelled using geologically realistic palaeo-sea bottom temperature and palaeo-heatflow models. The latter models involve two periods of high heatflow at the time of rifting and during a recent phase of hot fluid expulsion from source areas to the well sites. As a result, heatflows during the early Tertiary in many wells may be considerably less than calculated present day values.

RECOMMENDATIONS FOR FURTHER WORK

* This study concentrated on producing an integrated North West Shelf set of results. Wells from the Petrel and Papuan Basin modules could be similarly modelled.
* The current study could be usefully agumented by modelling a number of pseudowells in undrilled depocentres, such as in the Beagle Sub-basin.

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APPENDIX 1

INDIVIDUAL WELL PLOTS AND DISCUSSION

Table of Contents

Introduction

Five plots illustrate the salient features of each well model, and are described in the next section. The general features of each plot are :-

Geohistory Plot

The geohistory plot shows the burial history (against time and depth axes) of the well from a fluctuating sea level datum. Source rocks have been highlighted by shading, with no particular colour scheme. The same shades are employed on the bed temperature plots. The calculated vitrinite reflectance is contoured across the geohistory diagram. This is preferred to "top oil maturity window" type shading as the top oil maturity window reflectance value varies with kerogen type.

The well stratigraphy is shown at the right of the geohistory diagram.

Heatflow & Tectonic Subsidence Plot

The normalised tectonic subsidence (all values are offset such that the minimum is 0) is displayed against right hand axis. Paleowaterdepth ranges are displayed as vertical error bars on the tectonic subsidence curve.

One-dimensional heatflow is plotted against the left hand axis.

Bed Temperature Plot

This plot shows bed temperature against the right hand axis. The sea bottom or surface temperatures at the top of the plot are shown as filled squares.

The geothermal gradient from seabottom to the base of the well is plotted against the left hand axis and is in °C/km.

Maturity Cross Plot

This is a semi-log plot with log Vitrinite Reflectance (Ro) across the top axis and depth as the left hand axis. The diagonal line shows computed present day Ro v depth. Observed maturity data is shown using various symbols and shades to identify analysts. These symbols are constant for all wells.

The well stratigraphy is shown at the left for context and unconformities are shown on the cross-plot for easy interpretation.

Hydrocarbon Generation Plot

The left hand column shows well stratigraphy. The next column shows source rocks present in the well. The middle panel shows, for each source rock, the rate of hydrocarbon generation and expulsion through time, with the scale at the right applying to each source rocks panel.

The total volume of oil and gas expelled from each source rock is given beneath each source rock panel.

Angel 2 - Dampier Sub-basin

Geohistory

After rapid mid Jurassic burial, erosion took place in the late Jurassic. Subsequent rapid subsidence in the early Cretaceous established deep water conditions and was followed by uniform gradual subsidence and fill, till a more rapid subsidence event in the late Tertiary is evidenced by thick Cz5-7 sediments.

Tectonic Subsidence

Rapid tectonic subsidence in the mid Jurassic to early Cretaceous, assumed to relate to rifting, is interrupted during the late Jurassic. This event is presumably wrench related. Tectonic subsidence from late Early Cretaceous to late Tertiary shows a thermal cooldown curve. Increased tectonic subsidence during the late Tertiary is probably related to carbonate shelf flexural loading.

Heatflow

Paleoheatflow increased in the mid Jurassic, according to the regional rift/sag model, reaching a maximum at about 160Ma. Decline since then has been in accord with the thermal cooldown phase. A late Tertiary heatflow increase indicates migration of hot fluids into the well.

Bed Temperature

Only the J5 unit experienced temperatures higher than 100°C during the early Cretaceous. Both J5 and J6 have been hotter than 100°C during the late Tertiary with temperatures increasing to present.

Maturity Cross Plot

A good fit of observed to calculated maturity indicates a valid model for Angel 2

Source Rock Generation

Time Slice J5 generated a small amount of hydrocarbons in the early Cretaceous. Larger amounts were generated during the late Tertiary, sufficient to expel gas, but not oil.

Bambra 2 - Barrow Sub-basin

Geohistory
After rapid mid Jurassic to early Cretaceous burial in deep water conditions, shallow waterdepths were attained. This was followed by more gradual, uniform though decreasing subsidence and fill till present.

Tectonic Subsidence
Rapid tectonic subsidence in the mid Jurassic to early Cretaceous is assumed to relate to rifting. A slight tectonic uplift event (controlled by paleowaterdepth data) may be wrench related. Tectonic subsidence from late Early Cretaceous to late Tertiary shows a thermal cooldown curve. Variable tectonic subsidence during the late Tertiary is probably related to carbonate shelf flexural loading.

Heatflow
Paleoheatflow increased in the mid Jurassic, according the regional rift/sag model, reaching a maximum at about 150Ma. Decline since then has been in accord with the thermal cooldown phase. A late Tertiary heatflow increase indicates migration of hot fluids into the well.

Bed Temperature
Time Slice J7 unit has experienced increasing temperatures, higher than 100°C since the late Jurassic. Both J7 and J8 have been hotter than 100°C since the early-mid Cretaceous with temperatures increasing more rapidly from mid Miocene to present.

Maturity Cross Plot
No observed maturity data was available for this well.

Hydrocarbon Generation
Time Slice J7 generated hydrocarbons in the early Cretaceous with gas and oil expelled. Lesser amounts of oil were expelled during the late Cretaceous and early Tertiary, by which time the unit had reached full transformation. Time Slice J8 generated minor hydrocarbons in the Cretaceous and large amounts of oil were expelled during the late Tertiary.

Barcoo 1 - Browse Basin

Geohistory
Moderately rapid subsidence and fill at shallow depths during the late Triassic to mid Jurassic is followed by slow subsidence during the mid Jurassic to mid Cretaceous. This is followed by increasing subsidence and slightly slower fill results in increasing water depth during the Tertiary.

Tectonic Subsidence
Slow thermal cooldown tectonic subsidence during the Jurassic and early Cretaceous is followed by increasing tectonic subsidence during the Tertiary, presumably due to increasing carbonate shelf flexural loading effects. The latest phase of rapid tectonic subsidence in the late Tertiary is related to the collision of the northern margin of Australia with Timor.

Heatflow
Paleoheatflow is modelled higher during the Jurassic with lower values during the Cretaceous and Tertiary. Increasing heatflow during the late Tertiary is presumably related to migration of hot fluids into the well.

Bed Temperature
Deeper units in the well experience temperatures hotter than 100°C during the late Tertiary, primarily due to increasing burial. No source rocks are present in this deeper interval.

Maturity Cross Plot
A fair fit of observed to calculated maturity indicates a valid paleotemperature for Barcoo-1 and can only be achieved with a late increasing heatflow event.

Hydrocarbon Generation
Source rocks in this well were never hot enough to generate hydrocarbons.

Barrow Deep 1 - Barrow Sub-basin

Geohistory
After rapid mid Jurassic to early Cretaceous burial in deep water conditions., shallow waterdepths were attained. This was followed by more gradual, uniform though decreasing subsidence and fill till present.

Tectonic Subsidence
Rapid tectonic subsidence in the mid Jurassic to early Cretaceous is assumed to relate to rifting. A slight tectonic uplift event in the early Cretaceous (controlled by paleowaterdepth data) may be wrench related. Tectonic subsidence from mid Early Cretaceous to late Tertiary shows a thermal cooldown curve.

Heatflow
Paleoheatflow was modelled very high in the mid Jurassic, according the regional rift/sag model and presumed effects of pull apart basin development, reaching a maximum at about 170Ma. Decline since then has been in accord with the thermal cooldown phase.

Bed Temperature
Time Slices J6 and 7 experienced temperatures higher than 100°C since the late Jurassic with most of the rise in the late Jurassic. Both J6 and J7 have declined in temperature since then due to lower heatflows and slower rates of subsidence and deposition. The lower parts of Time Slice J8 achieved 100°C during the early Cretaceous with slowly declining temperatures since.

Maturity Cross Plot
The calculated maturity for this well is slightly low compared to observed maturity data, indicating the mid Jurassic heatflow is still too low. However the observed data is relatively old and may need revision. (to do)

Hydrocarbon Generation
Time Slice J6 generated and expelled hydrocarbons and was completely transformed, in the late Jurassic. Time Slice J7 generated and expelled hydrocarbons during the late Jurassic and early Cretaceous and was also completely transformed. Time slice J8 generated minor gas and oil during the early Cretaceous and vary small amounts subsequently. It does not appear to be fully transformed.

Bedout 1 - Beagle Sub-basin

Geohistory

Rapid deposition in the early Triassic is followed by mid Triassic uplift. This is followed by moderately rapid rift related deposition during the Jurassic and early Cretaceous interrupted by a stillstand during the late Jurassic. Subsequent fluctuating waterdepths and rates of deposition leads to a phase of more rapid deposition during the late Tertiary

Tectonic Subsidence

Tectonic inversion during the Triassic appears to be regional (Bedout Movement). Tectonic subsidence during the late Triassic to late Jurassic exhibits slow rift development. Subsequent erratic tectonic subsidence may be due to incorrect paleowaterdepth constraints but generally conform to a thermal sag phase, with flexural loading effects in the late Tertiary.

Heatflow

Paleoheatflow was modelled higher during at the end of regional rifting declining to present according to the extensional model..

Bed Temperature

Only the lowest levels in the well reached 100°C during the latest Tertiary. This interval does not include any source horizons.

Maturity Cross Plot

A good fit of observed to calculated maturity indicates a valid model for Bedout 1. Slight undermodelling at the base of the well may result from the effects of localised Triassic intrusives. These would not affect the overlying younger source rocks in the well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Bluebell 1 - Rankin Platform

Geohistory

Rapid deposition in the late Triassic is followed by stillstand in the Jurassic. Increased subsidence in the Cretaceous to present is interrupted by two erosional events in the late Cretaceous, presumably due to shelf edge canyon cutting.

Tectonic Subsidence

Presumed rift subsidence is followed by tectonic stillstand during the Jurassic, somewhat at odds with the regional model. This may indicate that Bluebell occupied a shoulder site at the time of rifting. Increased tectonic subsidence during the Tertiary is assumed to be due to flexural loading effects of the carbonate shelf development.

Heatflow

The heatflow has been modelled according to the regional rift/sag model with a slight recent increase due to late movement of hot fluids into the well.

Bed Temperature

Time Slice Tr5 was hotter than 100°C during the mid Cretaceous, primarily as a result of early Cretaceous burial. During the Tertiary Tr5-6 and J1 experienced increasing temperatures higher than 100°C.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

The lower part of Tr5 generated minor hydrocarbons during the early Cretaceous. These were not expelled. During the late Tertiary, Tr5, Tr6 and J1 expelled gas while Tr6 expelled some oil.

Brewster 1A - Browse Basin

Geohistory

Unusually Brewster 1A exhibits almost straight line subsidence and fill from late Jurassic to present.

Tectonic Subsidence

Slow and possibly erratic tectonic subsidence during the Jurassic is followed by a period of declining tectonic subsidence till the end of the Cretaceous. Rejuvenated early Tertiary tectonic subsidence is followed by a late Tertiary phase of rapid subsidence due to collision of the northern margin of Australia with Timor

Heatflow

Paleoheatflow is modelled according to the regional rift/sag model, declining through the late Cretaceous and early Tertiary. Increased heatflows in the late Tertiary (necessary to model the observed maturity data is presumably due to hot fluid migration into the area.

Bed Temperature

The lower intervals in the well, most of which are source rich, become hotter than 100°C from the early Tertiary. Late Tertiary declining temperatures are caused by static heatflow and lower seabed temperatures, which in turn are caused by increased accommodation space due to plate collision.

Maturity Cross Plot

A good fit of computed to observed maturity indicates a valid paleotemperature model for Brewster 1A

Hydrocarbon Generation

Source rich units J4-5, J8, K2 and K3 all experienced high temperatures during the mid Tertiary, resulting in expulsion of gas from J4-5 and J8, oil and minor gas from K2 and minor oil from K3.

Brigadier 1 - Rankin Platform

Geohistory
Triassic and early Jurassic rapid subsidence and fill is followed by stillstand and slow subsidence and fill till the early Tertiary. Late Tertiary subsidence is characterised by increasing rates of deposition and subsidence and finally by rapid subsidence with increasing waterdepth.

Tectonic Subsidence
An early rapid period of tectonic subsidence in the Triassic is followed by generally slow tectonic subsidence till the early Tertiary when the flexural loading effects of the developing carbonate shelf to the southeast are noted.

Heatflow
Paleoheatflow is modelled according to the regional rift/sag model, declining through the late Cretaceous and early Tertiary. Increased heatflows in the late Tertiary (necessary to model the observed maturity data) is presumably due to hot fluid migration into the area.

Bed Temperature
Bed temperatures in the Tr5 source rock at the base of the well are just below 100°C during the earliest Cretaceous. Subsequently, these temperatures are not attained till the latest Tertiary.

Maturity Cross Plot
A fair fit of observed to calculated maturity indicates a valid paleotemperature for Brigadier 1 and can only be achieved with a very late increasing heatflow event.

Hydrocarbon Generation
Very minor hydrocarbon generation is noted for Tr5 in the late Jurassic and late Tertiary, however no hydrocarbons are expelled.

Buccaneer 1 - Browse Basin

Geohistory

Buccaneer exhibits almost straight line subsidence and fill at shallow water depths, from late Jurassic to present, apart from the mid Cretaceous.

Tectonic Subsidence

The tectonic subsidence curve shows generally declining values from mid Jurassic to late Cretaceous. During the Tertiary increased tectonic subsidence indicates the effects of the northern edge plate collision.

Heatflow

Paleoheatflow is modelled according to the regional rift/sag model, declining through the late Cretaceous and early Tertiary. Increased heatflows in the late Tertiary (necessary to model the observed maturity data) is presumably due to hot fluid migration into the area.

Bed Temperature

The deeper parts of the well attain 100°C during the late Tertiary with a rapid increase in the last 5Ma.

Maturity Cross Plot

The computed reflectance curve shows a fair fit to observed data which shows considerable scatter. Note that while the observed values can be easily obtained using a constant present heatflow, it is not possible to simultaneously model the values higher in the well without the mid Tertiary heatflow values being lower than present.

Hydrocarbon Generation

Time slice J8 exhibits very minor hydrocarbon generation.

Buffon 1 - Browse Basin

Geohistory

Generally slow subsidence and fill prevail from late Triassic to late Cretaceous. During the early Tertiary subsidence and fill increase as the carbonate shelf develops.

Tectonic Subsidence

Tectonic uplift during the mid Jurassic is presumably related to rifting (breakup uplift). Subsequent late Jurassic to early Tertiary subsidence is slow, and typical of the thermal sag phase. Tectonic subsidence increases in the early Tertiary, perhaps due to shelf loading and then increases rapidly in the latest Tertiary due to plate collision.

Heatflow

Paleoheatflow has been modelled higher during the late Jurassic according to the plate tectonic model. Heatflow increases dramatically during the late Tertiary due to migration of hot fluids into the well site.

Bed Temperature

The lower section of the well reach 100°C during the late Tertiary phase of increased heatflow and deposition.

Maturity Cross Plot

A fair fit of observed to calculated maturity indicates a valid paleotemperature for Buffon 1 and can only be achieved with a late increasing heatflow event.

Hydrocarbon Generation

Time slices J1 at the base of, and K6-7 near the base of the well generated and expelled gas during the late Tertiary. No oil was expelled due to leanness of source rock.

Candace 1 - Barrow Sub-basin, Candace Terrace

Geohistory

After rapid subsidence and fill during the Permian to early Triassic, this well exhibits slow subsidence and fill apart from slow subsidence and deposition during the Triassic to early Jurassic and early to mid Cretaceous. Uplift and erosion occur at the Jurassic/Cretaceous boundary and in the late Tertiary.

Tectonic Subsidence

Erratic Permian tectonic subsidence is presumably related to proto-rift development. Early Cretaceous tectonic uplift is related to rift shoulder uplift, and late Tertiary tectonic uplift is probably caused by flexural loading to the northwest of the well.

Heatflow

Paleoheatflow is modelled higher during rift/sag transition, with a slight increase in the late Tertiary by comparison with nearby wells.

Bed Temperature

Maximum bed paleotemperatures for the deepest beds in the well are only 80°C during the mid Jurassic.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons. This modelling agrees with Bentley's (1988) interpretation of the area.

Caswell 1 - Browse Basin

Geohistory

This well exhibits almost continuous straight line subsidence and fill at shallow waterdepths from the early Cretaceous till present.

Tectonic Subsidence

Slow thermal cooldown subsidence is evident throughout the Cretaceous. Renewed tectonic subsidence in the early Tertiary may be related to flexural loading of the shelf to the southeast. Rapid tectonic subsidence in the late Tertiary is due to the Australia/Timor plate collision.

Heatflow

Heatflows decline from their rift values (older than the well section) till the mid Tertiary. Subsequently heatflow increases to its present day value as hot fluids migrate into the well area.

Bed Temperature

The deepest beds in the well, including source intervals, experienced increasing temperatures above 100°C during the late Tertiary. A latest Tertiary temperature drop of 5°C results from deeper water depths and associated lower seabottom temperatures.

Maturity Cross Plot

A good fit of computed vs observed maturity can only be obtained with rising Tertiary heatflows.

Hydrocarbon Generation

Time slice K2-4 generated and expelled oil and gas during the late Tertiary. Time slice K5-6 generated and expelled gas during the same period

Cossigny 1 - Beagle Sub-basin

Geohistory

Rapid Triassic subsidence and fill is followed by intermittent stillstand, uplift and subsidence phases till the late Cretaceous when increased fill rates are obtained. Subsequent Tertiary fill takes place in shallow water environments.

Tectonic Subsidence

Presumed rift related tectonic subsidence is observed in the Triassic and mid Jurassic. This followed by a long period of tectonic stillstand before a latest Cretaceous tectonic uplift event. A tectonic sag phase throughout the Tertiary with increasing tectonic subsidence may indicate flexural loading effects.

Heatflow

The regional rift/sag heatflow model has been used.

Bed Temperature

Maximum attained bed temperatures for units at the base of the well (including source rocks) are less than 100°C.

Maturity Cross Plot

A poor fit of computed to observed data suggests that the mid Tertiary and late Jurassic heatflows may be slightly high. However this would not affect the source rock expulsion model because :-

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Cowle 1 - Barrow Sub-basin

Geohistory

This shallow well exhibits continued though declining rates subsidence and fill throughout the Cretaceous and Tertiary.

Tectonic Subsidence

Tectonic subsidence from the early Cretaceous to Pliocene exhibits thermal sag characteristics. A late Tertiary tectonic uplift event is probably related to flexural loading of the shelf to the northwest.

Heatflow

The regional rift/sag heatflow model has been used.

Bed Temperature

Bed temperatures do not exceed 55°C throughout time

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Dampier 1 - Dampier Sub-basin

Two models have been created for this well

1. A regional heatflow model - with a peak heatflow of 70 mW/m² in the Late Jurassic.
2. A pull-apart model - with a peak heatflow of 120 mW/m² in the Late Jurassic.

Geohistory

A late Jurassic phase of rapid subsidence and fill is followed by generally even, though slower, subsidence and fill in shallowing waterdepths.

Tectonic Subsidence

The thermal cooldown phase of rift tectonic subsidence dominates this curve. Note that the rift phase has easily been included from 160 to 145 Ma, but is unconstrained by paleowaterdepth data. During the late Tertiary effects of flexural shelf loading become apparent.

Heatflow

The regional rift/sag heatflow model has been used here. A late Tertiary increase in heat flow is apparent from modelling of the maturity data.

On the pull-apart model the paleoheatflow has been increased to greater than 100 mW/m².

Bed Temperature

The deeper intervals of the well, including source rocks, have been hotter than 100°C since the late Jurassic.

Maturity Cross Plot

A good fit of computed to observed maturity has been obtained over most of the well. Near the base of the well some anomalously high reflectance values may support a pull-apart high paleoheatflow regime for the well. However other deeper data than this have very low maturity values and may indicate poor and unreliable data at the base of the well. The pull apart model still fails to intersect the high value data. These alternate models could be validated by fission track analysis as, for the pull apart model, paleotemperatures at the base of the well are higher than at present.

Hydrocarbon Generation

In the low paleoheatflow model, time slice J8 generates and expels minor gas and abundant oil during the late Tertiary. The overlying J9 also expels lesser amounts of oil and gas.

In the pull-apart model, J8 expels oil and gas at the end of the Jurassic and none in the Tertiary. J9 is unaffected.

Discorbis 1 - Browse Basin

Geohistory

After unmodelled Triassic to mid Jurassic stillstand and slow late Jurassic to early Cretaceous subsidence and fill, very rapid subsidence and fill applies during the late Cretaceous and Tertiary.

Tectonic Subsidence

Tectonic stillstand is followed by increasing Tertiary tectonic subsidence due to flexural loading of the shelf and the Australia/Timor collision.

Heatflow

The regional rift/sag heatflow model has been used here. A rapid latest Tertiary increase in heat flow is necessary to model the observed maturity data and presumably indicates late hot fluid movement into the well site.

Bed Temperature

Bed temperatures only rise above 100°C during the very recent heatflow rise.

Maturity Cross Plot

A poor fit to the observed data is obtained although many values are still unobtainably low, even with the late Tertiary rise in heatflow.

Hydrocarbon Generation

Source rocks at the base of the well are generating hydrocarbons at present.

East Mermaid 1 Offshore Canning Basin

Geohistory
A Jurassic phase of rapid subsidence and fill is interrupted by minor uplift in the late Jurassic. This is followed by almost linear subsidence and fill till present.

Tectonic Subsidence
A poorly developed rift/sag curve obtains till the late Cretaceous. Tectonic subsidence in the late Cretaceous and Tertiary is anomalously steep probably indicating flexural load effects of the nearby prograding shelf edge to the southwest.

Heatflow
A high paleoheatflow is modelled in the Jurassic, declining during the early Cretaceous. A recent heatflow increase is necessary to model the observed maturity data.

Bed Temperature
The deepest levels of the well almost reach 100°C during the early Cretaceous and Plio/Pleistocene.

Maturity Cross Plot
A very good fit of predicted to observed maturity data has been obtained supporting the paleotemperature model.

Hydrocarbon Generation
Source rocks in this well were never hot enough to generate hydrocarbons.

Gandara 1 - Rankin Platform

Geohistory

Moderately rapid subsidence and fill is observed during the Triassic and early Jurassic. Slow subsidence and slower fill in deeper water continues till the late Tertiary when rapid subsidence and fill are observed.

Tectonic Subsidence

A general rift tectonic subsidence regime is apparent till about 180 Ma when thermal sag occurs. In the Tertiary the effects of flexural shelf loading can be observed as increased tectonic subsidence.

Heatflow

The standard rift/sag heatflow model has been used. A late Tertiary increase in heatflow has been modelled in surrounding wells and is used here also.

Bed Temperature

Temperatures in the bottommost beds of the well have exceeded 100°C for the last few Ma. Unfortunately the source rocks are higher in the well.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Goodwyn 6 - Rankin Platform

Geohistory

After a period of rapid subsidence and fill in the Triassic, the Jurassic is dominated by successive deposition/erosion events. From the late Jurassic to mid Tertiary slow then increasing sedimentation rates result in a deepening then shallowing of the sediment interface. More rapid subsidence and fill is indicated during the late Tertiary.

Tectonic Subsidence

After a Triassic phase of rift subsidence, erratic, presumably wrench related, tectonics apply during the mid Jurassic. This is followed by thermal cooldown tectonic subsidence through to the late Tertiary, when flexural loading effects are observed.

Heatflow

The heatflow has been modelled higher during the rift/sag transition and declines till the late Tertiary. Heatflow rises slightly during the latest Tertiary in accord with surrounding wells.

Bed Temperature

The lower beds of the well experienced temperatures greater than 100°C during the late Tertiary.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Time slice Tr5 in this well was hot enough to generate hydrocarbons in the late Tertiary but were insufficiently rich to generate enough to cause expulsion.

Griffin 1 - Barrow Sub-basin

Geohistory

Rapid subsidence and fill in the Triassic and early Jurassic is followed by stillstand and mid Jurassic uplift and erosion. After a further stillstand moderately rapid subsidence and fill recommences in the Cretaceous and declines through the late Cretaceous and early Tertiary. The late Tertiary is characterised by very rapid subsidence and fill.

Tectonic Subsidence

Rift subsidence in the Triassic and earliest Jurassic is followed by erratic, presumably wrench related tectonics during the remainder of the Jurassic. The Cretaceous and early Tertiary is characterised by thermal sag subsidence with the influence of minor flexural loading effects becoming apparent through increased tectonic subsidence in the late Tertiary.

Heatflow

Paleoheatflow has been modelled extremely high in the wrench phase, which is considered to represent pull-apart tectonics. Subsequent thermal cooldown is applied till the late Tertiary when the influence of migrating hot fluids is observed as a rise in heatflow.

Bed Temperature

Time slice Tr6 was at temperatures greater than 100°C in the early Jurassic and is currently just over that temperature. Time slice K1 above the unconformity is currently just on 100°C.

Maturity Cross Plot

A good fit of computed to observed maturity data is obtained. Note that the sharp break in the observed profile over the Cretaceous/Triassic unconformity can only be modelled by high heatflow and moderate deposition in the early Jurassic.

Hydrocarbon Generation

According to the temperature model time slice Tr6 generated and expelled hydrocarbons during the early Jurassic wrench phase.

Jupiter 1 - Exmouth Plateau

Geohistory
Rapid subsidence and fill in the Triassic is followed by stillstand during most of the Jurassic. Rapid deepening of the sediment interface during the Cretaceous is followed by slower subsidence and fill through the Tertiary.

Tectonic Subsidence
Rift related subsidence is seen during the Triassic. This is followed by minor uplift at about 150 Ma at the end of major rifting in the area. Rapid tectonic subsidence after 150 Ma is presumably related to the timing of the M5 ridge jump in the Gascoyne/Cuvier oceanic crust: Prior to this the Exmouth Plateau was artificially buoyed by the proximity of Greater India on its southwest margin.

Heatflow
Paleoheatflow has been modelled according to the regional rift/sag model.

Bed Temperature
Source rocks at the base of the well have been hotter than 100°C since the beginning of the Jurassic, although they have cooled considerably since the end of the Jurassic.

Maturity Cross Plot
The fit of computed to observed to observed data is good, although the observed data exhibits considerable scatter. Some of the results of FAMM analysis are shown and together, are difficult to model. The much steeper slope and surface intercept of the FAMM data could realistically only be modelled with much higher sea bottom temperatures (inner shelf values eg 25°C) through the Cretaceous and Tertiary. However in the deep water setting of the Exmouth Plateau sea bottom temperatures are quite low (<5°C).

Hydrocarbon Generation
According to the calculated temperature paths, the deeper source rocks have been hot enough to generate and expel gas and generate some in situ oil. Most of this generation took place during the Jurassic.

Keraudren 1 - Offshore Canning Basin

Geohistory

rapid subsidence and fill during the early and mid Triassic is followed by slower, almost linear subsidence and fill till present.

Tectonic Subsidence

Early Triassic rift subsidence is followed by cooldown. Minor Jurassic subsidence is followed by Cretaceous cooldown subsidence. Late Tertiary fluctuations in subsidence are probably due to flexural loading of the shelf.

Heatflow

Paleoheatflow has been modelled according to the regional rift/sag model.

Bed Temperature

The Tr2 source interval at the base of the well section has experienced temperatures higher than 100°C in the early Cretaceous. These temperatures were not exceeded in the late Tertiary.

Maturity Cross Plot

A good fit of computed to observed maturity data was obtained, although there is considerable scatter in the observed data.

Hydrocarbon Generation

Time slice Tr2 generated minor in situ oil during the late Jurassic/early Cretaceous.

Lacepede 1A - Offshore Canning Basin

Geohistory
Minor deposition of Carboniferous sediments was followed by stillstand in the Permo/Triassic and uplift and erosion of some sediments in the latest Triassic. Subsequent rapid subsidence and fill in the Jurassic and early Cretaceous was followed by reduced rates of subsidence and fill in the Cretaceous and Tertiary.

Tectonic Subsidence
Minor rift/sag subsidence can be seen in the Jurassic to Cretaceous tectonic subsidence pattern, with some latest Tertiary flexural loading effects.

Heatflow
The regional heatflow model has been imposed.

Bed Temperature
Bed temperatures in this well have not exceeded 100°C

Maturity Cross Plot
This well suffers the effects of Triassic (to do) intrusives, which have not been modelled.

Hydrocarbon Generation
Source rocks in this well were never hot enough to generate hydrocarbons.

Leatherback 1 - Exmouth Sub-basin

Geohistory

Rapid late Triassic and slow to moderate Jurassic subsidence and deposition is followed by uplift and erosion of the early late Jurassic during the latest Jurassic. This is followed by increasing mid Cretaceous subsidence and fill, slow late Cretaceous to early Tertiary subsidence and fill and moderately rapid late Tertiary subsidence and fill.

Tectonic Subsidence

A minor rift/sag phase in the Triassic to early Jurassic is followed by tectonic uplift (wrench related) at the end of the Jurassic. Subsequent slow tectonic subsidence indicates a thermal cooldown mechanism. In the late Tertiary renewed tectonic subsidence and a latest Tertiary uplift event is probably related to flexural loading of the shelf to the northwest.

Heatflow

The regional heatflow model has been imposed.

Bed Temperature

Bed temperatures in this well have not exceeded 80°C

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Lombardina 1 - Browse Basin

Geohistory

Moderately rapid Jurassic subsidence and fill is followed by rapid Cretaceous subsidence and fill. Reduced fill in the early Tertiary results in a deepening sediment interface. Late Tertiary sedimentation ıates increase resulting in shallower depositional conditions.

Tectonic Subsidence

Thermal sag subsidence is apparent in the Cretaceous with a period of increased tectonic subsidence in the Early Tertiary presumably related to flexural loading.

Heatflow

The regional heatflow model has been used for this well. A slight increase in the late Tertiary is modelled on surrounding wells.

Bed Temperature

The deepest layers of the well just exceed 100°C during the last few million years.

Maturity Cross Plot

A very poor observed data set provides no clues as to the validity of the model.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Lynher 1 - Browse Basin

Geohistory

Rapid Triassic and early Jurassic subsidence and fill is followed by linear subsidence and fill till present.

Tectonic Subsidence

Very minor impact of rift/sag subsidence can be seen in this well. A latest Tertiary phase of tectonic uplift may be related to flexural loading on the shelf.

Heatflow

The regional heatflow model has been used. A late Tertiary increase in heatflow is need to honour the maturity data.

Bed Temperature

The deepest layers of the well have been above 100°C in the last 10 million years. Unfortunately the source rocks are above this level.

Maturity Cross Plot

A good fit of computed to AGSO observed maturity data has been obtained. However the other observed data shows considerable scatter.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Madeleine 1 - Dampier Sub-basin

Geohistory
After rapid subsidence and fill in the Late Jurassic and early Cretaceous moderate rates of subsidence and fill are observed till present, increasing slightly in the late Tertiary.

Tectonic Subsidence
Rift subsidence is observed during the late Jurassic, followed by thermal sag tectonic subsidence till the mid Tertiary. A phase of renewed tectonic subsidence in the mid Tertiary is probably related to flexural loading.

Heatflow
The regional heatflow model has been used. A late Tertiary increase in heatflow is need to honour the maturity data and is presumably related to the influx of hot fluids into the well site.

Bed Temperature
Source rocks near the base of the well section were slightly hotter than 100°C in the early Cretaceous. These temperatures were re-attained during the latest Tertiary heatflow rise.

Maturity Cross Plot
Despite a wide scatter of observed maturity data (some unrealistically low), the fit of predicted to observed data is good indicating a valid paleotemperature model.

Hydrocarbon Generation
Source rock J7 expelled gas and oil in the latest Tertiary. J8 likewise generated oil and gas though in greater volumes due to increased thickness.

North Rankin 3 - Rankin Platform

Geohistory

Subsidence and fill rates were high in the late Triassic and early Jurassic, decreasing to low throughout the late Jurassic to Cretaceous. Rates increased during the Tertiary as the shelf edge prograded towards the well site.

Tectonic Subsidence

Rift tectonic subsidence in the Late Triassic is followed by sag subsidence till the end of the Cretaceous. Increased tectonic subsidence during the Tertiary indicates flexural loading effects of the carbonate shelf.

Heatflow

High paleoheatflows are modelled in the Late Jurassic and early Cretaceous, declining through to present.

Bed Temperature

Temperatures at the base of the well have only surpassed 100°C in the last 5Ma.

Maturity Cross Plot

Insufficient observed data allows only a bisecting fit for the basal unit of the well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate more than very minor hydrocarbons.

North Scott Reef 1 - Browse Basin

Geohistory

Variable subsidence and fill in the Triassic and early Jurassic is followed by stillstand and gradual subsidence and fill during the Jurassic/Cretaceous. During the Tertiary rates increase dramatically with declining fill rates in the late Tertiary leading to deepening waterdepths.

Tectonic Subsidence

A general quiescent phase during the Triassic and Cretaceous is followed by more rapid, presumably flexural loading tectonic subsidence in the early to mid Tertiary. Rapid subsidence during the late Tertiary is the result of collision of the Australian and Timor Plates.

Heatflow

The regional heatflow model has been used, with a slight late Tertiary increase modelled from nearby wells.

Bed Temperature

Bed temperatures for layers at the base of well, including source units, exceed 100°C over the last 25Ma.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Minor oil and gas generation and minor gas expulsion, takes place in the Tr3 unit at the base of the well during the late Tertiary. Coevally, time slice J1 generates but does not expel minor oil.

Novara 1 - Exmouth Sub-basin

Geohistory

Rapid subsidence and fill in deep water conditions in the late Jurassic is followed by very rapid fill in the Early Cretaceous as the Barrow Delta fills the area. Subsequent fill and subsidence rates are low with declining fill leading to deeper water deposition in the late Tertiary.

Tectonic Subsidence

Rapid rift subsidence in the late Jurassic and earliest Cretaceous is followed by thermal sag subsidence in the Cretaceous. Increased Tertiary subsidence is due to flexural loading at the shelf edge to the south west of the well site.

Heatflow

The regional rift based heatflow model has been used for the well with lower heatflows during the late Cretaceous and Tertiary than present, based on surrounding wells.

Bed Temperature

Bed temperatures at the base of the well briefly exceeded 100°C during the early Cretaceous and latest Tertiary.

Maturity Cross Plot

Insufficient observed data does not permit validation of the thermal model.

Hydrocarbon Generation

Minor gas expulsion took place from J8 during the earliest Cretaceous and late Cretaceous to early Tertiary.

Pearl 1 - Offshore Canning Basin

Geohistory

Erratic subsidence patterns for this well indicate other structural considerations than the dominant plate breakup mechanism.

Tectonic Subsidence

A possible Carboniferous rifting event is followed by thermal sag during the Permian and Triassic. Minor effects of the plate breakup may be seen in the late Jurassic and early Cretaceous rift/sag pattern.

Heatflow

The regional heatflow pattern has been used. Although another heatflow event could have been inferred in the Carboniferous, there is no observed maturity data to validate such a model.

Bed Temperature

Bed temperatures appear to have been lower than 80°C throughout time with maxima achieved in the early Cretaceous.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

This well contained no source rocks.

Perindi 1 - Offshore Canning Basin

Geohistory

Erratic subsidence and intrusions during the Devonian to early Jurassic is followed by rift style subsidence and fill in the Late Jurassic and early Cretaceous. General stillstand applies from then to present.

Tectonic Subsidence

Erratic tectonic subsidence patterns from the Devonian to early Jurassic suggests a number of rifting/wrenching events. Rift/sag tectonics can be seen from the mid Jurassic on.

Heatflow

The regional heatflow model has been used in this well. The effects of Triassic intrusions has not been modelled, as the current version of WinBury can only model steady state heatflow.

Bed Temperature

Generally increasing temperatures remain below 70°C throughout time.

Maturity Cross Plot

A wide scatter of observed data is the result of Triassic intrusion but also hot fluid flow beneath the base Jurassic unconformity.

Hydrocarbon Generation

This well contained no source rocks.

Phoenix 1 - Offshore Canning Basin

Geohistory

After rapid subsidence and fill in the mid Triassic, reduced rates of subsidence and fill in generally shallow water conditions continues through to the late Tertiary when subsidence rates increase slightly.

Tectonic Subsidence

A minor rift/sag event in the Triassic is followed by the regional event in the mid Jurassic with cooldown sag continuing till the end of the Cretaceous. Tertiary tectonic subsidence rates increase, presumably due to flexural shelf loading effects.

Heatflow

The regional plate event heatflow model has been used for this well. Decreased heatflows prior to the Late Tertiary are necessary to model the maturity data, implying late hot fluid influx.

Bed Temperature

Source rocks at the base of the well section were slightly hotter than 100°C during the late Jurassic and late Tertiary.

Maturity Cross Plot

A fair fit of predicted to observed maturity is obtained indicating a valid paleotemperature model.

Hydrocarbon Generation

The deepest source rock, Tr2 has generated minor in situ hydrocarbons in the late Tertiary.

Picard 1 - Beagle Sub-basin

Geohistory
Rapid subsidence and fill during the early Jurassic is followed by slow rates during the late Jurassic and Cretaceous. Subsidence and fill rates increase slightly during the early to mid Tertiary and dramatically during the latest Tertiary.

Tectonic Subsidence
A rift/sag tectonic subsidence pattern is apparent through the Jurassic with thermal subsidence declining by the end Cretaceous. Tectonic subsidence rates increase during the Tertiary presumably in response to flexural shelf loading.

Heatflow
The regional paleoheatflow model has been imposed with heatflows remaining relatively low during the late Cretaceous and Tertiary.

Bed Temperature
Temperatures in the deeper section achieve 100°C during the Jurassic. Increasing temperatures are realised during the Tertiary with maxima in the Pliocene.

Maturity Cross Plot
The maturity cross plot shows a good fit of computed to observed maturity data although the latter displays a wide spread.

Hydrocarbon Generation
Only the deepest source unit, J2 generated significant hydrocarbons, and even then, insufficient for expulsion to take place.

Poissonnier 1 - Offshore Canning Basin

Geohistory

Rapid subsidence and fill during the early Triassic is followed by uplift in the Late Triassic. Fill and subsidence rates are low then till the late Cretaceous when they increase through till the late Tertiary. During the latest Tertiary fill rates decline and water depths increase.

Tectonic Subsidence

Erratic tectonic subsidence from Triassic to early Jurassic suggest rift/wrench tectonics. Thermal sag subsidence during the late Jurassic and early Cretaceous is followed by a slight increase in subsidence rates in the late Cretaceous. This increase, followed by higher rates of subsidence in the late Tertiary presumably indicate flexural loading of the shelf.

Heatflow

The regional heatflow model has been used, with decreased values during the late Cretaceous and Tertiary necessary to model the observed maturity data.

Bed Temperature

Bed temperatures peaked in the late Tertiary, but did not exceed 95°C even at the base of the well section.

Maturity Cross Plot

A good fit of predicted to observed data has been obtained, with a spread of observed values around the Triassic/Jurassic unconformity suggesting local hot fluid effects.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Resolution 1 - Exmouth Plateau

Geohistory

After rapid subsidence in the late Triassic a deepwater stillstand phase lasted till the mid Jurassic. Subsequent rapid deposition led to shallow water depths by the early Cretaceous. Rapid subsidence in the mid Cretaceous reimposed deepwater conditions, which lasted through to present.

Tectonic Subsidence

A minor tectonic subsidence event in the late Triassic may indicate wrenching. In the late Cretaceous rapid subsidence after 125 Ma may have resulted from final separation of the Exmouth Plateau from Greater India. A late Tertiary phase of increased tectonic subsidence presumably indicates flexural loading effects of the prograding shelf to the south east of the well site.

Heatflow

The regional heatflow model has been used for this well, with lower heatflows in the late Cretaceous and Tertiary.

Bed Temperature

Bed temperatures at the base of the well reach 100°C during the early Cretaceous, but do not exceed that level subsequently.

Maturity Cross Plot

A dramatic spread of observed data for this well probably indicates intrusive volcanics immediately below the well section. These effects were not modelled in this study. Modelling bias has been towards the Cook Services data.

Hydrocarbon Generation

Minimal gas was expelled from the source rocks at the base of this well. This interpretation would change if the effects of the supposed intrusives were modelled.

Ronsard 1 - Beagle Sub-basin

Geohistory
After rapid subsidence and fill in the early and mid Jurassic, uplift and erosion took place in the early late Jurassic. Subsequent rates of subsidence and fill were slow in the early Cretaceous, moderately fast in the late Cretaceous to mid Tertiary and fast in the late Tertiary.

Tectonic Subsidence
Rift subsidence in the early and mid Jurassic is followed by uplift at the time of Argoland breakup. Subsequent tectonic subsidence follows a sag pattern, with increased rates in the early and latest Tertiary presumably due to flexural shelf loading.

Heatflow
The regional heatflow model has been used for the this well.

Bed Temperature
Bed temperatures reach maxima in the late Tertiary but do not exceed 100°C.

Maturity Cross Plot
A good fit of computed to observed maturity data was obtained.

Hydrocarbon Generation
Source rocks in this well were never hot enough to generate hydrocarbons.

Rosemary 1 - Dampier Sub-basin

Geohistory
Rapid subsidence and fill in the mid Jurassic was followed by generally slower rates till present, with some rapid intervals in the mid early and Late Cretaceous.

Tectonic Subsidence
Rift subsidence in the mid Jurassic is followed by thermal sag. Minor uplift events may be wrench related.

Heatflow
The regional heatflow model has been employed, with low heatflows during the Tertiary necessary to model the observed maturity data.

Bed Temperature
Bed temperatures at the base of the well were at about 100°C by the mid Early Cretaceous and increased rapidly in the last 10 Ma.

Maturity Cross Plot
A fair fit of predicted maturity to the AGSO observed data set has been obtained. Other older data shows a wide spread.

Hydrocarbon Generation
The deepest source rock, J6 generated minor oil and gas during the late Cretaceous and Tertiary and expelled moderate amounts of gas in the late Tertiary.

Saturn 1 - Exmouth Plateau

Geohistory

After rapid subsidence and fill in the late Triassic a shallow water stillstand phase lasted till the end of the Jurassic. Rapid subsidence in the early and mid Cretaceous led to deepwater conditions, which lasted through to present.

Tectonic Subsidence

A minor tectonic subsidence event in the late Triassic may indicate wrenching or rift development. Rapid tectonic subsidence after 150 Ma is presumably related to the timing of the M5 ridge jump in the Gascoyne/Cuvier oceanic crust. Prior to this the Exmouth Plateau was artificially buoyed by the proximity of Greater India on its southwest margin. A late Tertiary phase of increased tectonic subsidence presumably indicates flexural loading effects of the prograding shelf to the south east of the well site.

Heatflow

The regional heatflow model has been used for this well with a recent heatflow increase inferred due to influx of hot fluids.

Bed Temperature

Bed temperatures at the base of the well reached 100°C only during the last few Ma.

Maturity Cross Plot

A wide spread of observed data for this well has been modelled fairly successfully.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

Scott Reef 1 - Browse Basin

Geohistory

Rapid subsidence and fill in the late Triassic is followed by general stillstand and slow subsidence and fill till the mid Cretaceous. Increased rates of subsidence and fill are observed in the late Cretaceous increasing markedly in the mid and late Tertiary.

Tectonic Subsidence

After a period of erratic tectonic subsidence from late Triassic to early Cretaceous subsidence rates increase. This is inferred to be caused by flexural loading on the carbonate shelf. A late Tertiary increase in tectonic subsidence rates is caused by the Australia/Timor plate collision.

Heatflow

The regional heatflow model is applied with the high heatflow event extending back into the mid Jurassic.

Bed Temperature

Bed temperatures increase markedly during the late Tertiary to levels well above 100°C at the base of the well, where abundant source intervals have been interpreted.

Maturity Cross Plot

A very wide scatter of observed maturity data implies intrusive or hot fluid events. Modelling of these has not been attempted.

Hydrocarbon Generation

All source intervals at the base of the well sequence generate and expel minor gas. Some in situ oil is generated in the richer units.

Sirius 1 - Exmouth Plateau

Geohistory

After rapid subsidence and less rapid fill in the late Triassic to early Jurassic, deep water conditions were attained. Rapid fill during the Barrow Delta phase led to shallowing of the sediment interface by the end of K1 times. Subsequent rapid subsidence and slow sedimentation resulted in deep water conditions being re-established in the early Cretaceous. These conditions persisted to present.

Tectonic Subsidence

A minor tectonic subsidence event in the late Triassic may indicate wrenching or rift development. Rapid tectonic subsidence after 150 Ma is presumably related to the timing of the M5 ridge jump in the Gascoyne/Cuvier oceanic crust. Prior to this the Exmouth Plateau was artificially buoyed by the proximity of Greater India on its southwest margin.

Heatflow

The regional heatflow model has been used with a lower maximum heatflow in the late Jurassic due to the distance from active rift axes.

Bed Temperature

Peak bed temperatures were attained in the early Cretaceous. These temperatures were never above 85°C.

Maturity Cross Plot

A fair fit of predicted to observed data was obtained, especially near the base of the well.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

South Pepper 1 - Barrow Sub-basin

Geohistory
Rapid subsidence and fill in deep water in the late Jurassic leads to shallow water conditions by the mid Early Cretaceous. Subsequent subsidence and fill is at consistent moderate rates till present.

Tectonic Subsidence
Rift subsidence is defined in the late Jurassic and earliest Cretaceous. Subsequent tectonic subsidence indicates thermal cooldown with slightly increased rates in the Tertiary, and a tectonic uplift event in the latest Tertiary indicating some flexural loading effects.

Heatflow
The regional heatflow model has been applied, with a recent increase in heatflow modelled as in nearby wells.

Bed Temperature
The basal source unit in the modelled well section attains 100°C in the early Cretaceous. A rapid increase in temperature is modelled over the last 10 Ma.

Maturity Cross Plot
No observed maturity data was available for this well.

Hydrocarbon Generation
The deepest modelled unit in the well (J8) generates minor oil in the Cretaceous and considerable oil and minor gas in the late Tertiary.

Strickland 1 - Dampier Sub-basin

Geohistory
Several deposition/erosion events have been modelled after rapid Triassic deposition and interspersed with slow Jurassic fill. A further erosional event has been modelled in the early Cretaceous. Subsequent slow deposition in water deep water leads to the present day.

Tectonic Subsidence
After Triassic rift subsidence erratic tectonic subsidence during the Jurassic and early Cretaceous may result from wrench related tectonism. Late Cretaceous subsidence follows a thermal cooldown relationship, with a minor flexurally related uplift at the end of the Tertiary.

Heatflow
The regional paleoheatflow model has been applied to the well, with a lower heatflow during the late Cretaceous and Tertiary modelled according to surrounding wells.

Bed Temperature
Bed temperatures vary, but never attain values greater than 60°C at the base of the well.

Maturity Cross Plot
No observed maturity data was available for this well.

Hydrocarbon Generation
This well contained no source rocks.

Talisman 1 - Dampier Sub-basin

Geohistory
After rapid subsidence and fill in the mid Jurassic, sediment bypass results in deeper water conditions by the end of the Jurassic. Subsequent, generally constant, moderate subsidence and fill results in gradually shallowing conditions through to the Tertiary.

Tectonic Subsidence
Rift related tectonic subsidence is observed in the mid and late Jurassic. Thermal cooldown subsidence applies from then till the early Tertiary, when slight increase in tectonic subsidence indicate flexural loading effects.

Heatflow
The regional paleoheatflow pattern has been employed for the well, with lower values during the late Cretaceous and early to mid Tertiary modelled as for surrounding wells.

Bed Temperature
Bed temperatures at the base of the well section exceed 100°C only briefly at the end of the Tertiary.

Maturity Cross Plot
No observed maturity data was available for this well.

Hydrocarbon Generation
Source rocks in this well were never hot enough to generate hydrocarbons.

Tryal Rocks 1 - Barrow Sub-basin

Geohistory

Rapid subsidence and fill in the late Jurassic and Early Cretaceous is followed by slower subsidence and fill till the mid Tertiary. Generally rapid subsidence and fill is noted in the late Tertiary.

Tectonic Subsidence

Prolonged rift subsidence is noted till the mid Cretaceous in this well. A late Cretaceous to Tertiary phase of thermal sag subsidence shows some flexural effects in increased tectonic subsidence in the mid and late Tertiary and a slight tectonic uplift at the end of the Tertiary.

Heatflow

This well has been modelled as a pull-apart basin well with very high heatflows in the Late Jurassic. These decline to values slightly higher than surrounding wells in the late Cretaceous and Tertiary.

Bed Temperature

Bed temperatures increase rapidly to above 100°C at the base of the well in the early Cretaceous. These temperatures remain till the mid Tertiary when further increases result from increased burial.

Maturity Cross Plot

A fair fit of computed maturity to the central spread of observed data.

Hydrocarbon Generation

The lower source units expel considerable oil and gas in this well, primarily in the late Tertiary.

West Barrow 2 - Barrow Sub-basin

Geohistory

Rapid subsidence and fill in the early Cretaceous is followed by generally slower subsidence and fill till present.

Tectonic Subsidence

A poorly defined thermal cooldown curve is inferred during the Cretaceous with increased Tertiary subsidence resulting from flexural loading.

Heatflow

This well has been inferred to be in a pull-apart basin setting and high heat flows have been inferred in the early Cretaceous.

Bed Temperature

The lower unit (not a source rock) may have experienced very high temperatures in the early Cretaceous if the pull-apart setting is realistic. Source rocks immediately overlying this bed attains 100°C only briefly at the end of the Tertiary.

Maturity Cross Plot

An excellent fit of predicted to observed data can only be achieved with the modelled high pull-apart heatflows, especially at depth. The necessary high paleotemperatures would be increased by overpressure effects.

Hydrocarbon Generation

Source rocks penerated in this well were never hot enough to generate hydrocarbons.

Withnell 1 - Dampier Sub-basin

Geohistory

Rapid subsidence and fill in the mid and late Jurassic was followed by generally slower rates of fill in the early Cretaceous leading to the establishment of deep waster conditions. Increased sedimentation in the late Cretaceous led to a shallowing of waterdepths by the Eocene and generally constant moderate subsidence and fill continued to present.

Tectonic Subsidence

Rift related rapid subsidence at the end of the Jurassic gave way to thermal sag during the Cretaceous. Minor flexural loading effects may be noted in the Tertiary.

Heatflow

The regional paleoheatflow model has been applied to the well, with low heatflows in the late Cretaceous and early Tertiary necessary to model the observed maturity data.

Bed Temperature

The deepest units in the well attained 100°C in the earliest Cretaceous and again during the latest Tertiary.

Maturity Cross Plot

A good fit of computed to observed data has been obtained.

Hydrocarbon Generation

Minor in situ oil and gas generation and some gas expulsion has taken place from the deepest source unit (J9).

Yampi 1 - Browse Basin

Geohistory

Generally slow subsidence and fill occurred from the Permian to latest Jurassic. Subsidence and fill rates increased during the Early Cretaceous, declined slightly during the early Tertiary and increased again in the late Tertiary

Tectonic Subsidence

Erratic tectonic subsidence from Permian to end Jurassic is hard to characterise. Thermal sag is evident from the early Cretaceous on, with some flexural loading effects and the collision of the Australian and Timor plates evident in the late Tertiary.

Heatflow

The regional paleoheatflow model has been employed, with a late Tertiary increase in heatflow presumably caused by hot fluid influx.

Bed Temperature

Bed temperatures at the base of the well have risen above 100°C since the early Cretaceous. Source rocks in the well have been above 100°C since the early Tertiary.

Maturity Cross Plot

A very scattered spread of observed data makes this well difficult to model. The predicted model is fairly close to most of the "AGSO" data set, except in the basal Permian section which may be influenced by intrusives.

Hydrocarbon Generation

The deepest source rocks generate minor oil and expel some gas in the latest Tertiary.

Zeepaard 1 - Exmouth Plateau

Geohistory

Rapid Triassic subsidence and slow sedimentation leads to deep water conditions by the early Jurassic. After a period of bathyal (submarine canyon) erosion, increased sedimentation rates occur as the Barrow Delta reaches the site in K1 times, leading to the attainment of shallow water conditions. Subsequently, bathyal conditions are reattained due to reduced sedimentation in the mid Cretaceous. General stillstand conditions through the early Tertiary give way to increased sedimentation as the north-westerly prograding shelf reaches the site.

Tectonic Subsidence

A minor tectonic subsidence event in the late Triassic may indicate wrenching or rift development. Rapid tectonic subsidence after 125 Ma is presumably related to the timing of the M5 ridge jump in the Gascoyne/Cuvier oceanic crust: Prior to this the Exmouth Plateau was artificially buoyed by the proximity of Greater India on its southwest margin. A late Tertiary subsidence event may be related to flexural loading effects of the approaching shelf edge.

Heatflow

The regional paleoheatflow model has been used with higher heatflows in the late Jurassic/Early Cretaceous and lower heatflows in the Tertiary. A rise of heatflow at the end of the Tertiary related to hot fluid influx has been modelled similarly to surrounding wells.

Bed Temperature

Source rocks at the base of the well attain 100°C by the early Tertiary, but do not exceed that value by much until the late Tertiary.

Maturity Cross Plot

No observed maturity data was available for this well.

Hydrocarbon Generation

Minor gas and in situ oil generation and some gas expulsion takes place in the latest Tertiary from the source rocks at the base of the well.

Zeewulf 1 - Exmouth Plateau

Geohistory

Moderately rapid Triassic subsidence and slow sedimentation leads to deep water conditions by the early Jurassic. After a period of bathyal (submarine canyon) erosion, increased sedimentation rates occur as the Barrow Delta reaches the site in K1 times, leading to the attainment of shallow water conditions. Subsequently, bathyal conditions are reattained due to reduced sedimentation in the mid Cretaceous. General stillstand conditions through the early Tertiary give way to rapid subsidence as the flexural effects of the north-westerly prograding shelf influence the site.

Tectonic Subsidence

A minor tectonic subsidence event in the late Triassic may indicate wrenching or rift development. Rapid tectonic subsidence after 125 Ma is presumably related to the timing of the M5 ridge jump in the Gascoyne/Cuvier oceanic crust: Prior to this the Exmouth Plateau was artificially buoyed by the proximity of Greater India on its southwest margin. A late Tertiary subsidence event may be related to flexural loading effects of the approaching shelf edge.

Heatflow

The regional paleoheatflow model has been used with higher heatflows in the late Jurassic/Early Cretaceous and lower heatflows in the Tertiary. A rise of heatflow at the end of the Tertiary related to hot fluid influx has been modelled similarly to surrounding wells.

Bed Temperature

Source rocks at the base of the well never attained temperatures greater than 80°C.

Maturity Cross Plot

A good fit of computed to observed maturity data has been obtained, with a preferential bias towards the Cook Services data.

Hydrocarbon Generation

Source rocks in this well were never hot enough to generate hydrocarbons.

APPENDIX 2

PALEOBATHYMETRIC MODELLING

Contents

Figures

Introduction

In part, sedimentary basins subside because of the isostatic loading of the sediment itself. However, brief reflection will reveal that a sediment pile deposited entirely by shallow, or non-marine environments (ie at sea level) must have a tectonic component to basement subsidence to create the space for sediment to accumulate.

Tectonic Subsidence

The removal of the load of sediment in Figure 1 would result in a readjustment of basement to the water loaded column. Movement of this adjusted basement position is termed **tectonic subsidence** or **stripped basement subsidence**.

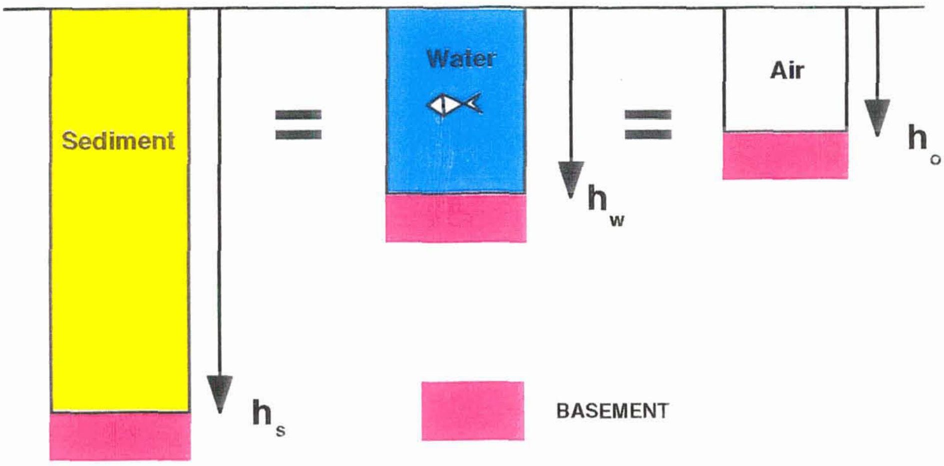


Figure 1 - Isostatically equivalent loads on basement.

Mathematically we derive the isostatically adjusted position from

$$h_w = \frac{\rho_m - \overline{\rho}_s}{\rho_m - \rho_w} h_s$$

$$h_0 = \frac{\rho_m - \overline{\rho}_s}{\rho_m} h_s \qquad \textit{Equations 1}$$

Where ρ_m is mantle density (3.35), $\overline{\rho}_s$ is mean sediment density (let us say, 2.3), ρ_w is seawater density (1.03). Thus:

$$h_w \approx 0.45\ h_s$$
$$h_0 \approx 0.31\ h_s$$

Equations 1 are derived from simple Airy Isostatic mass balance. Expressed simply, one kilometre of sediment in a basin represents a driving force affecting basement with an amplitude of 310 metres. It is more usual, however, to consider the driving force amplitude to be that given by submarine subsidence (450 metres) rather than free air subsidence since most sediment deposition is under water.

The reason for using this is that, of course, $\overline{\rho}_s$ varies with h_s due to compaction. Thus there is no simple linear relationship between h_s and h_w, but there is between h_w and h_0. Other spurious affects on the observed sediment loaded basement subsidence as observed on a geohistory diagram are palaeo water depths, which vary from sea level, and palaeo sea level variation relative to the present day.

The true tectonic submarine subsidence that would have occurred

- had there been no sedimentation
- had the palaeo water depth at the time of observation been zero
- had the sea level at the time of observation been the same as present

is calculated by correcting for the loading effects of each item (ie sediment mass, water mass, and differential paleo sea level mass) as follows:

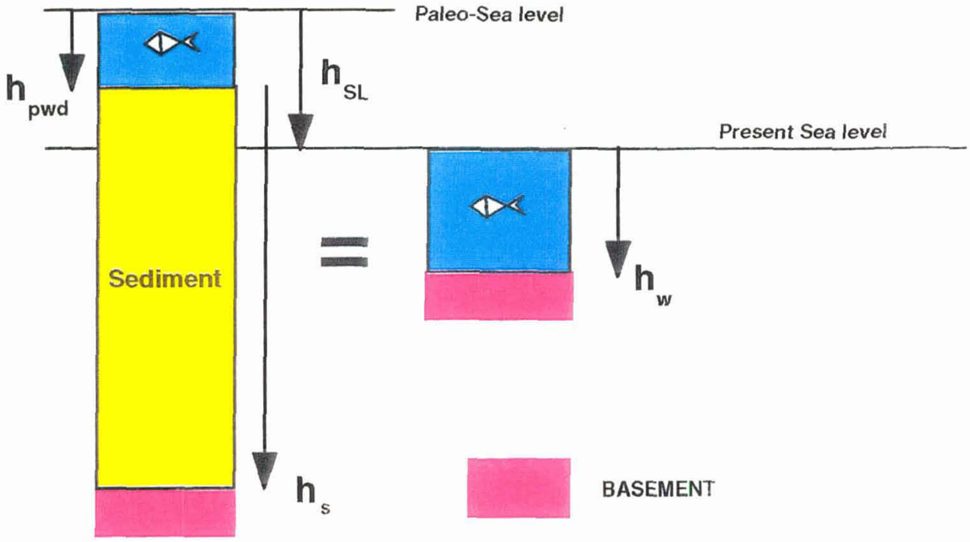


Figure 2 - Equivalent isostatic loads for a fluctuating sea level.

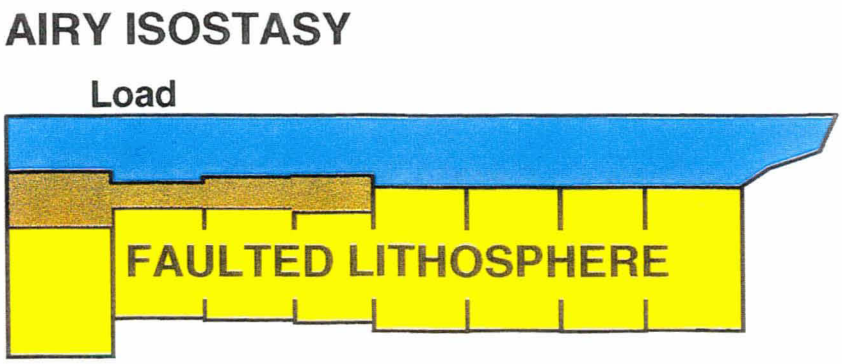
$$h_w = h_{pwd} + \frac{\rho_m - \overline{\rho}_s}{\rho_m - \rho_w} h_s - \frac{\rho_m}{\rho_m - \rho_w} h_{sl} \qquad \textit{Equation 2}$$

which is the sum of the thickness of matrix in the sediment pile, plus the thickness of water in the pore spaces of the sediment pile.

$$h_w = \frac{1}{k} \ln(1 + \phi_0 k h_s)$$
$$h_m = h_s - \frac{1}{k} \ln(1 + \phi_0 k h_s) \qquad \textit{Equation -3}$$

where h_m is the thickness of matrix. This follows from integration of the inverse average porosity/depth function of Falvey and Middleton (1981).

The above calculations assume that the isostatic adjustment occurs under an Airy model - this is appropriate when the crust is weak, hot, or is heavily faulted. A cooler and/or more rigid crust behaves as an elastic plate - and bends. The two forms of subsidence are shown schematically in Figure 3. Full calculation of flexural isostasy requires cross-sectional considerations; in Figure 3 the arrows show the relative magnitude of the tectonic subsidence anomaly due to the flexural load of the shelf margin wedge. Note that uplift of the elastic plate occurs shoreward of the wedge. In the Airy case there is no relative tectonic subsidence anomaly because the crust is everywhere in isostatic balance.



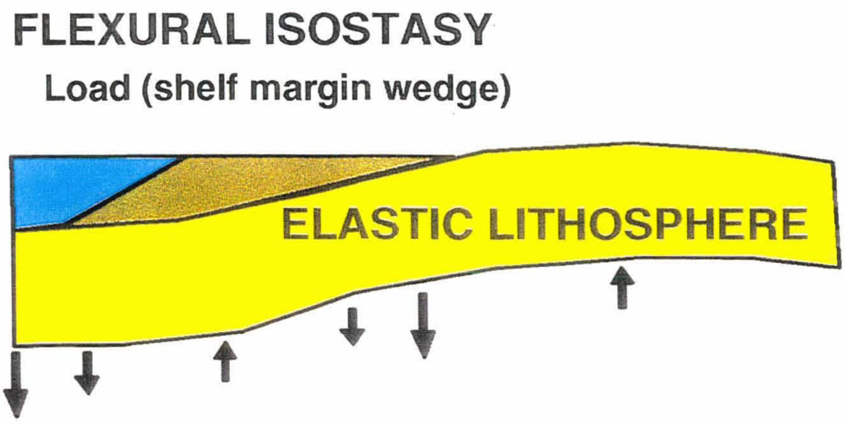


Figure 3 Two forms of isostatic behaviour of the lithosphere

<u>Paleobathymetric Interpolation</u>

Tectonic subsidence calculated according to the principles above represents more accurately the driving force for subsidence in the basin than the actual change in basement depth. It indicates long term changes in the lithosphere and short term faulting movement. Thus we can use the tectonic subsidence curve to interpolate paleobathymetry between accurate (fossil derived) control points on the geohistory diagram.

The geohistory diagram below shows the typical paleobathymetric range (envelope) from fossil analysis and seismic (clinoform) modelling of a shelf edge. How do we interpolate a reasonable paleo water depth model within this envelope ?

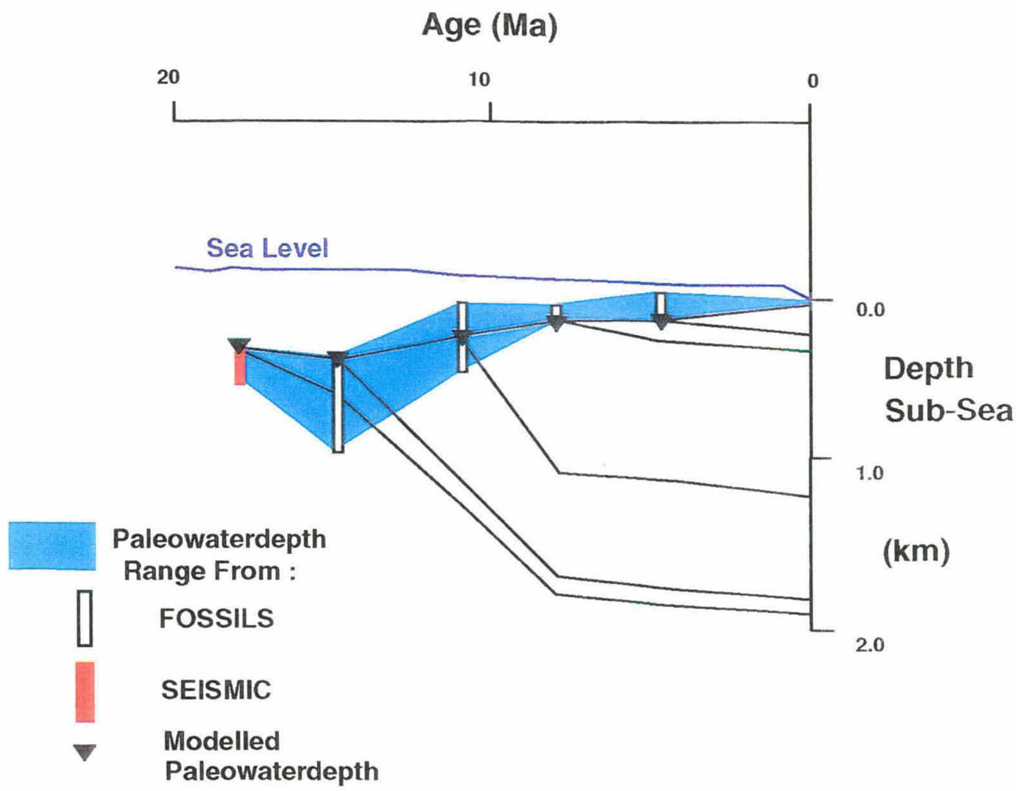


Figure 4 Geohistory Diagram showing paleo water depth ranges and a tectonic interpolation of modelled waterdepth.

It is clear from the discussion above that any deposition of sediment will, because of sediment load, cause the basement to subside. Figure 5 shows the tectonic subsidence equivalent envelope for this paleobathymetric data.

It is clear that there is only one smooth curve (as opposed to straight line) that fits between the tectonically adjusted data - this is shown by the triangles. These triangles have been transposed back onto the geohistory diagram as the modelled paleowaterdepth, showing a tectonic interpolation of the paleobathymetric model.

As a general observation we may note here that tectonic subsidence curves are usually a series of long period smooth declining curves, indicating thermal cooldown of the crust, separated by shorter periods of uplift or subsidence which, if present, represent collisional tectonics or heating events.

Note that it is not always possible or advisable to model smooth curves. Several cases where it would not be advisable are :

- During periods of compressional or strike slip tectonic activity.
- When uplift events are known from regional geology. Beware, however of regional hiatuses or unconformities which might more reasonably be explained by eustatic sea level fluctuations.
- When a deltaic wedge migrates over the well site. Here flexural isostasy would be more accurate.

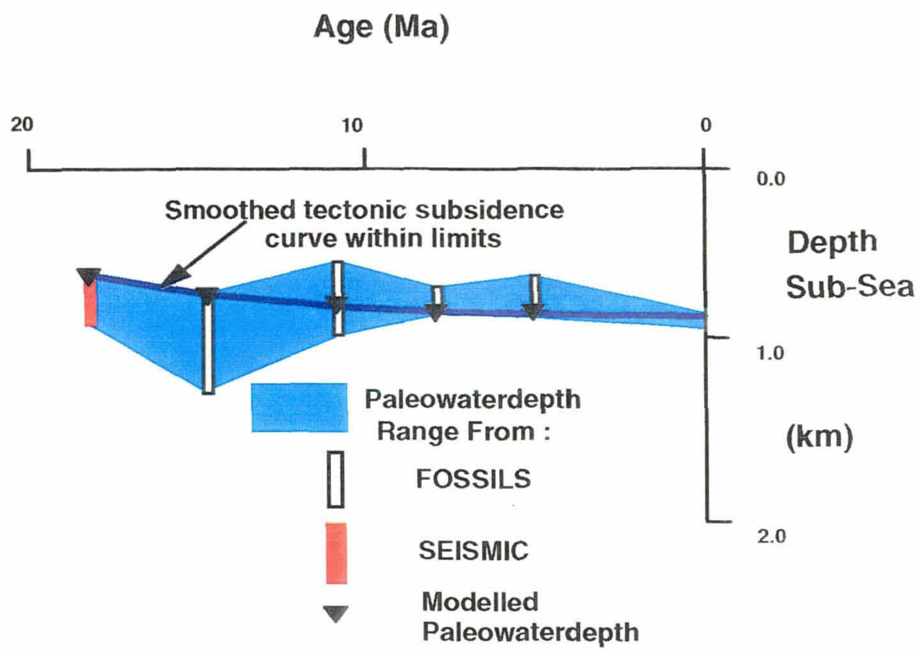


Figure 5 Tectonic subsidence diagram for the Geohistory Diagram in Fig 4.

In these cases, the paleobathymetric subsidence model should be compatible with the geology.

Accurate assessments of paleo water depth are useful for sea bottom temperature estimation and may also be used for fan sedimentological models. The variation of water temperature with depth in the oceans is shown in Figure 6. Sea bottom temperatures on continental margins may be less than those shown due to upwelling of cold bottom currents.

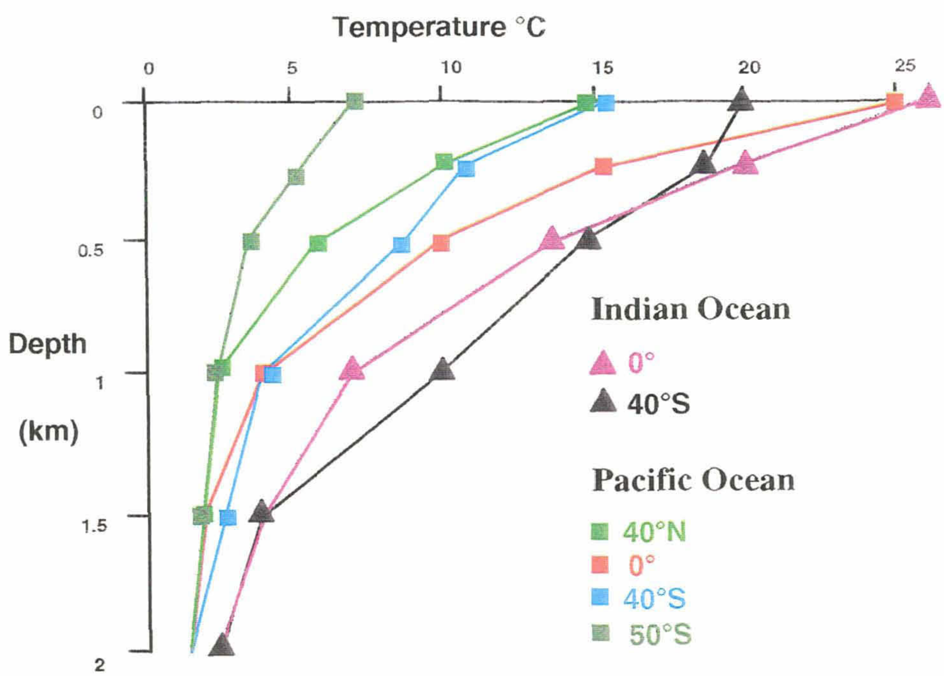
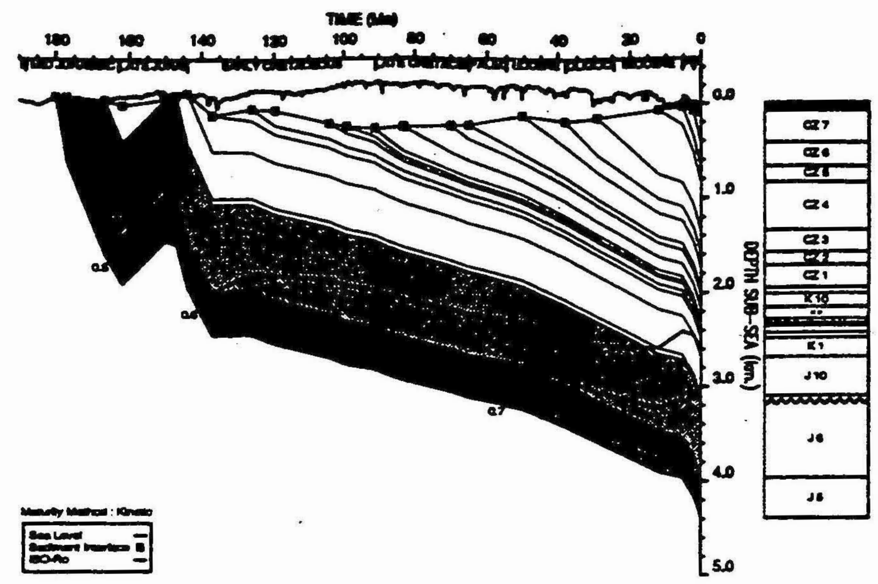
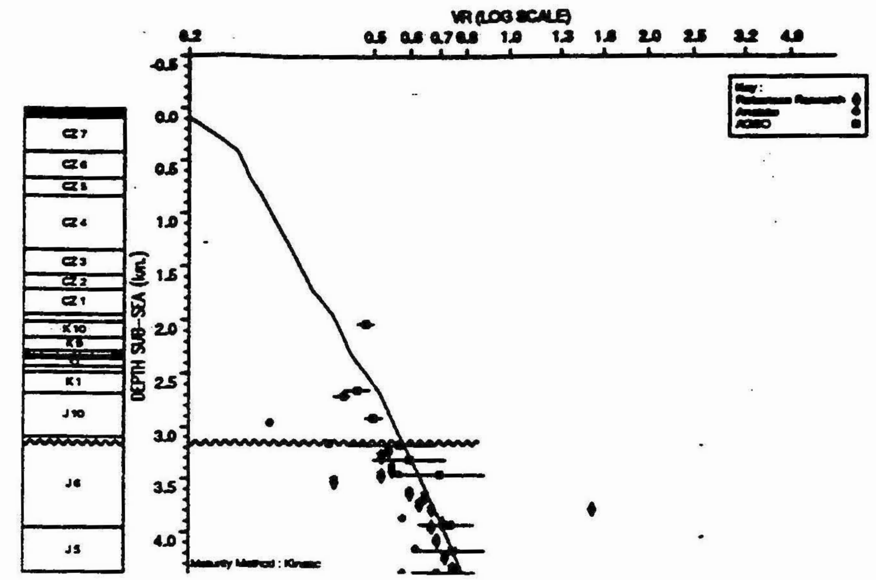


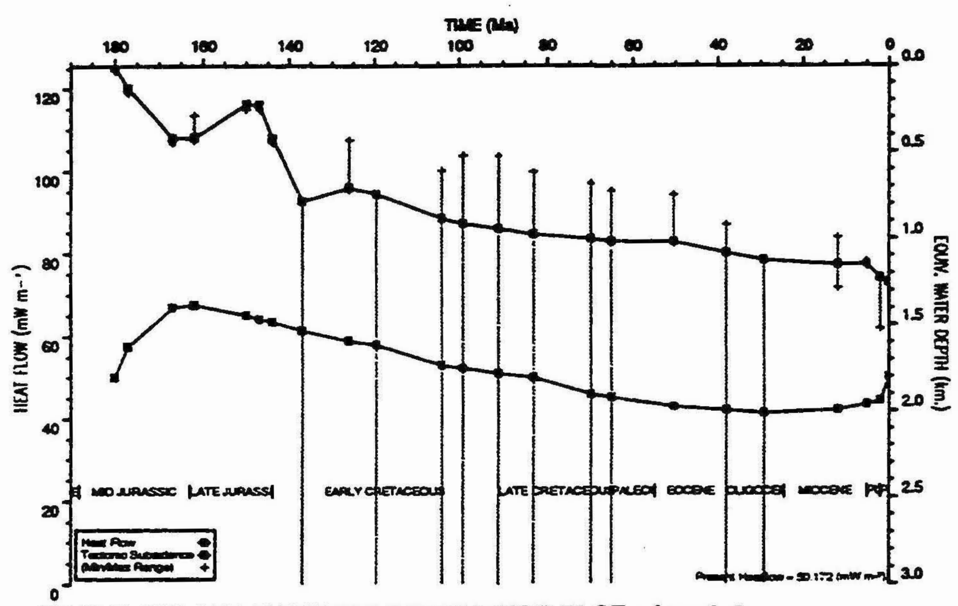
Figure 6. Variation of Temperature with water depth in the Indian and Pacific Oceans



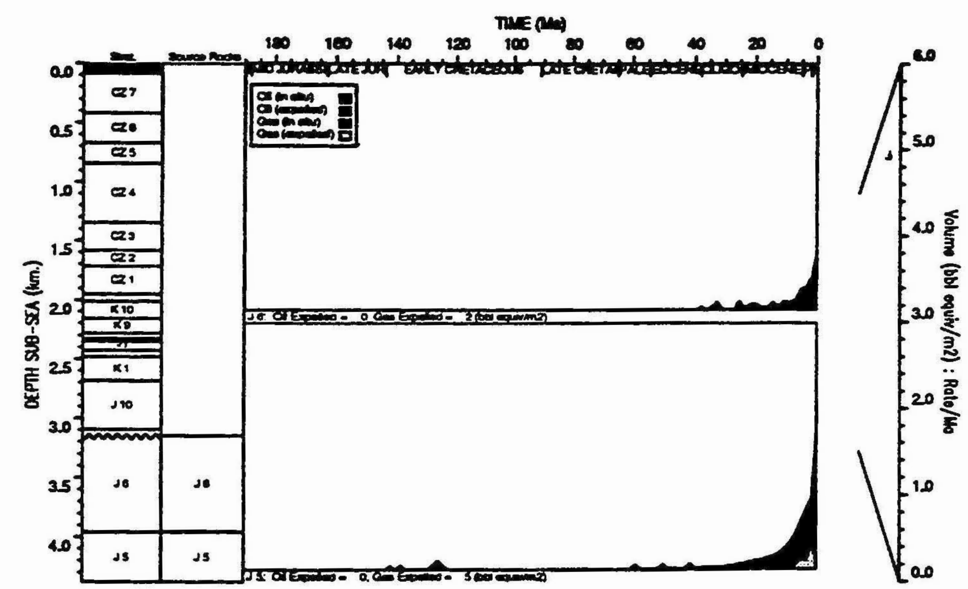
GEOHISTORY PLOT : Angel 2



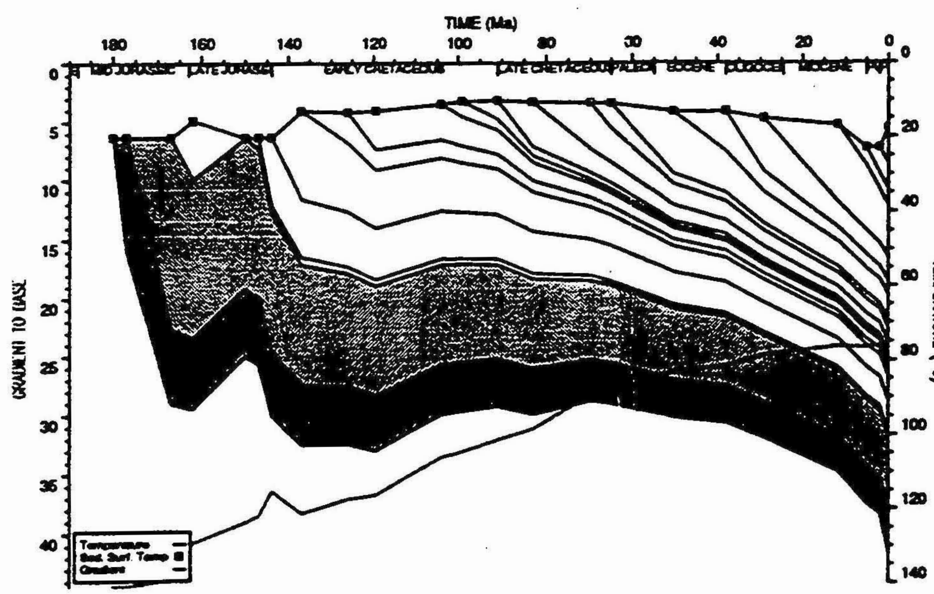
OBSERVED vs COMPUTED MATURITY PLOT : Angel 2



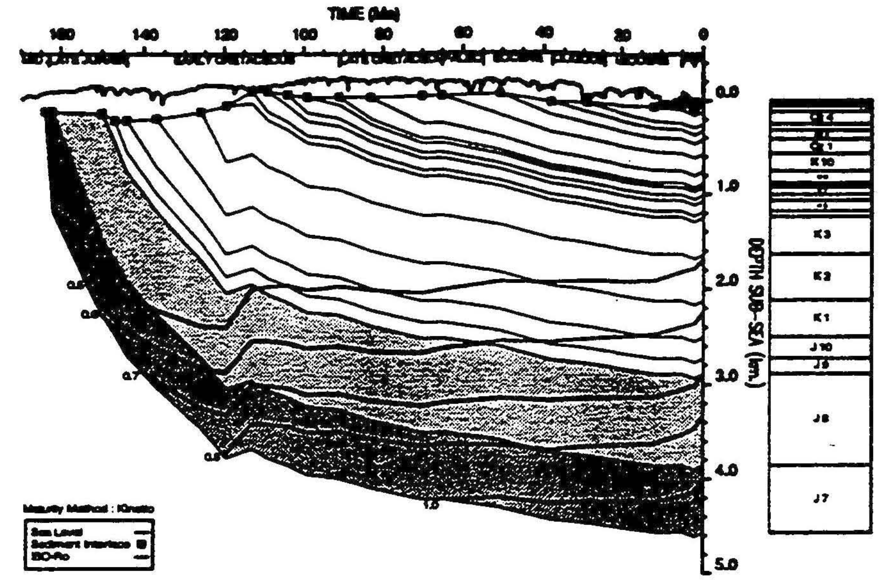
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Angel 2



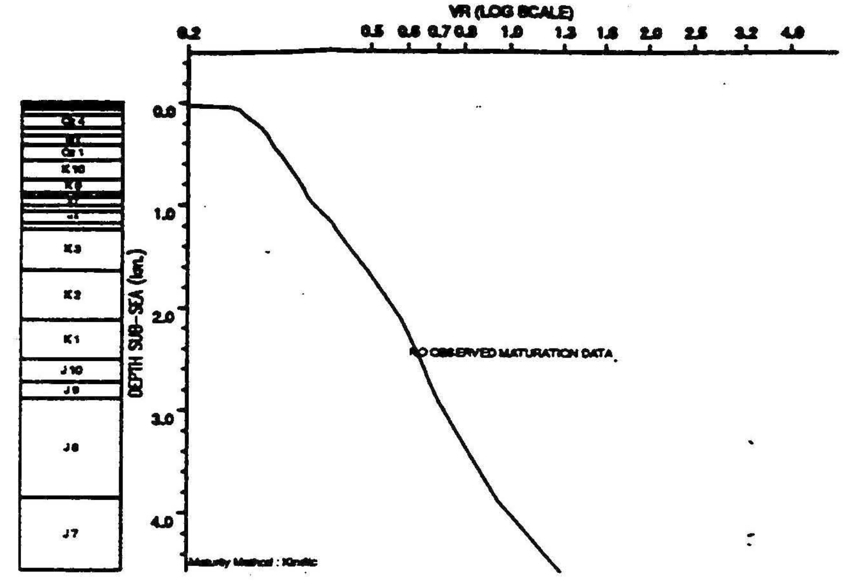
HYDROCARBON GENERATION PLOT : Angel 2



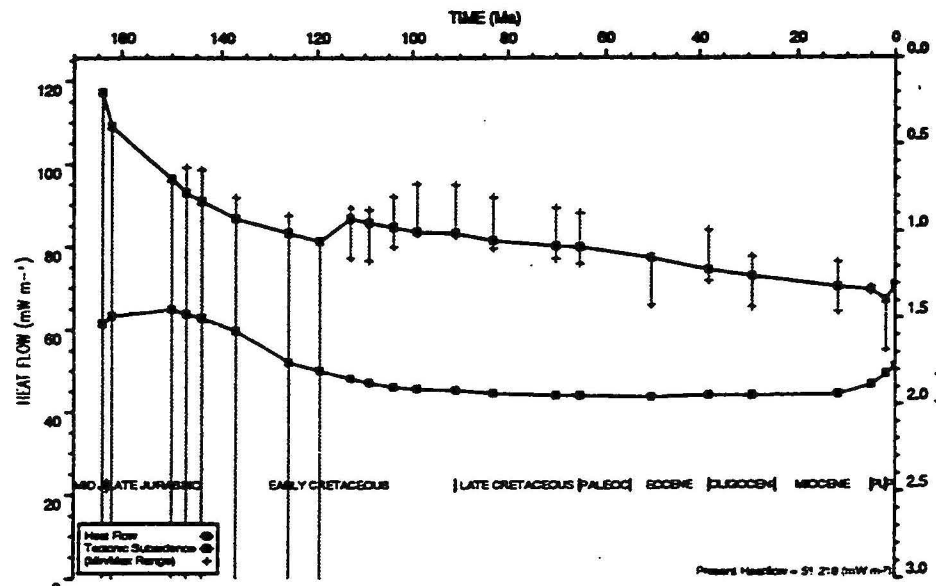
BED TEMPERATURE PLOT : Angel 2



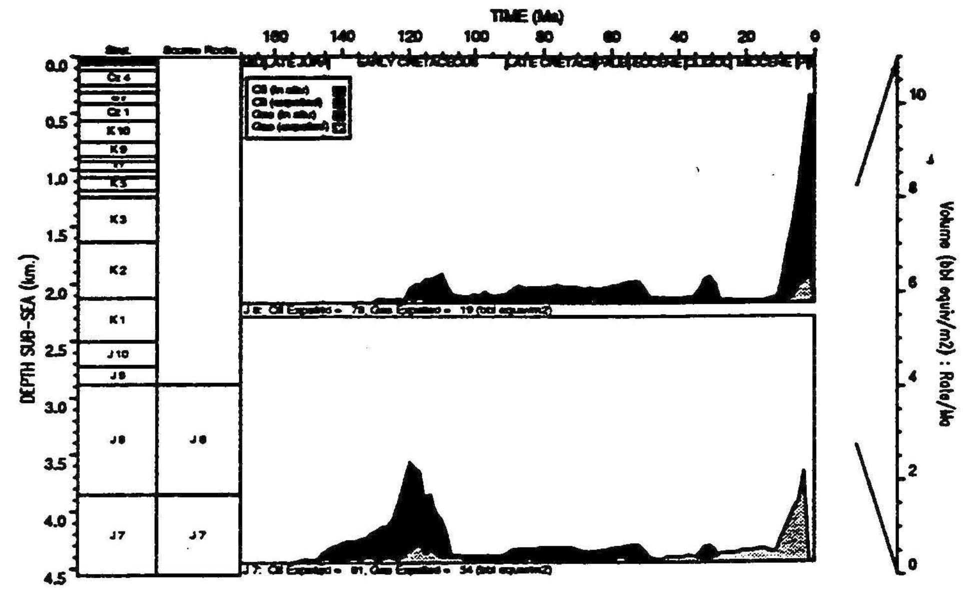
GEOHISTORY PLOT : Bambra 2



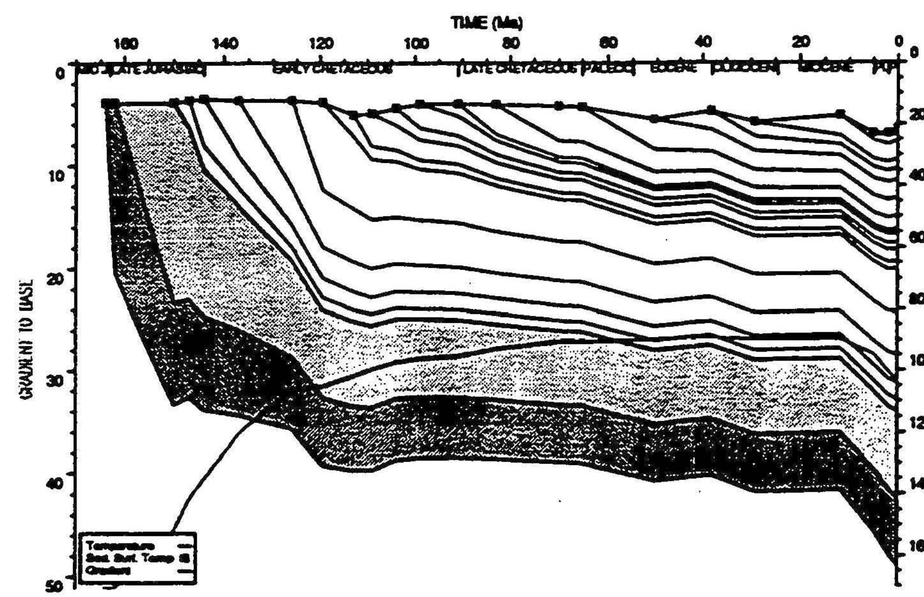
OBSERVED vs COMPUTED MATURITY PLOT : Bambra 2



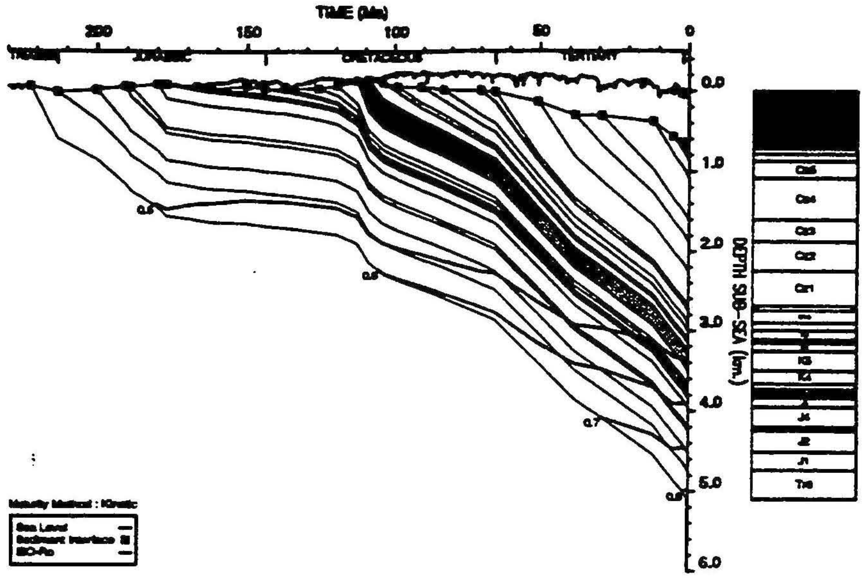
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Bambra 2



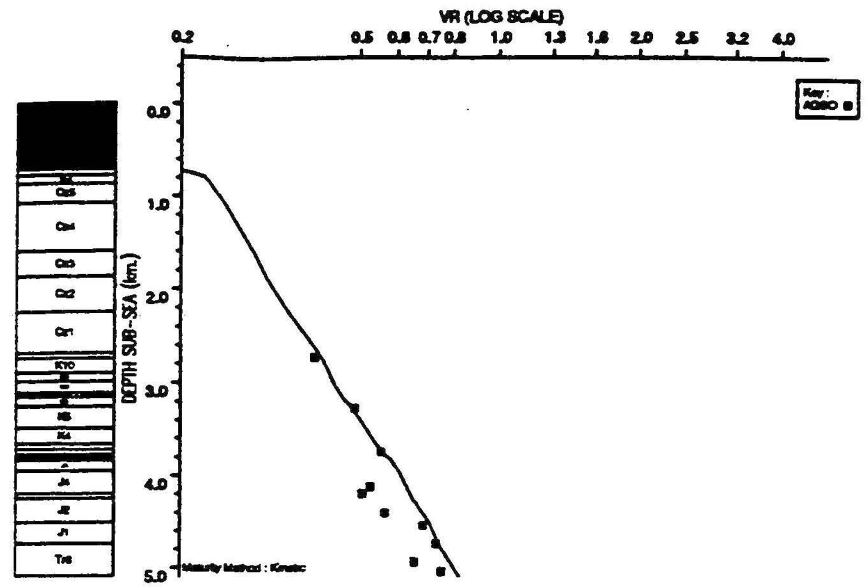
HYDROCARBON GENERATION PLOT : Bambra 2



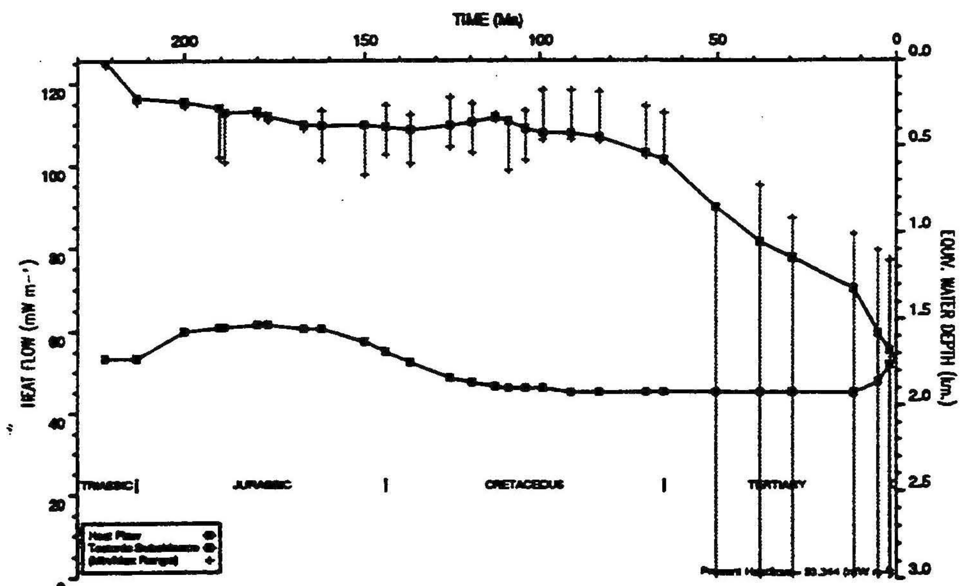
BED TEMPERATURE PLOT : Bambra 2



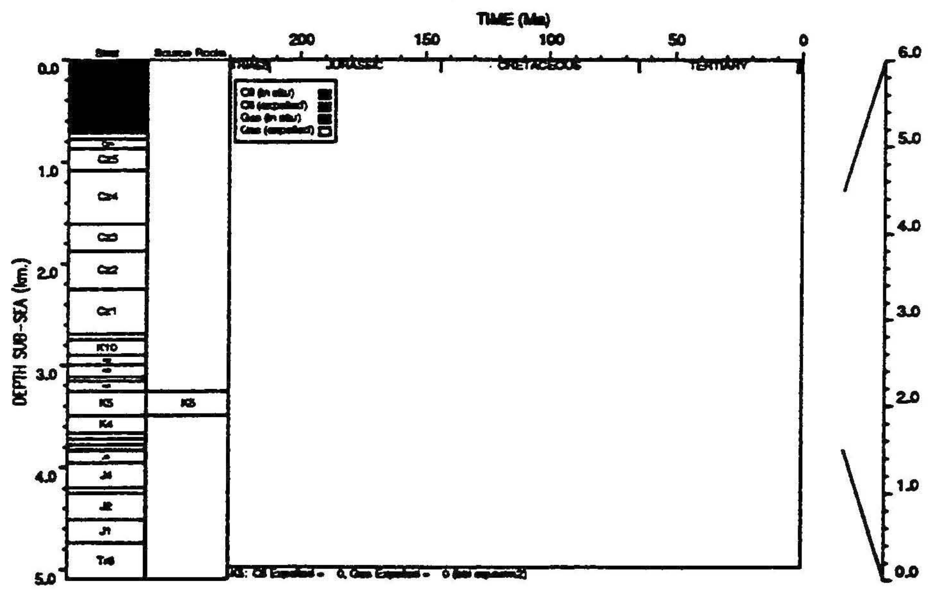
GEOHISTORY PLOT : Barcoo 1



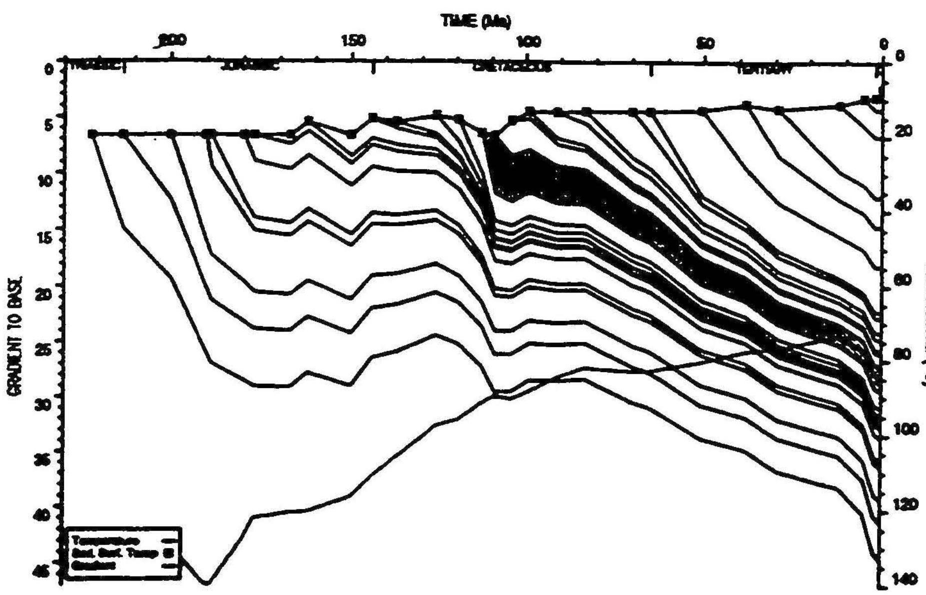
OBSERVED vs COMPUTED MATURITY PLOT : Barcoo 1



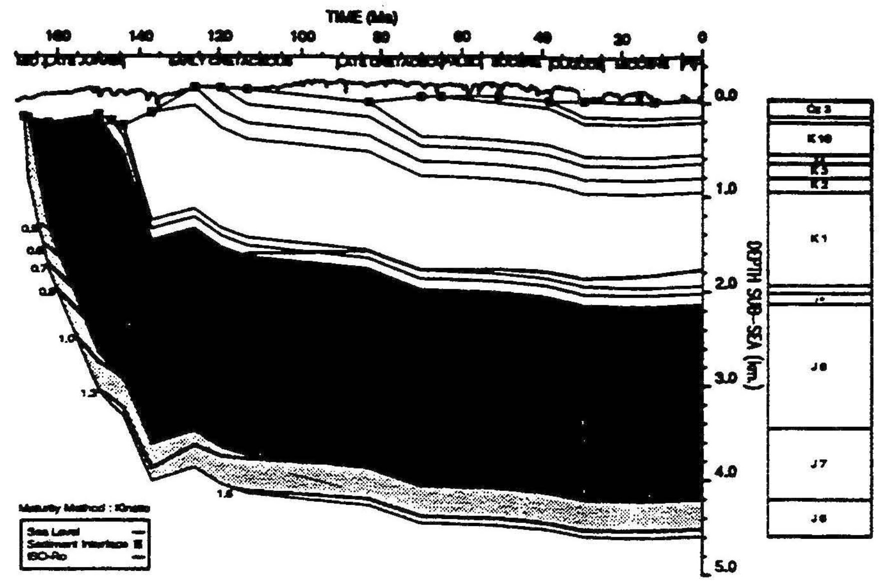
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Barcoo 1



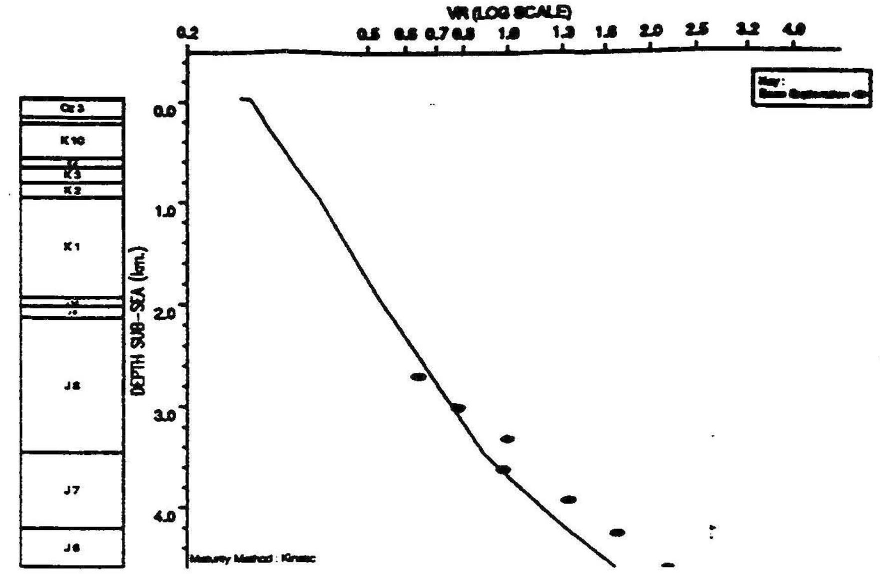
HYDROCARBON GENERATION PLOT : Barcoo 1



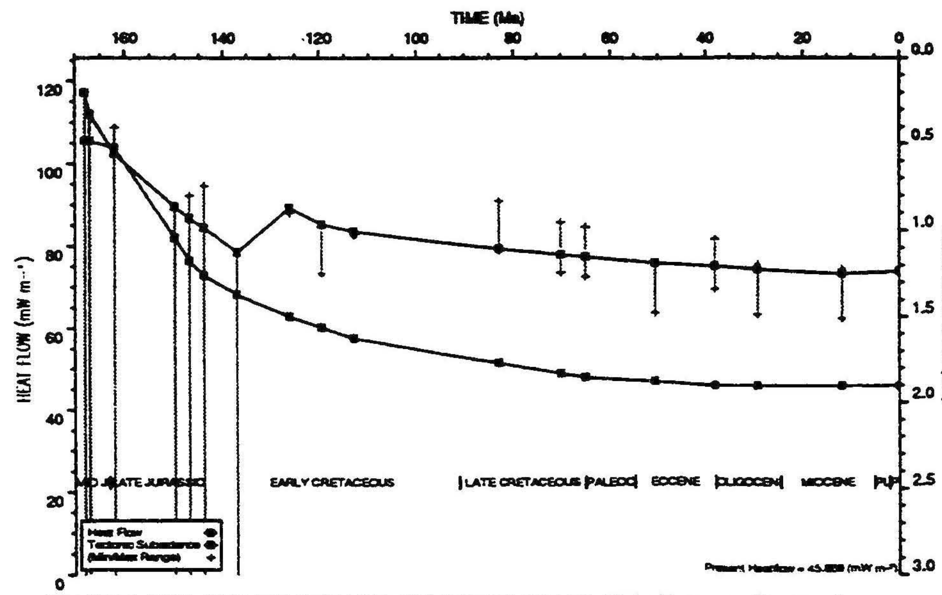
BED TEMPERATURE PLOT : Barcoo 1



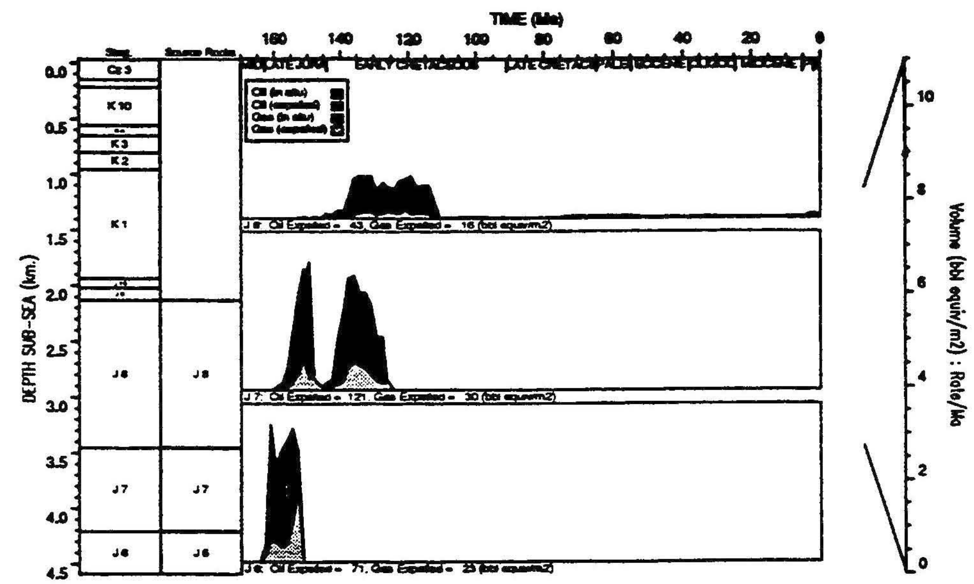
GEOHISTORY PLOT : Barrow Deep 1



OBSERVED vs COMPUTED MATURITY PLOT : Barrow Deep 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Barrow Deep 1



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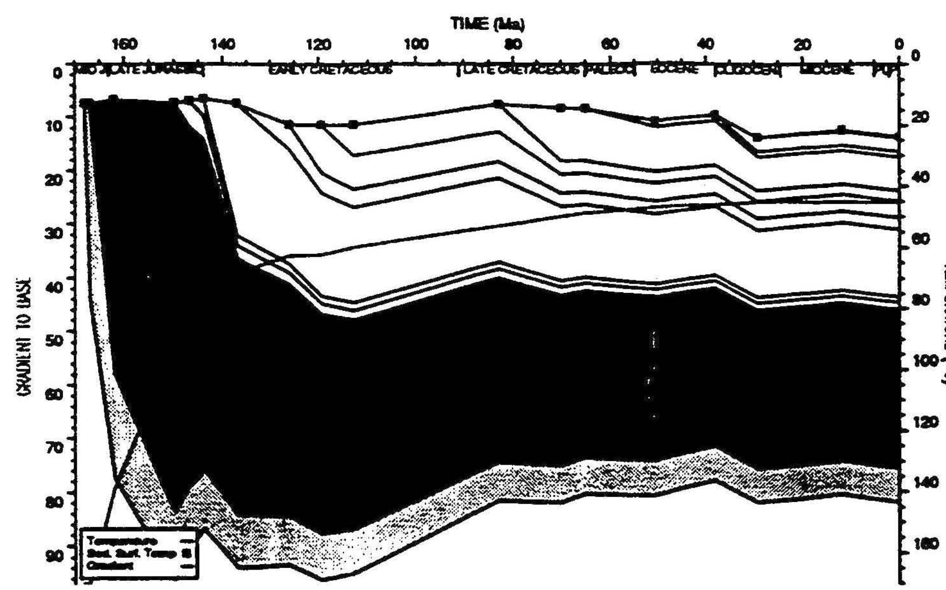

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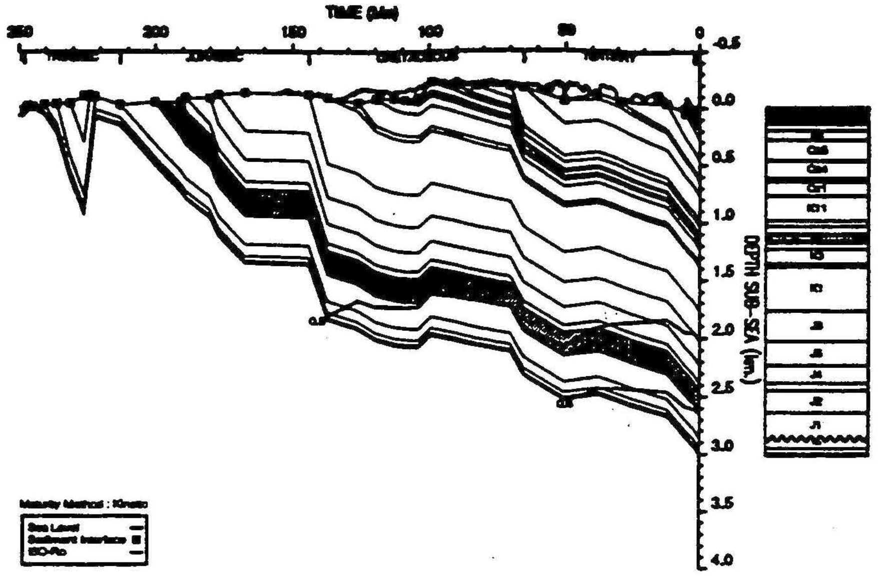
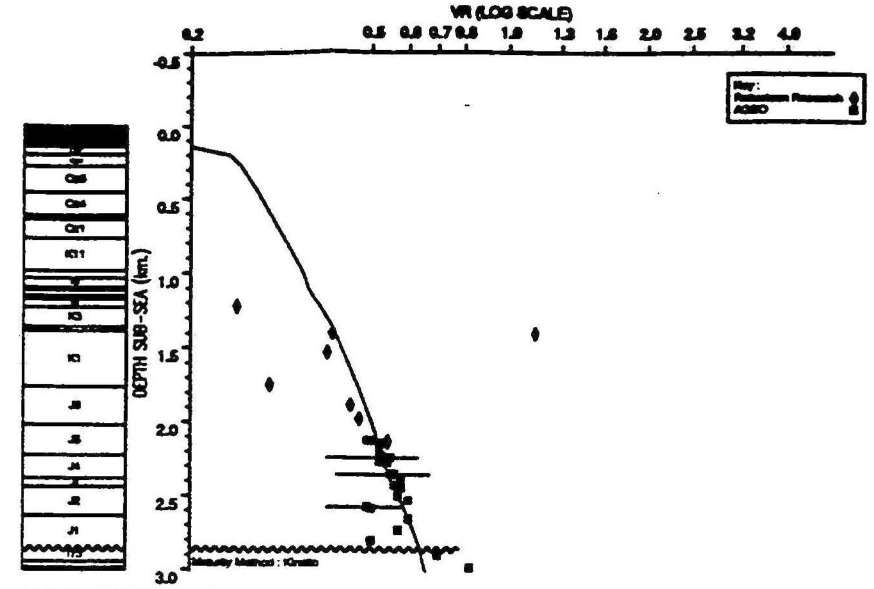


GEOHISTORY PLOT : Bedout 1



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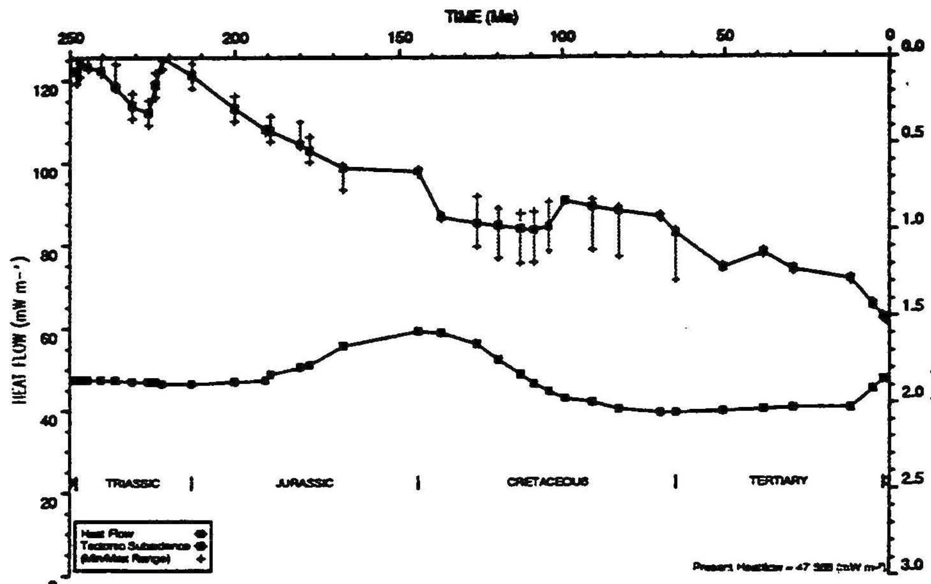

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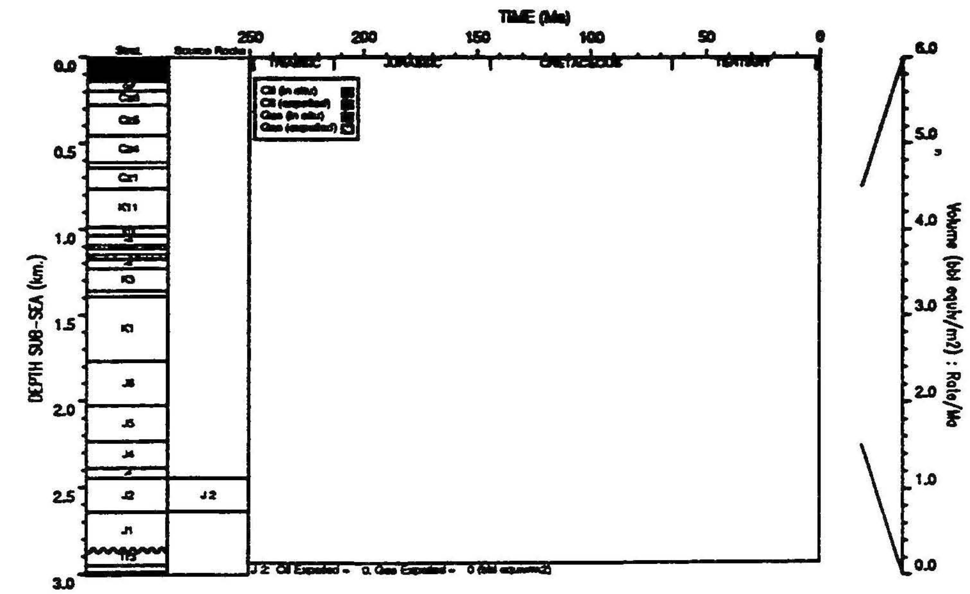

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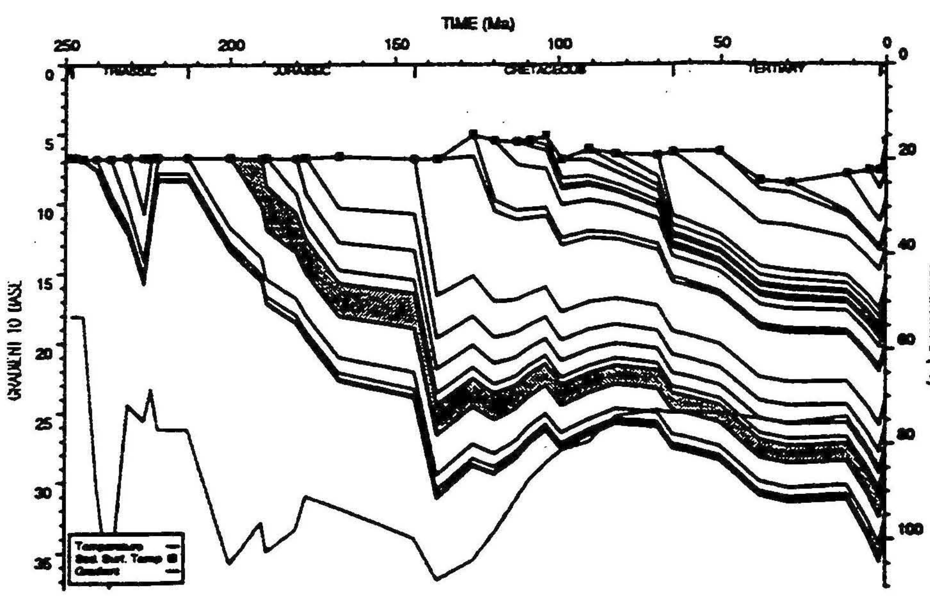

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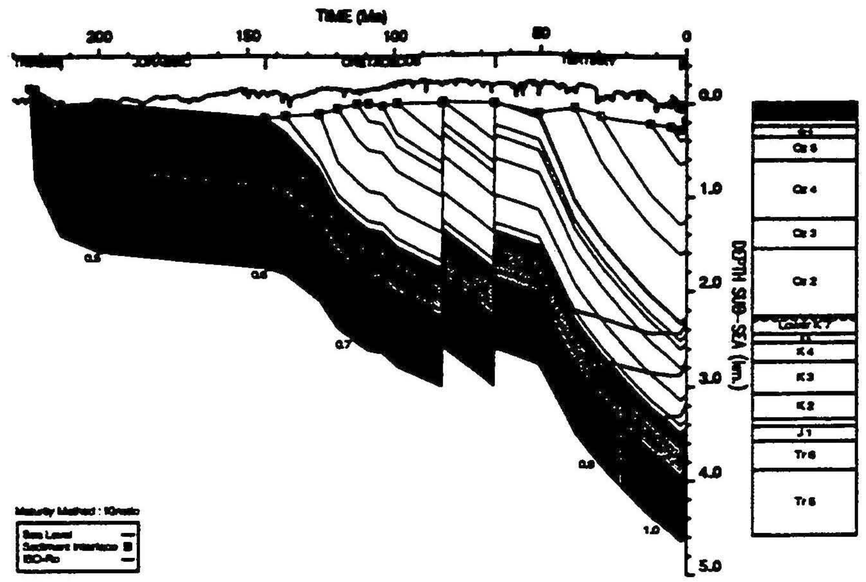
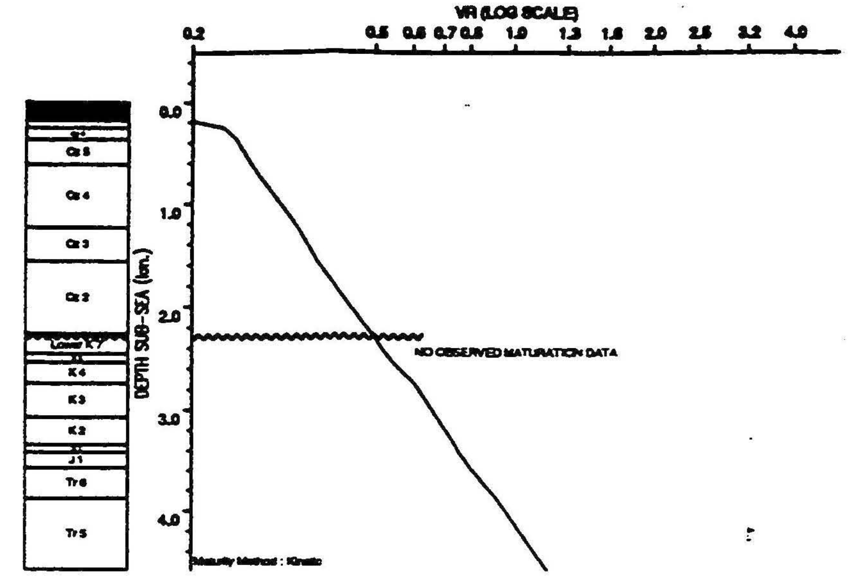
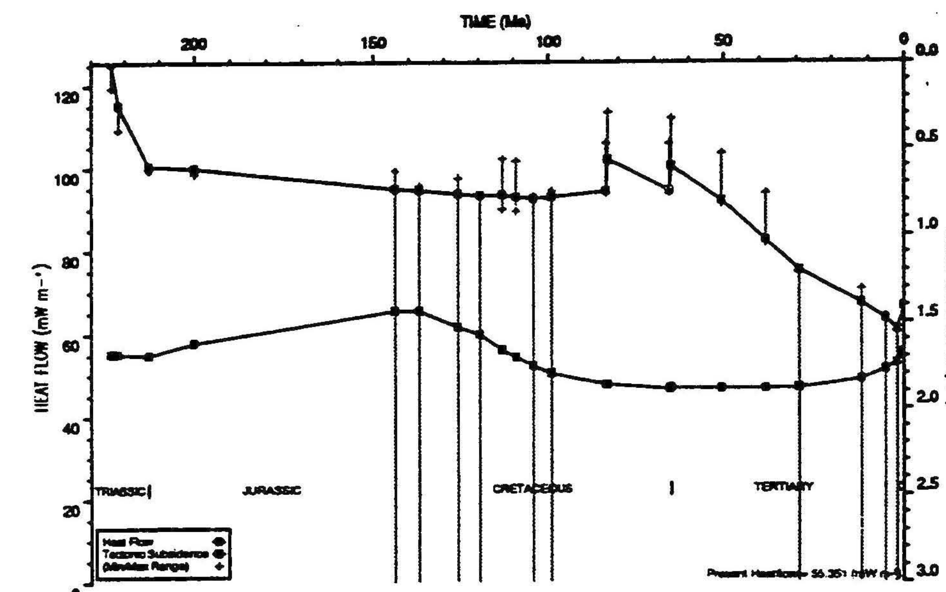


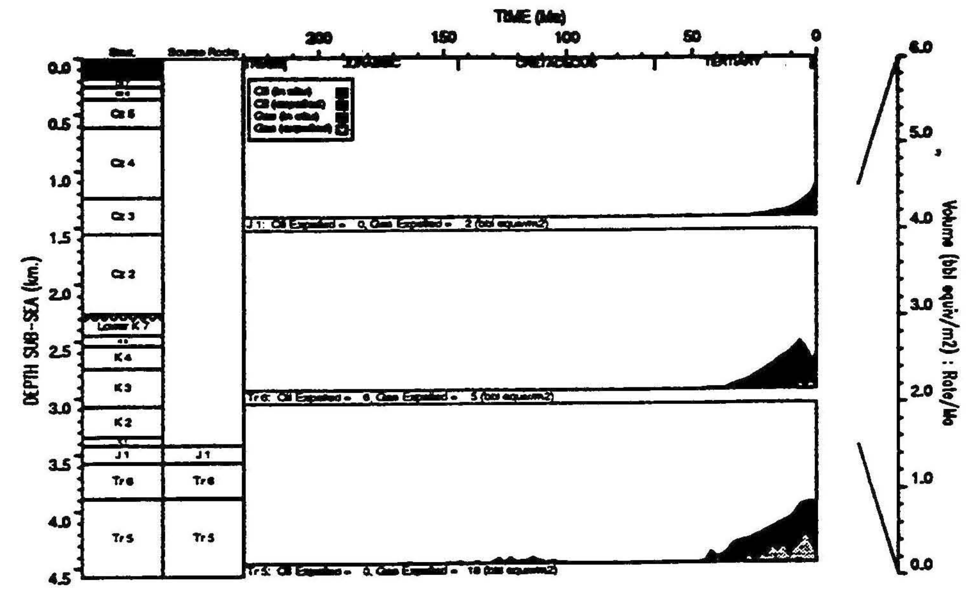
GEOHISTORY PLOT : Bluebell 1



OBSERVED vs COMPUTED MATURITY PLOT : Bluebell 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Bluebell 1



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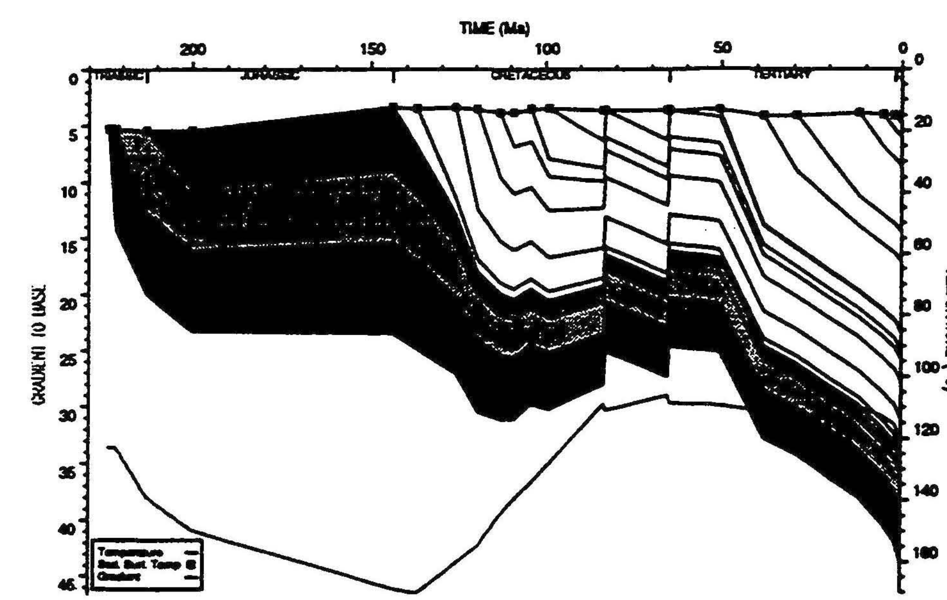

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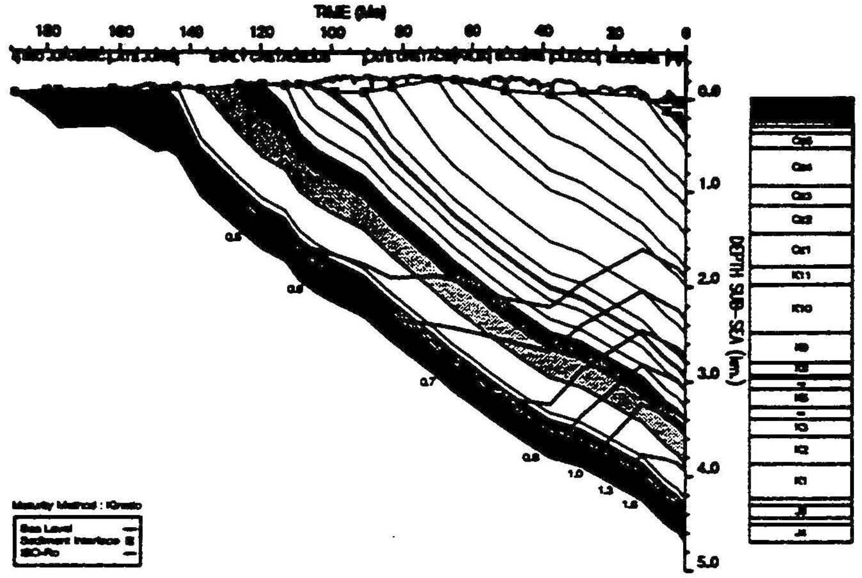
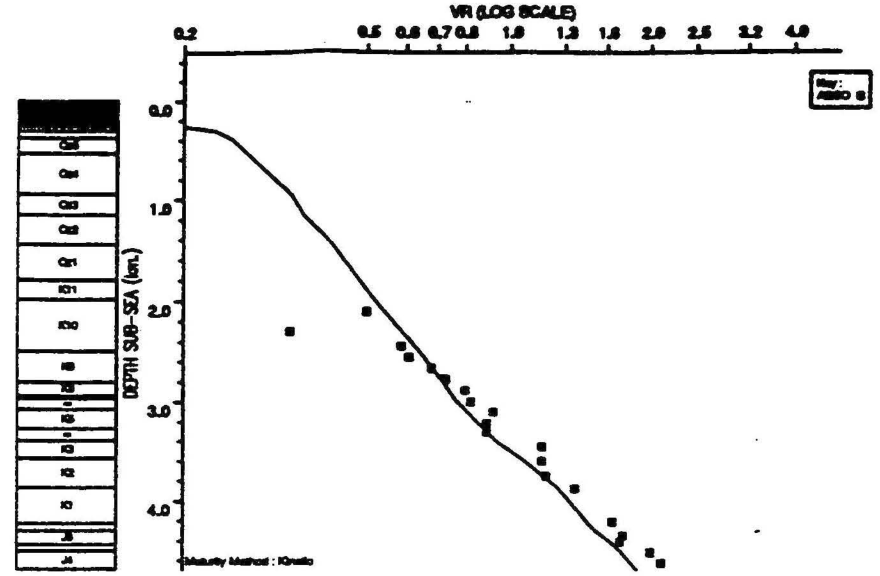
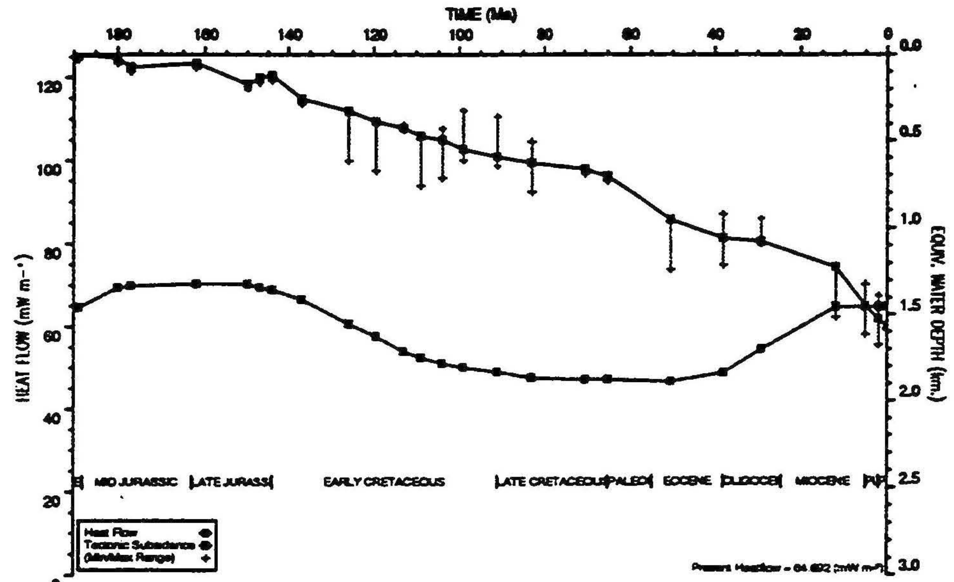


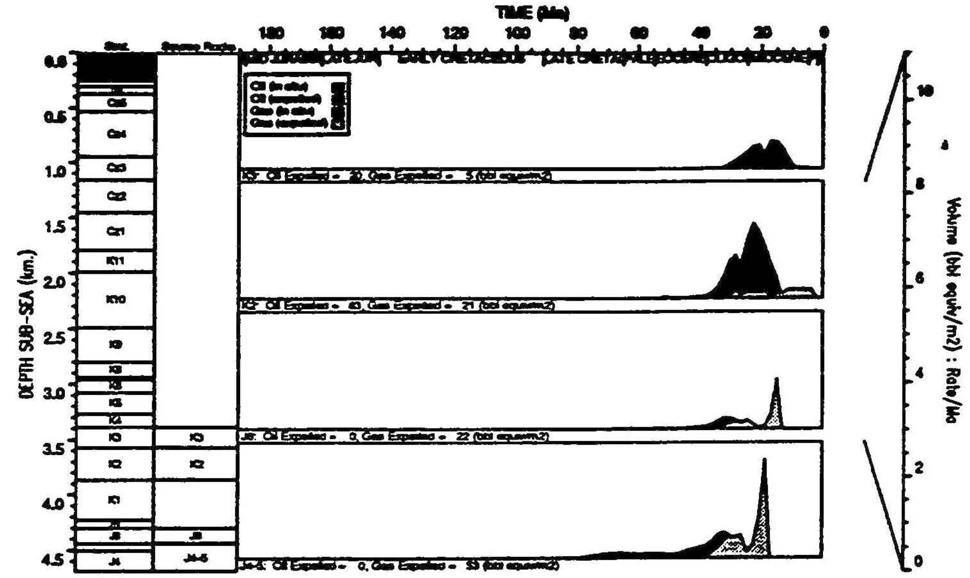
GEOHISTORY PLOT : Brewster 1A



OBSERVED vs COMPUTED MATURITY PLOT : Brewster 1A



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Brewster 1A



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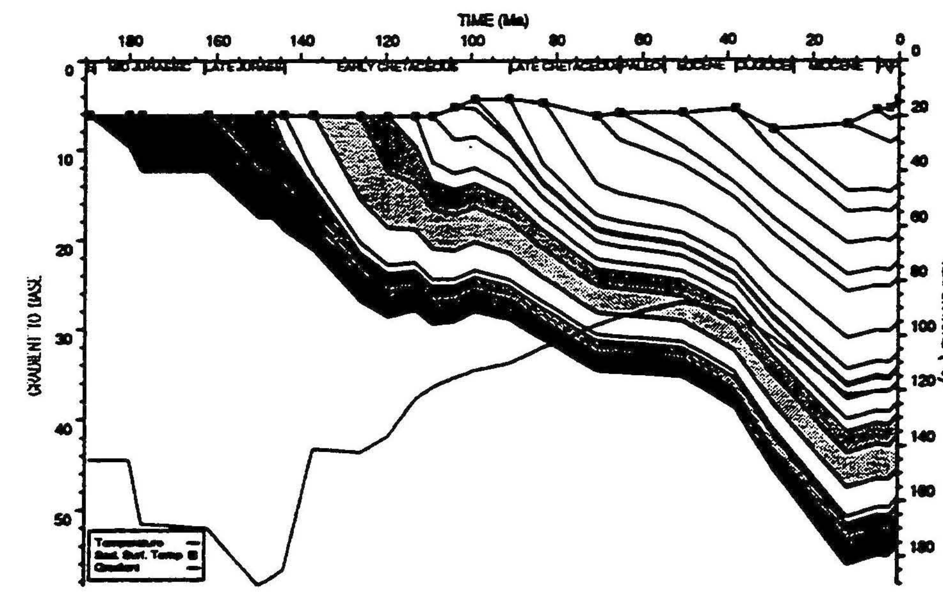

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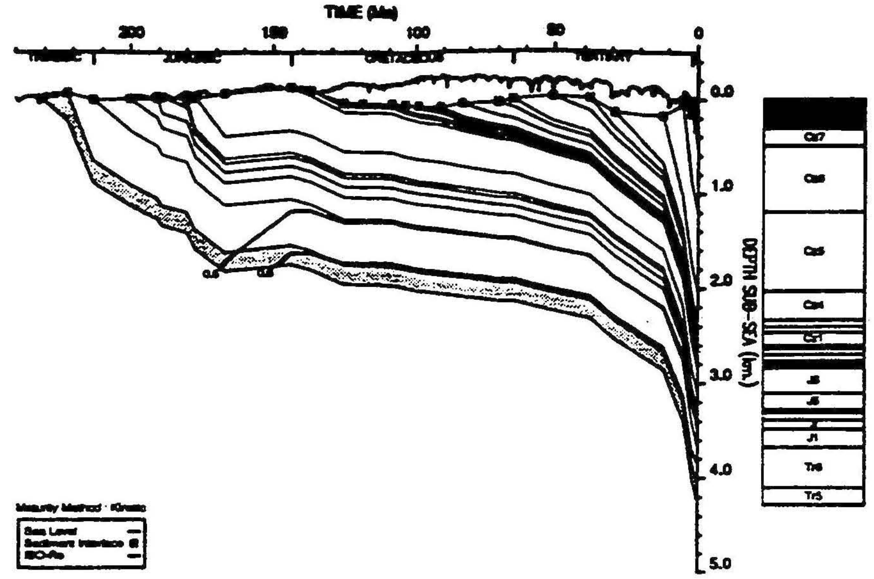
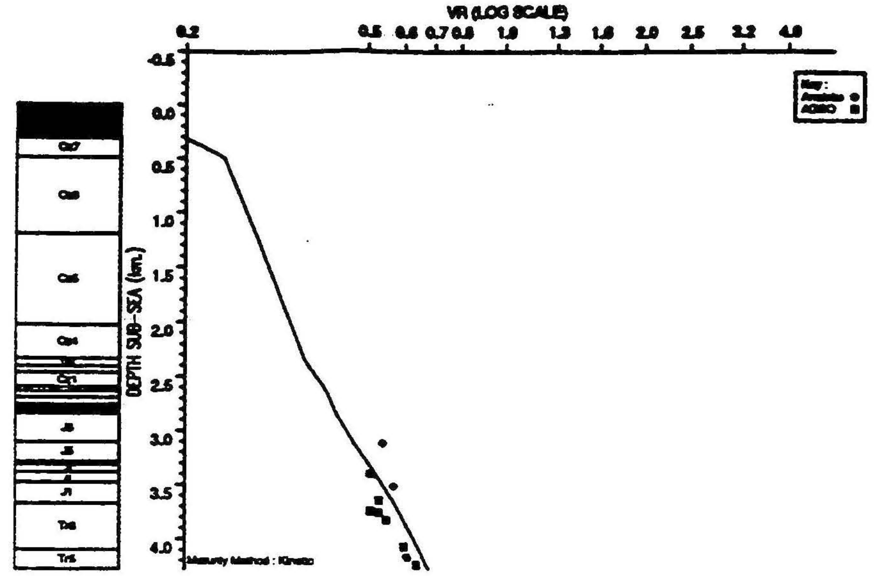
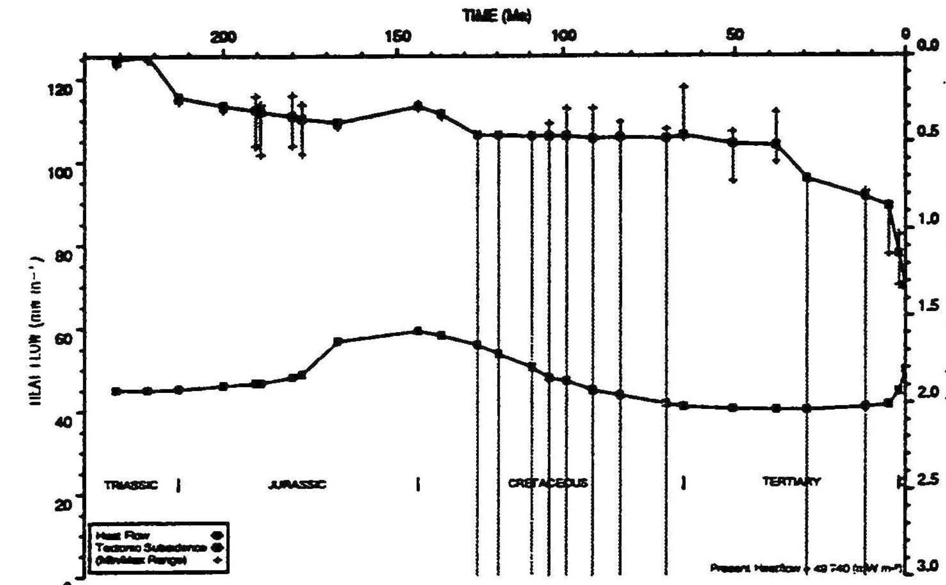


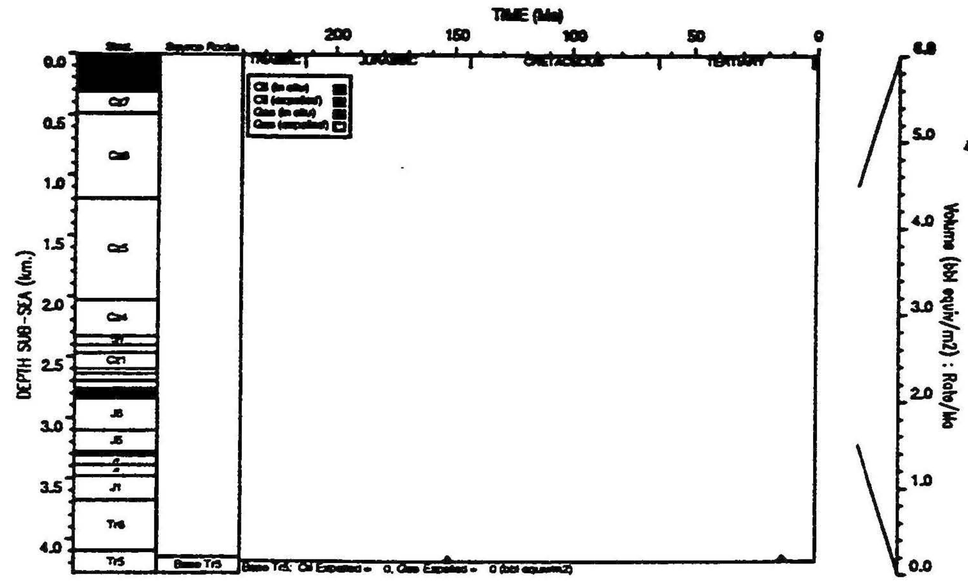
GEOHISTORY PLOT : Brigadier 1



OBSERVED vs COMPUTED MATURITY PLOT : Brigadier 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Brigadier 1



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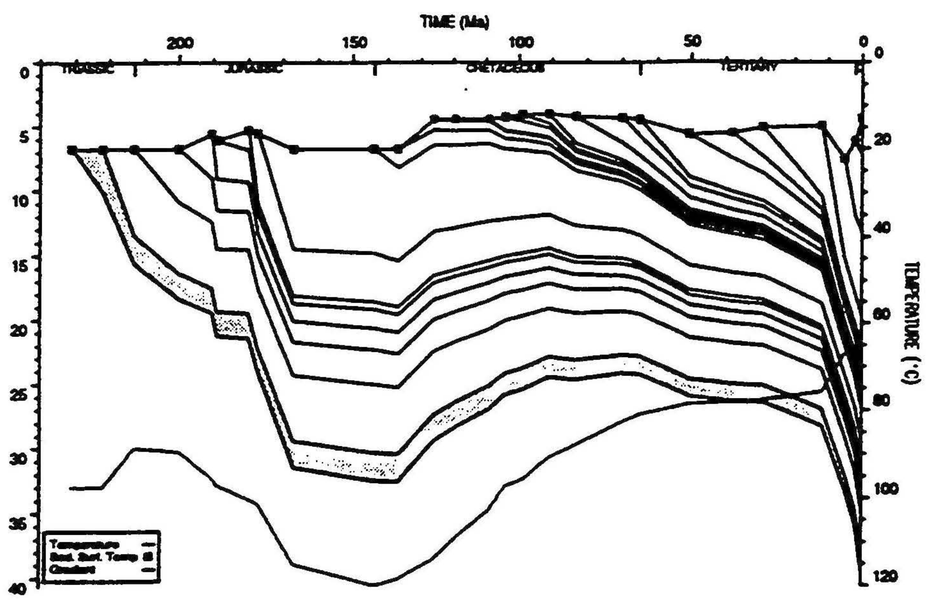

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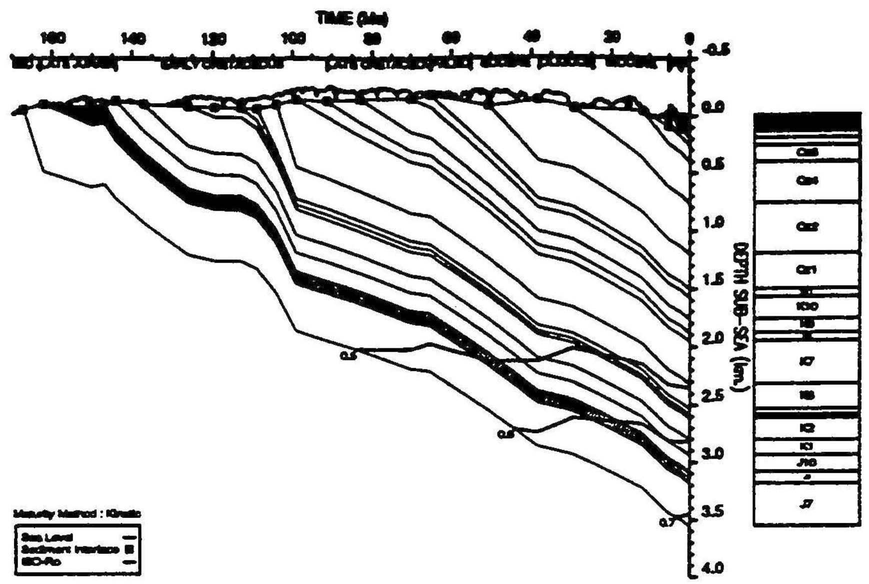
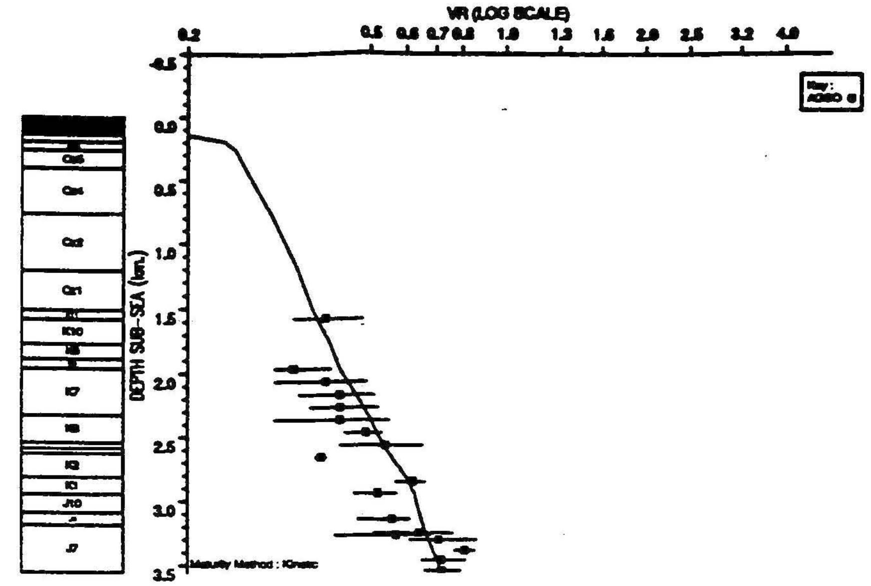
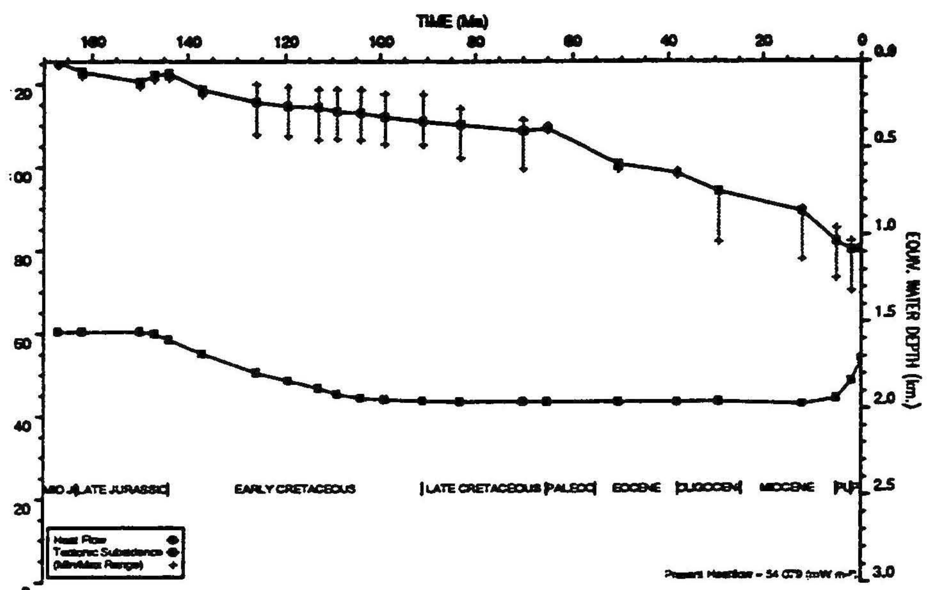


GEOHISTORY PLOT : Buccaneer 1



OBSERVED vs COMPUTED MATURITY PLOT : Buccaneer 1



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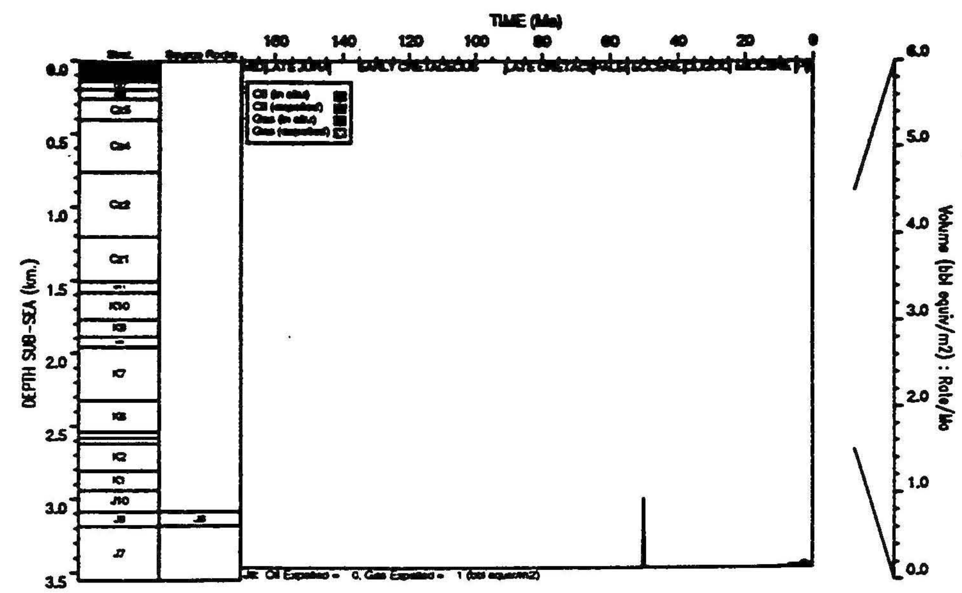

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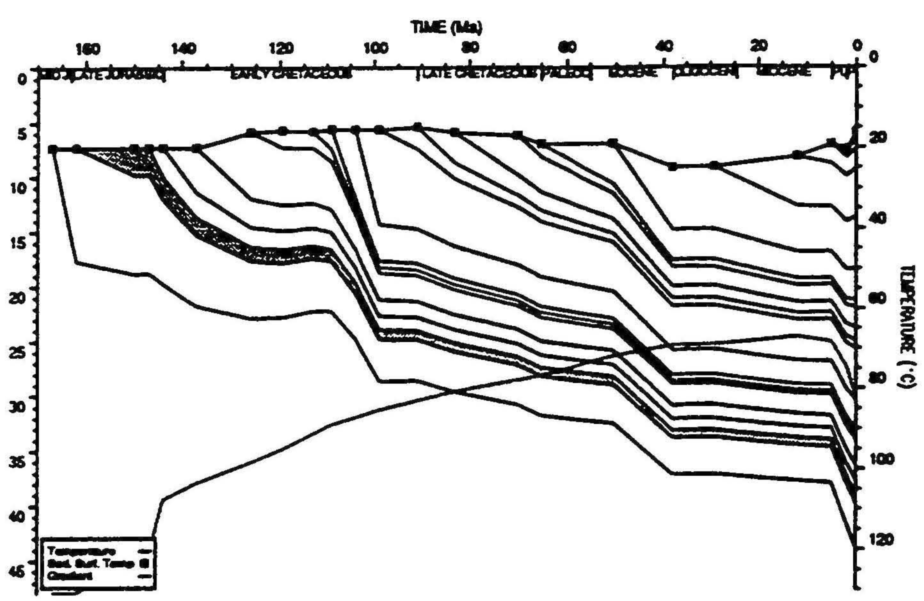

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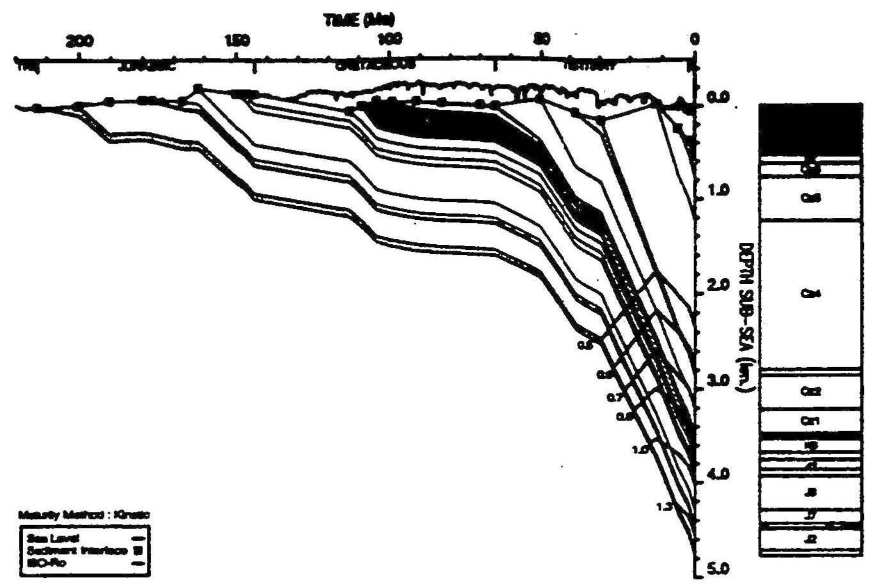

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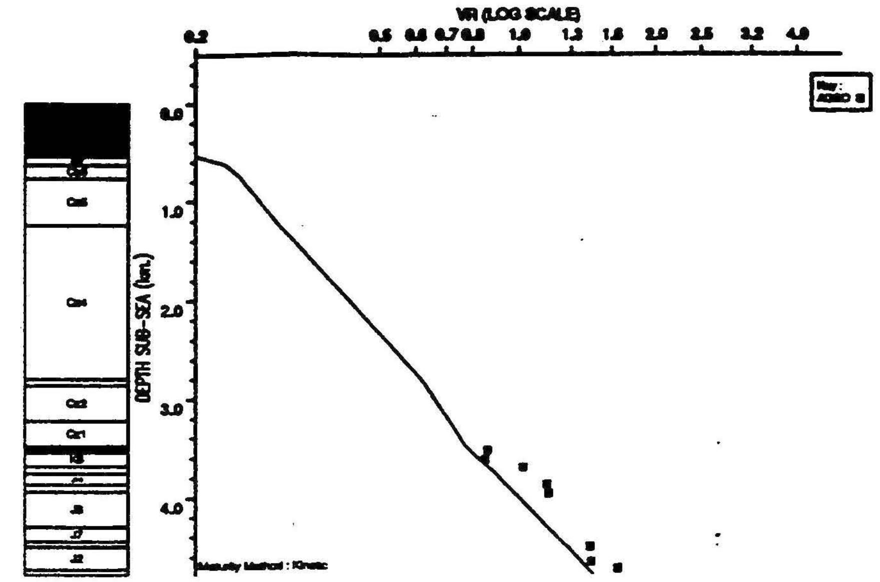
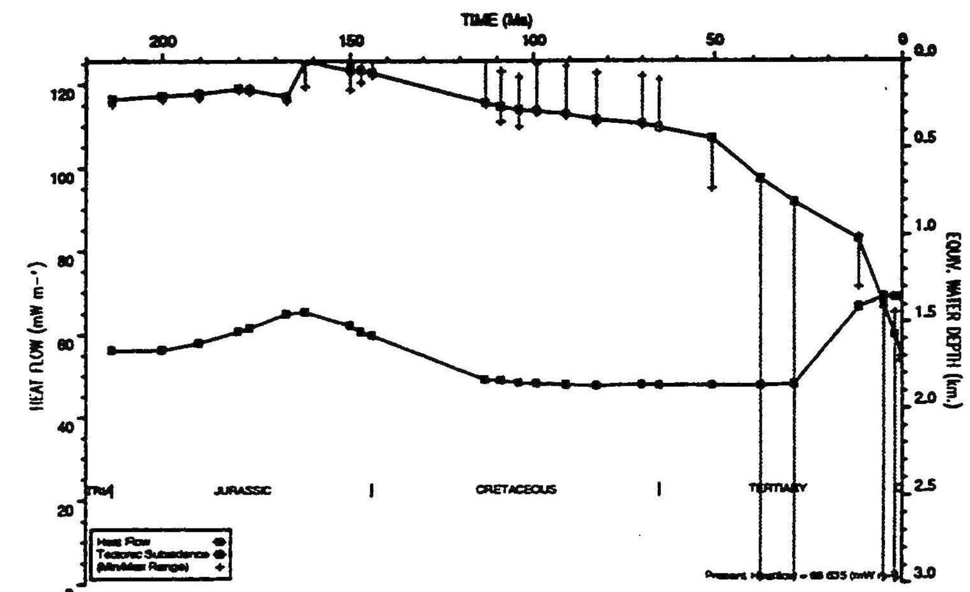


OBSERVED vs COMPUTED MATURITY PLOT : Buffon 1



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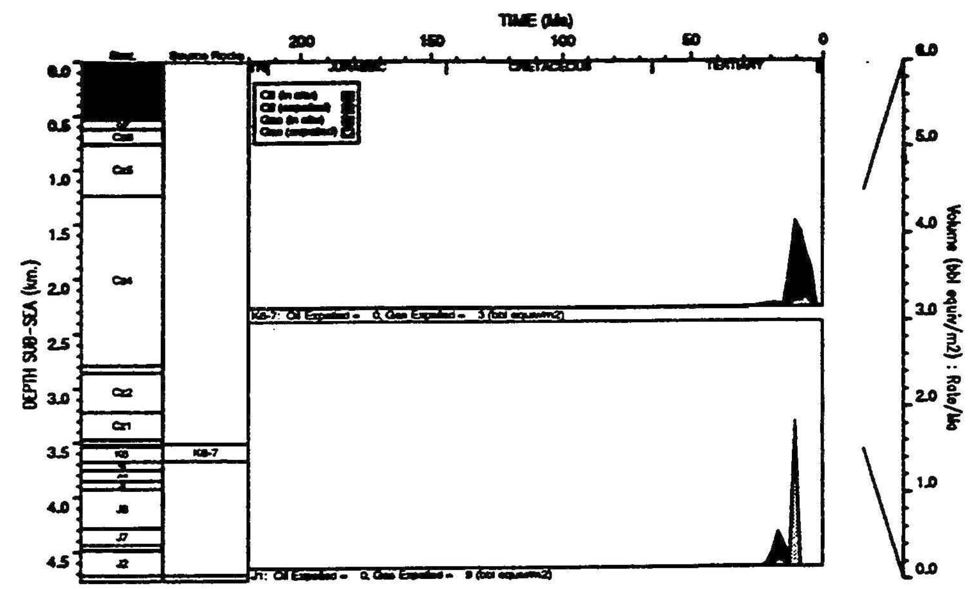

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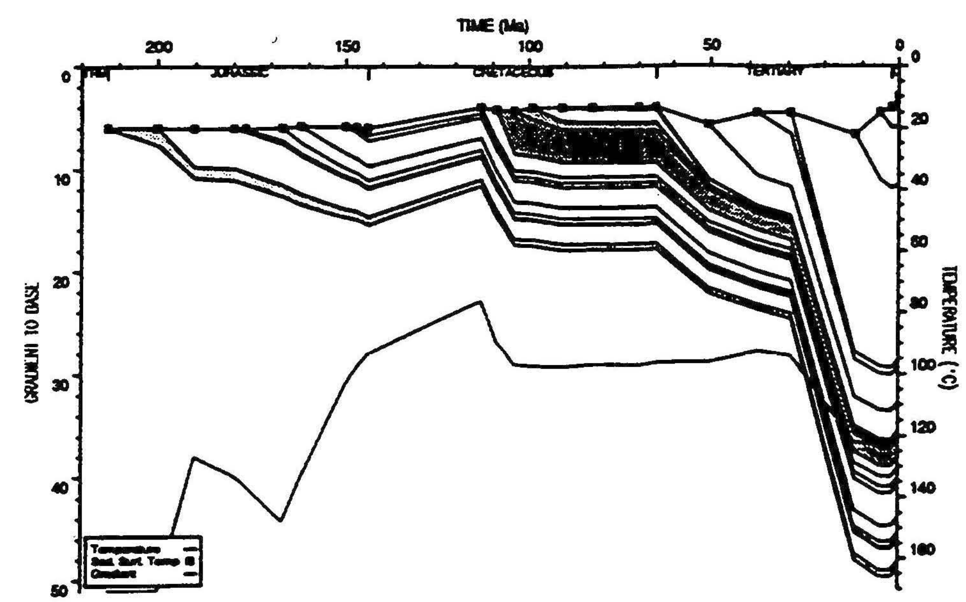

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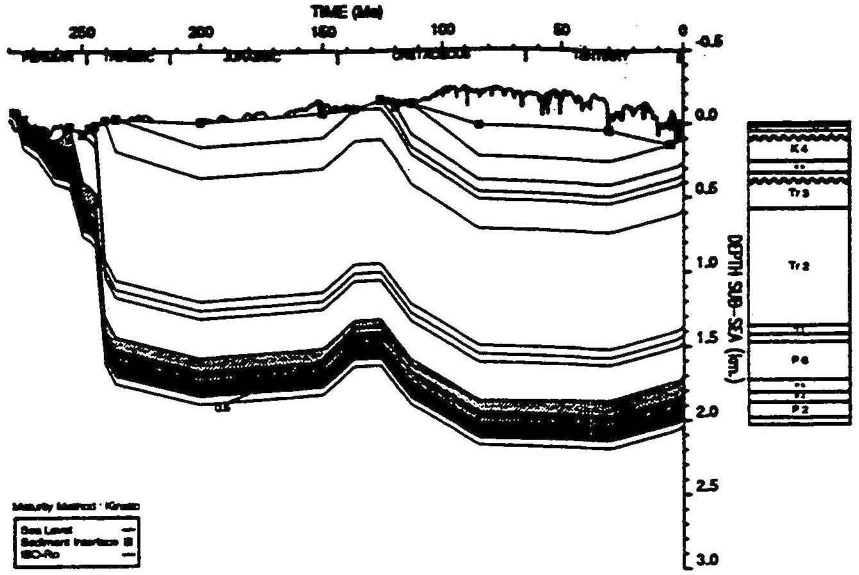

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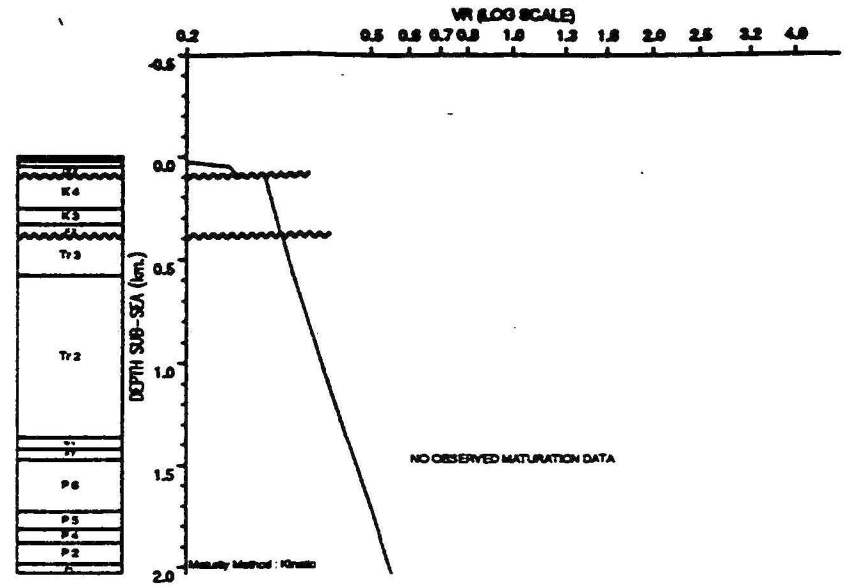
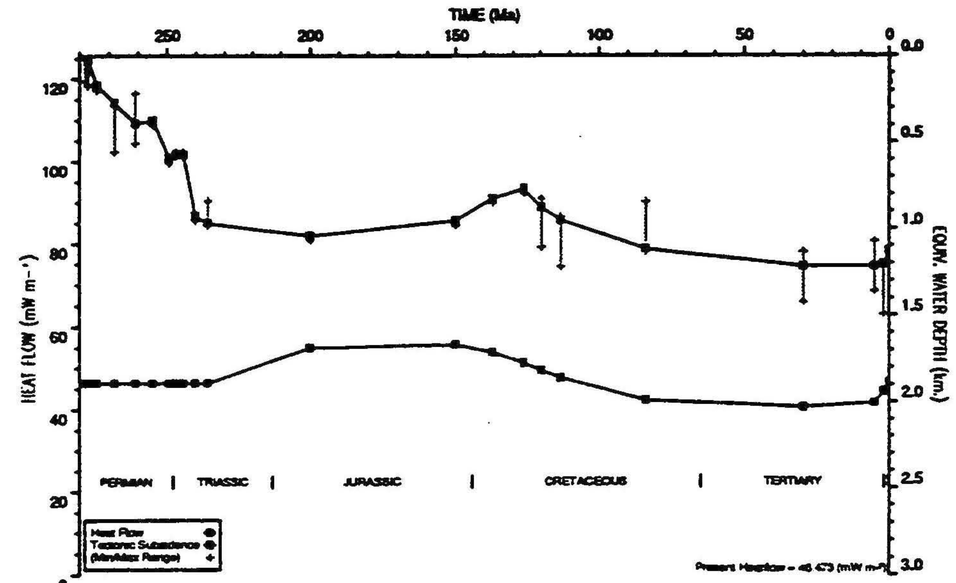
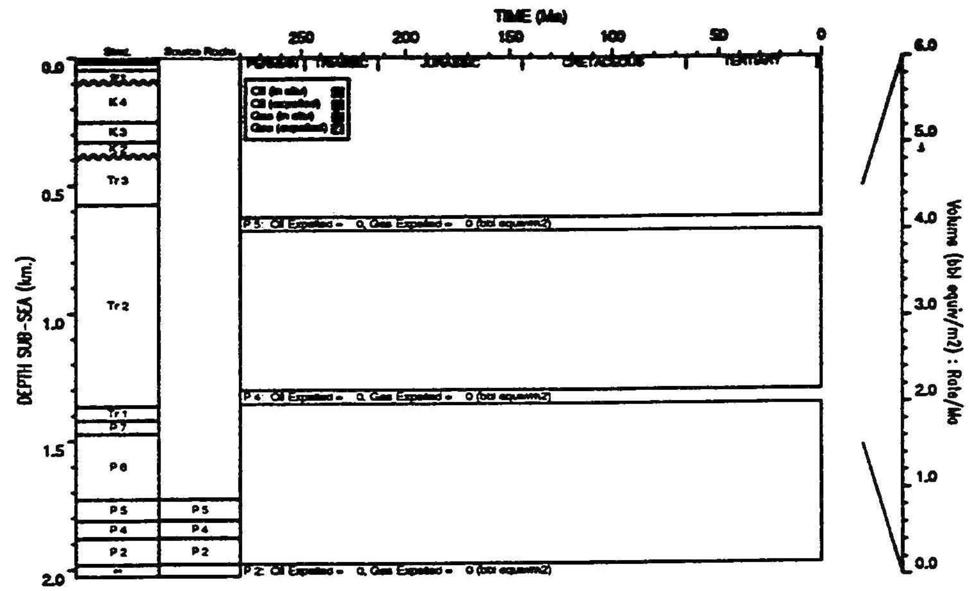


OBSERVED vs COMPUTED MATURITY PLOT : Candace 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Candace 1



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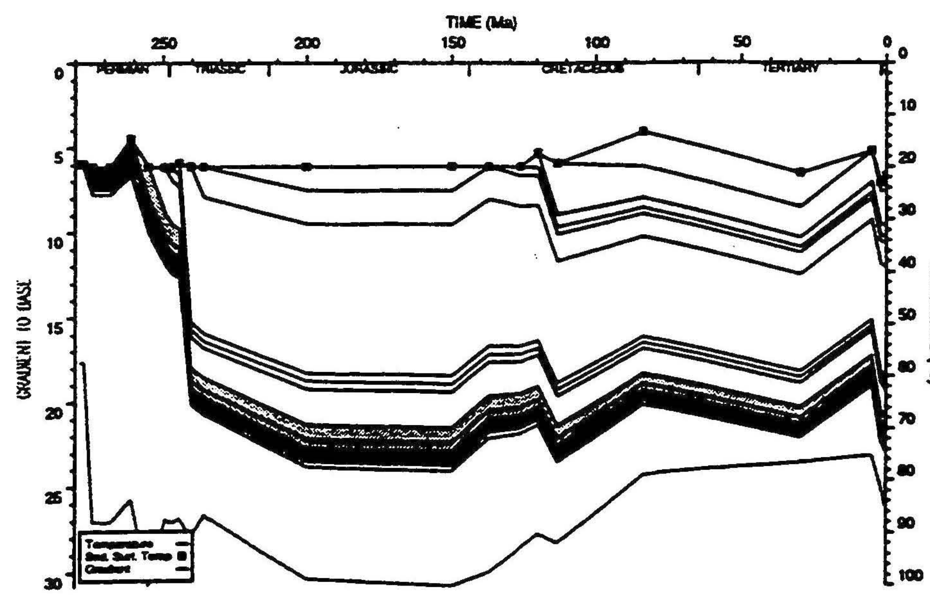

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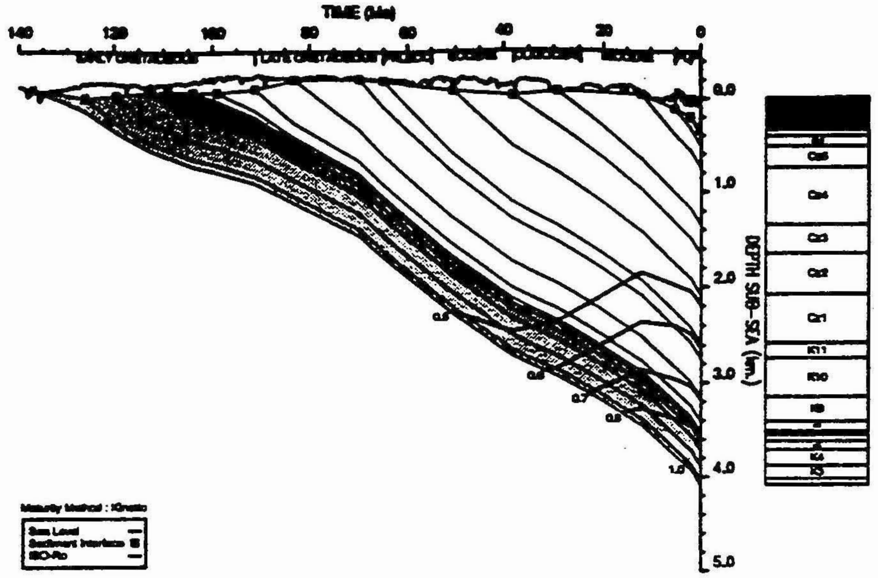

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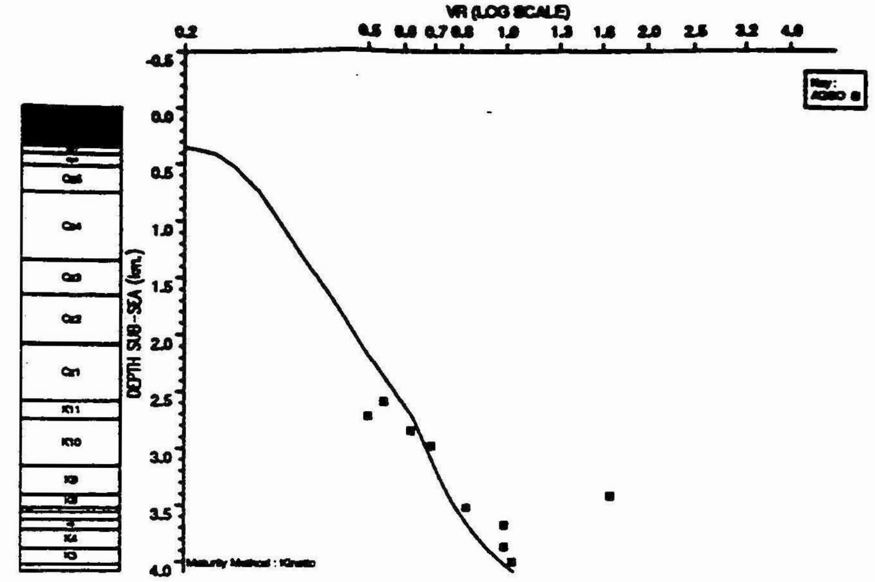
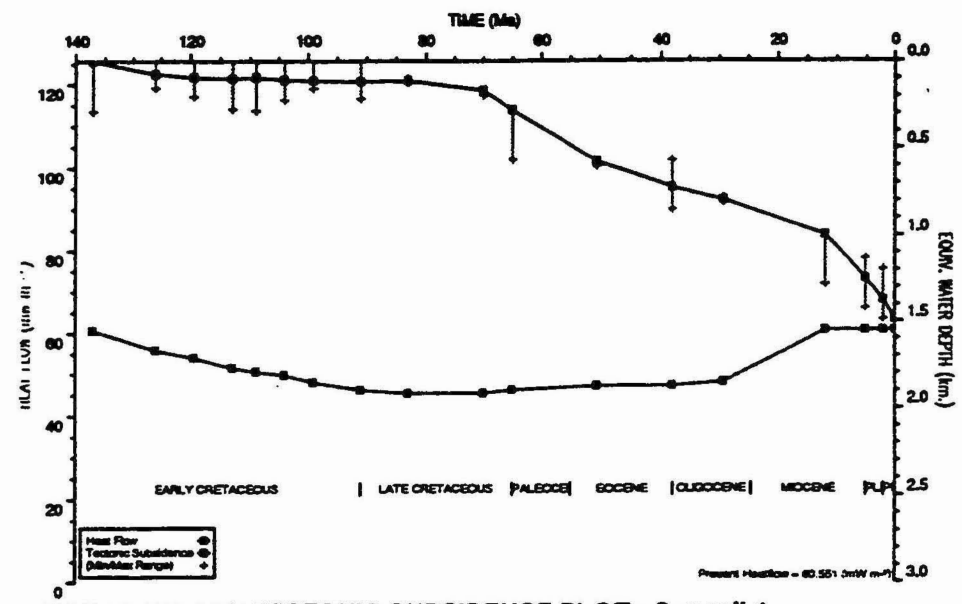


OBSERVED vs COMPUTED MATURITY PLOT : Caswell 1



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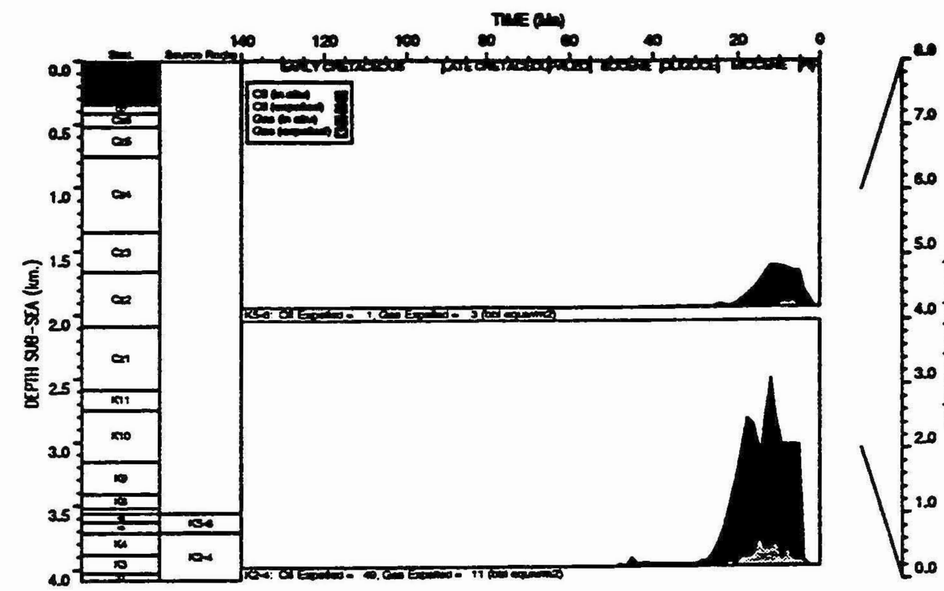

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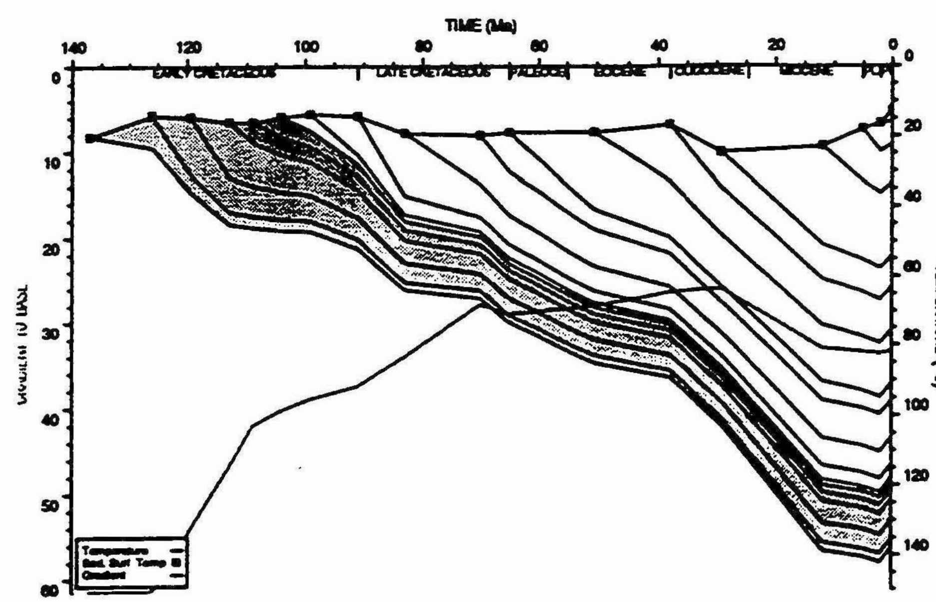
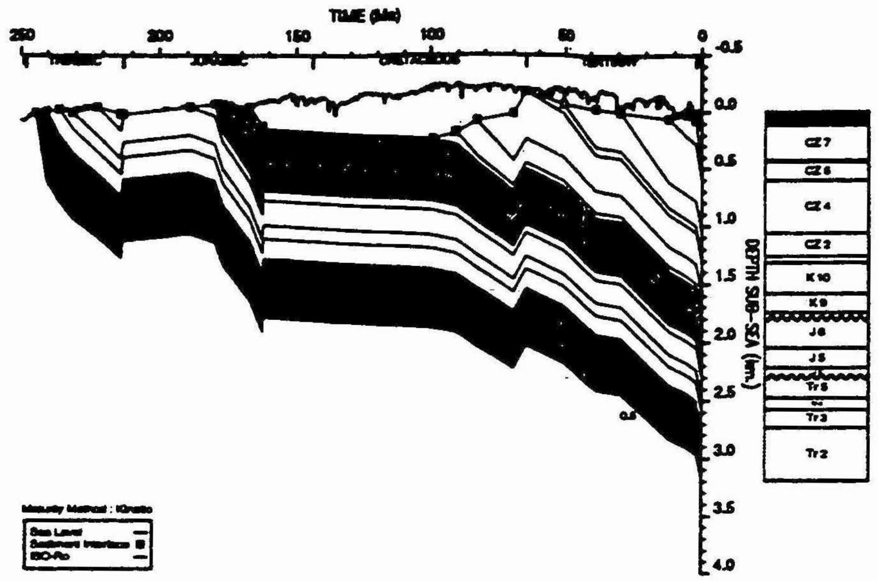


BED TEMPERATURE PLOT : Caswell 1



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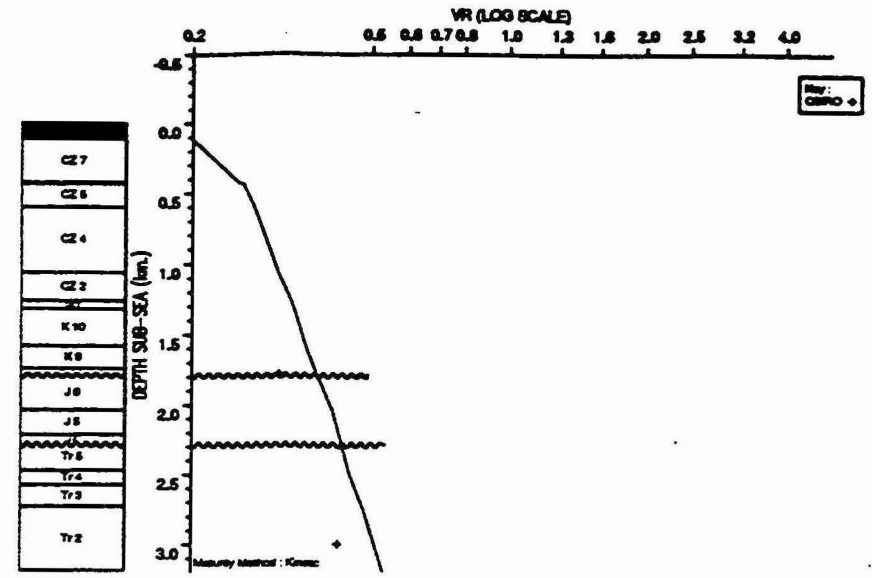
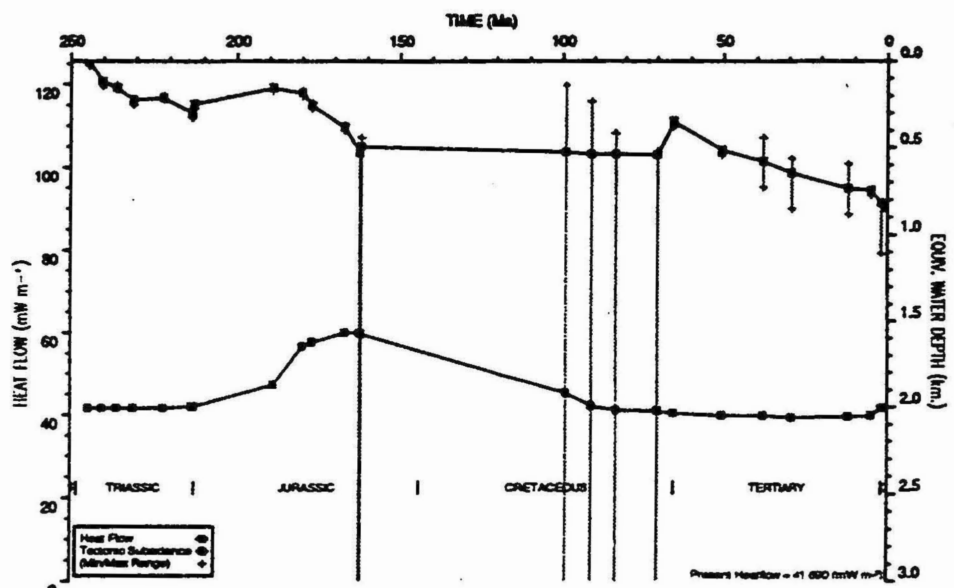


OBSERVED vs COMPUTED MATURITY PLOT : Cossigny 1



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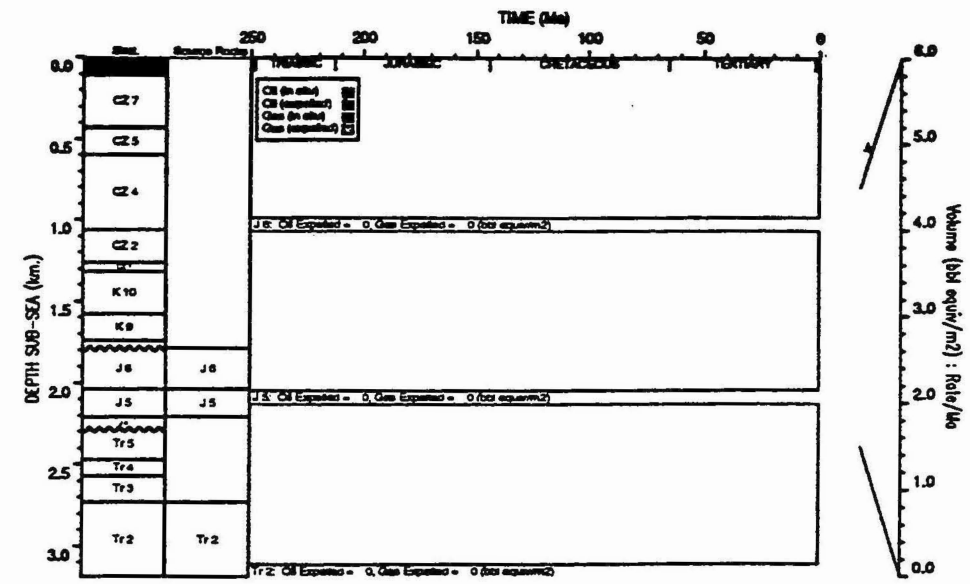

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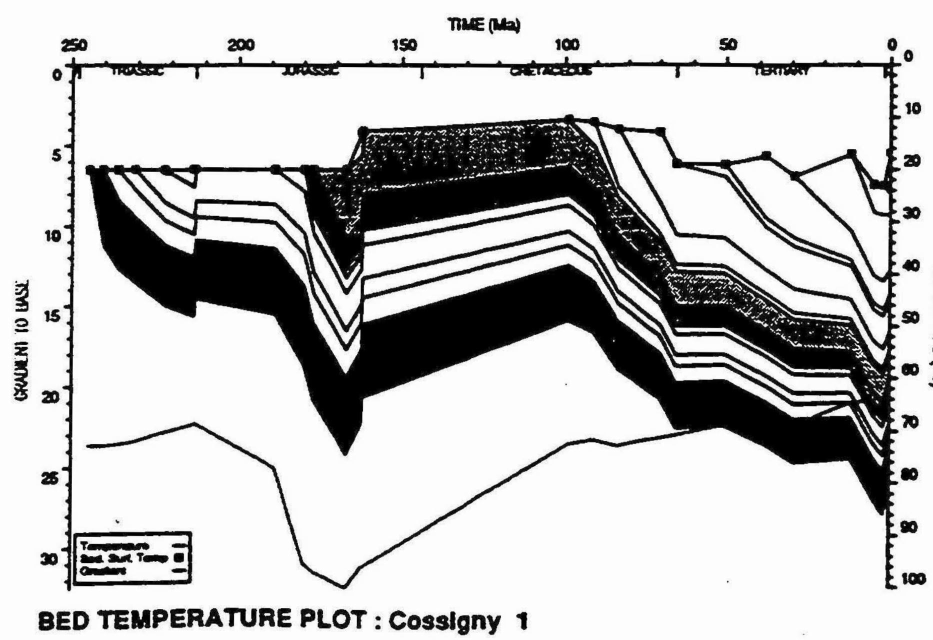

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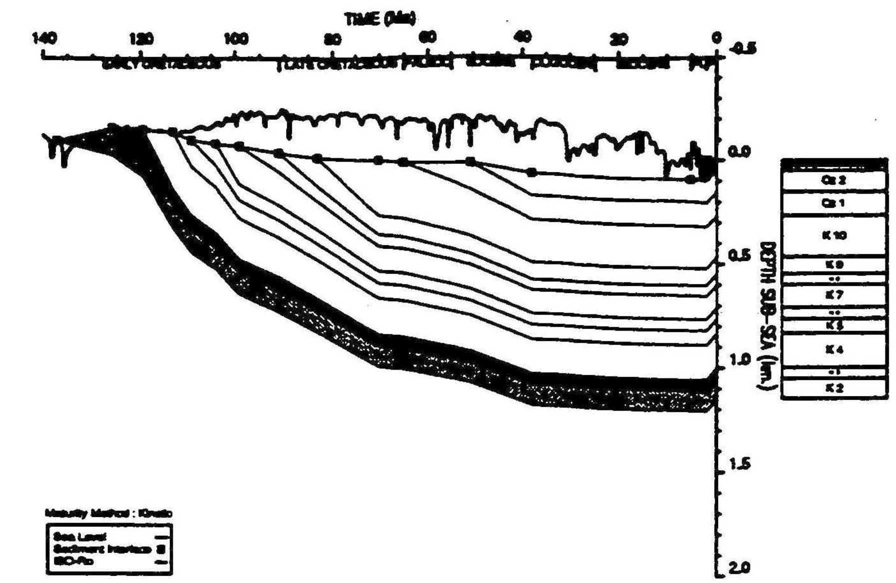

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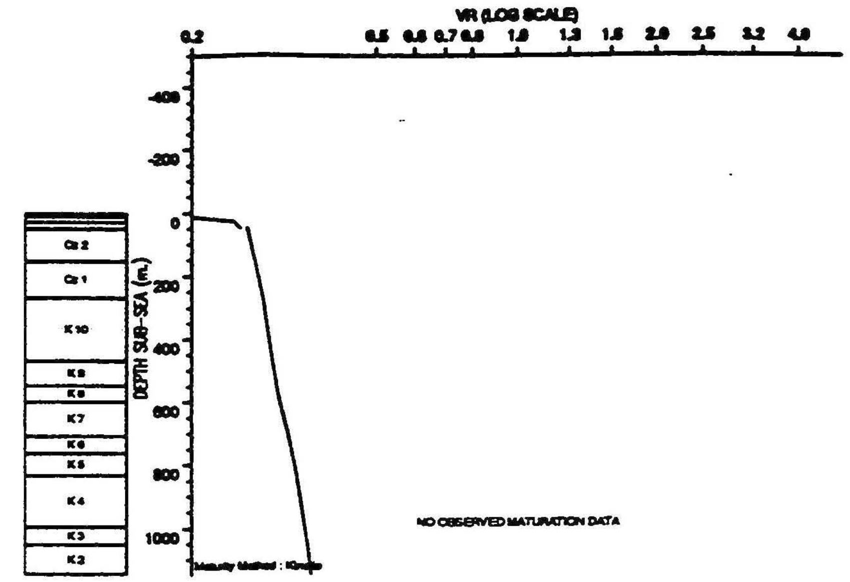
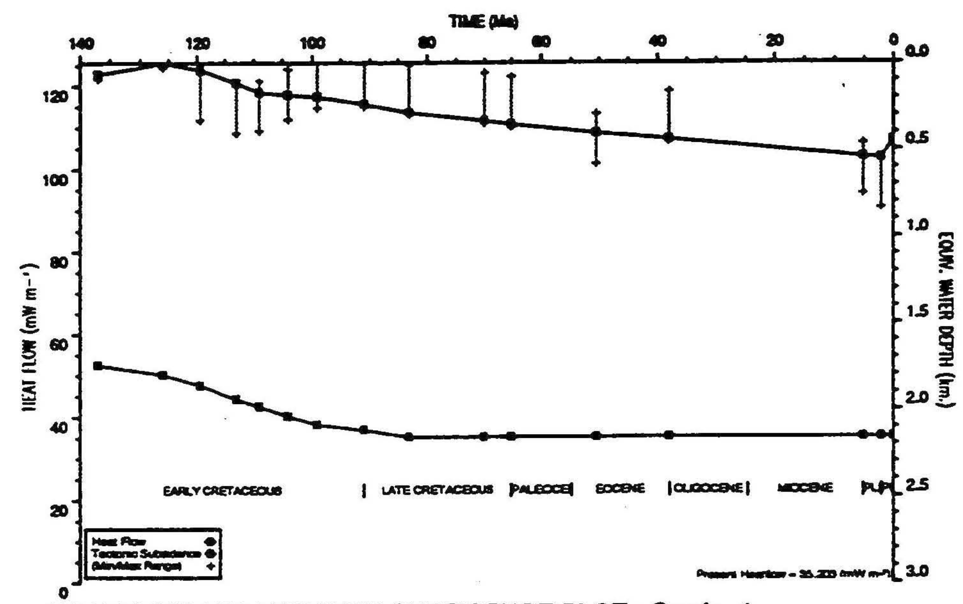
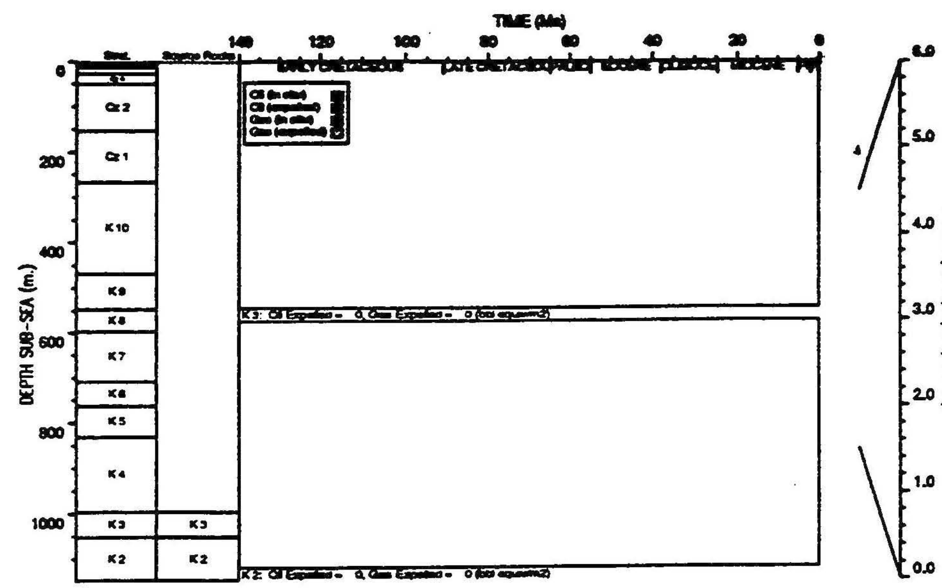


OBSERVED vs COMPUTED MATURITY PLOT : Cowie 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Cowie 1



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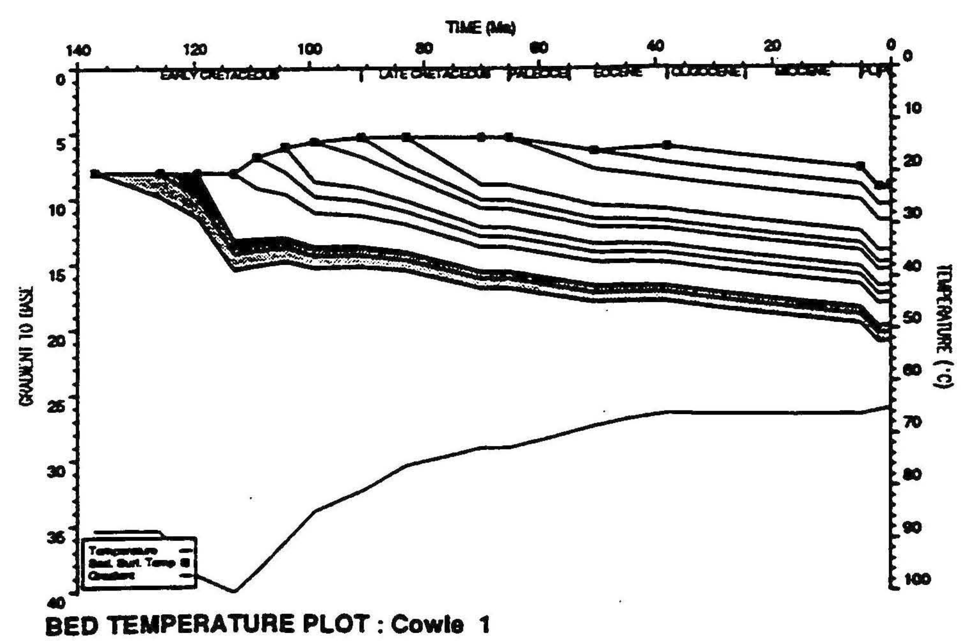
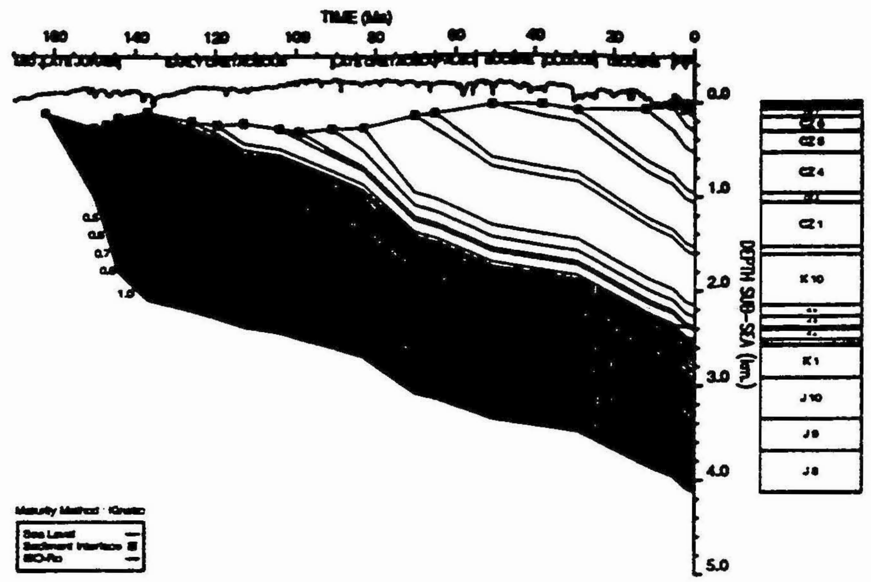
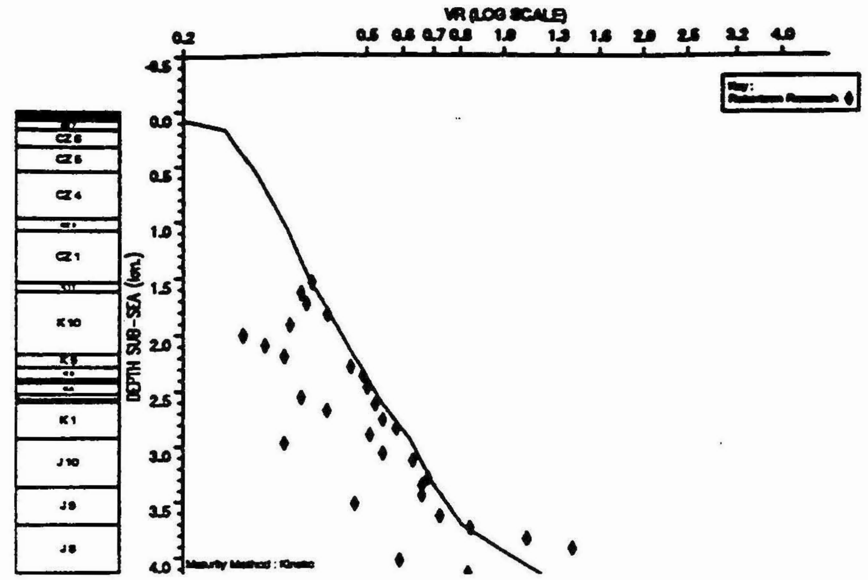


BED TEMPERATURE PLOT : Cowie 1



GEOHISTORY PLOT : Dampier 1



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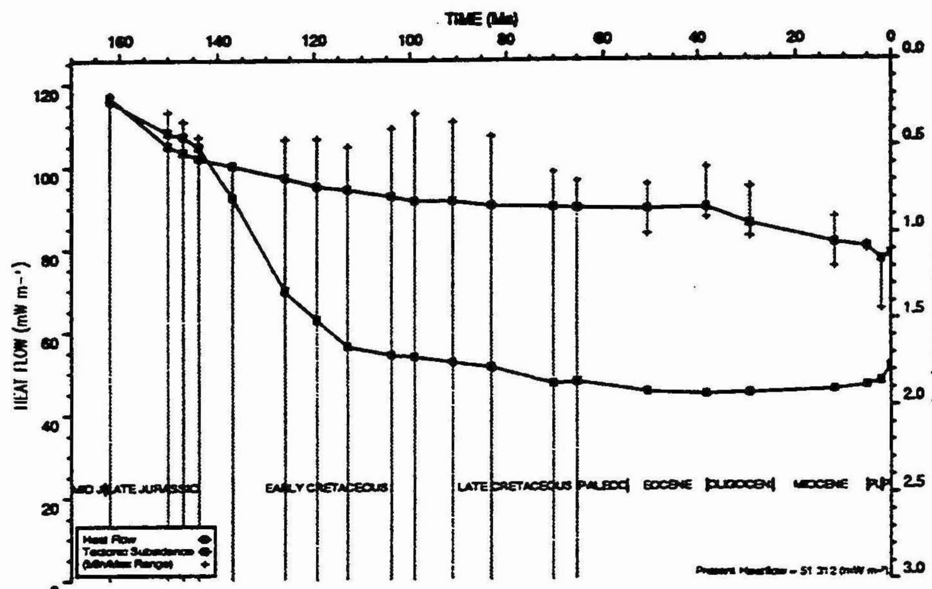

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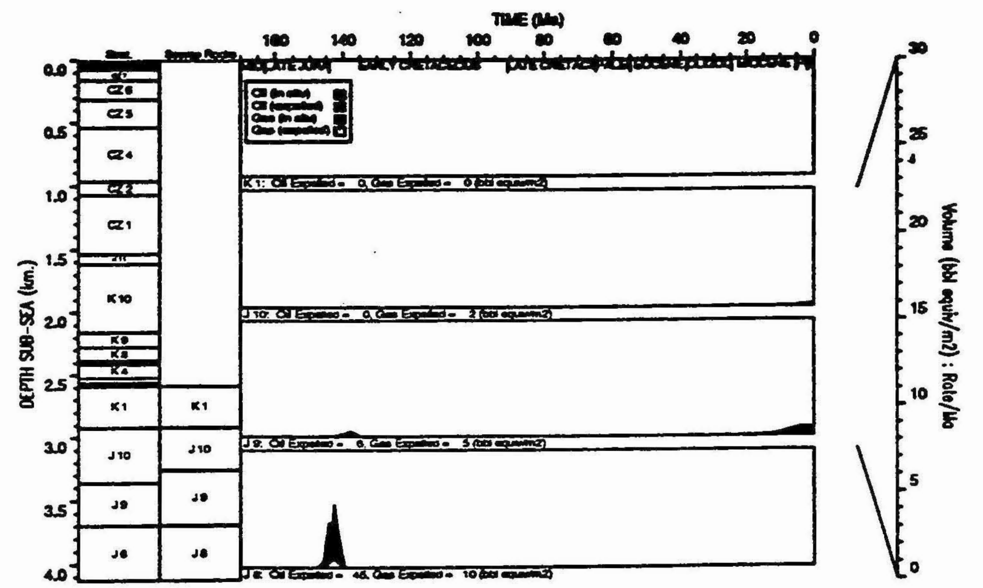

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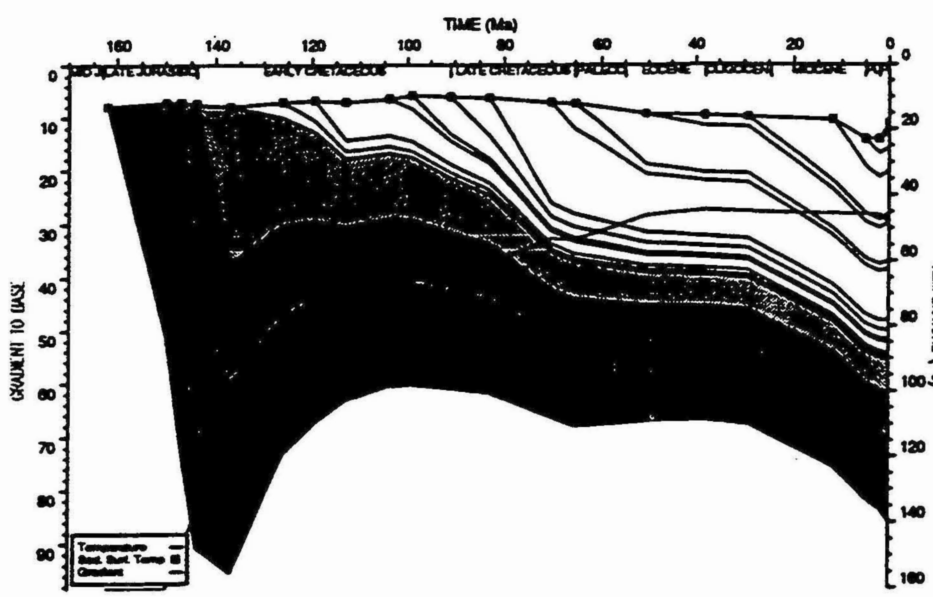
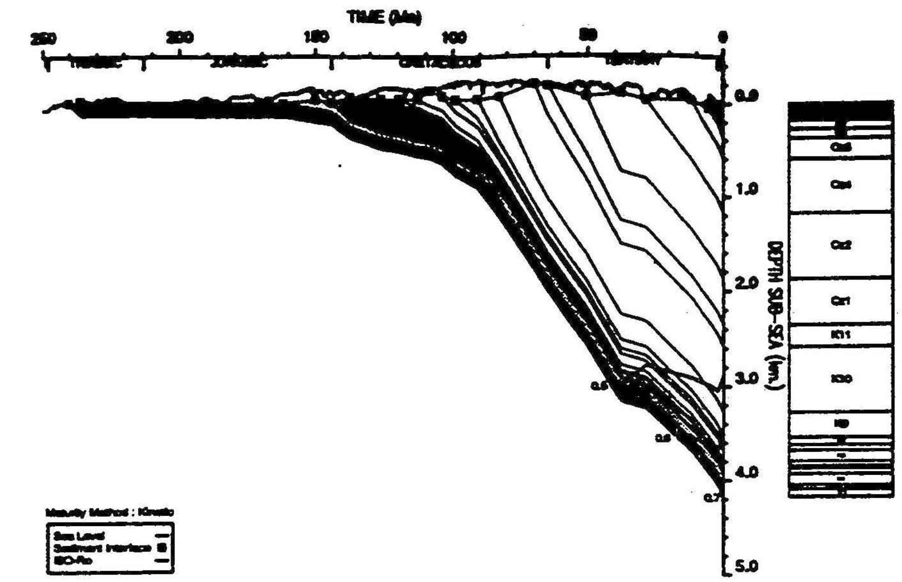
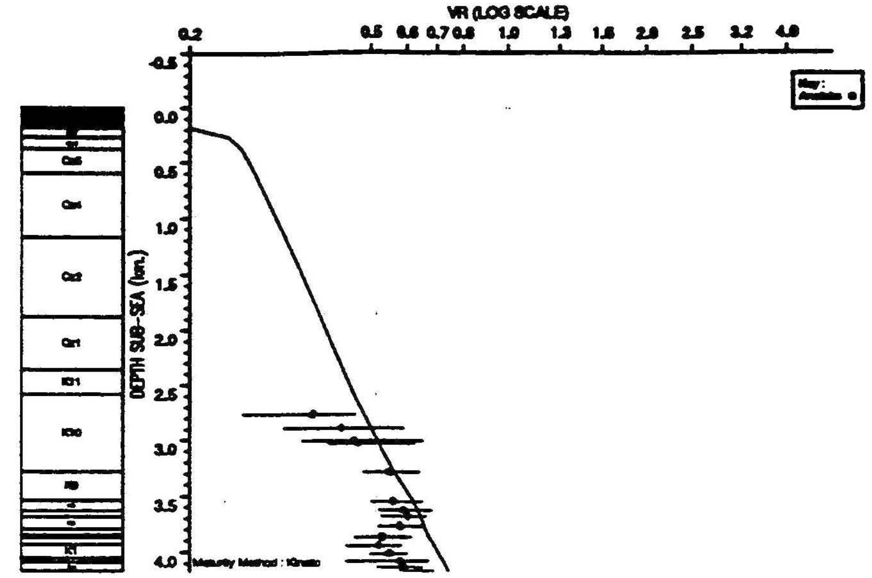


BED TEMPERATURE PLOT : Dampier 1

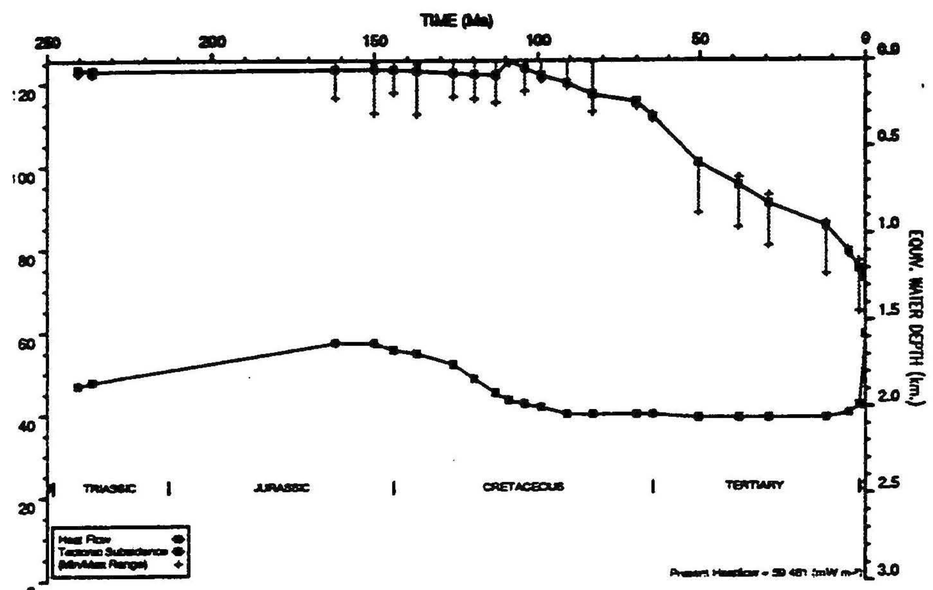
Pull Apart Model



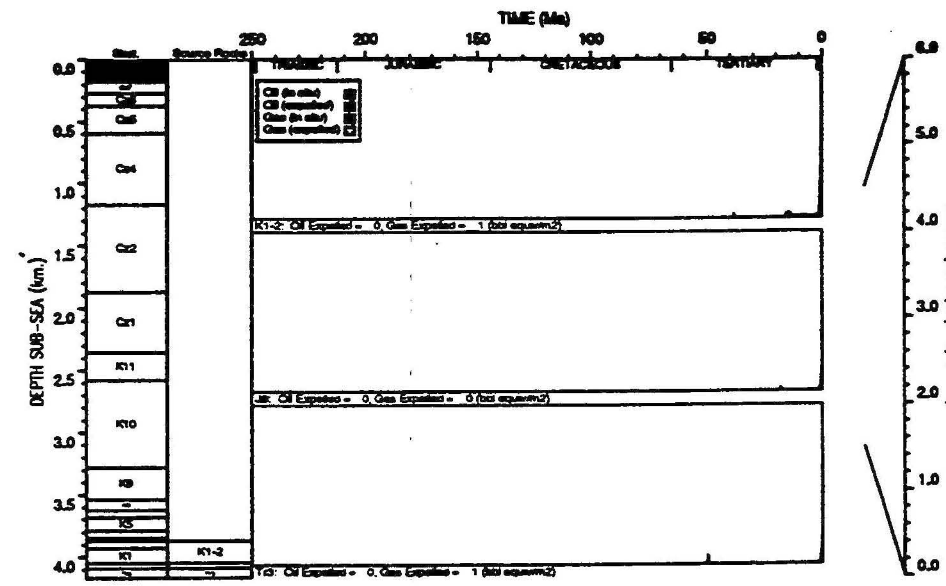
GEOHISTORY PLOT : Discorbis 1



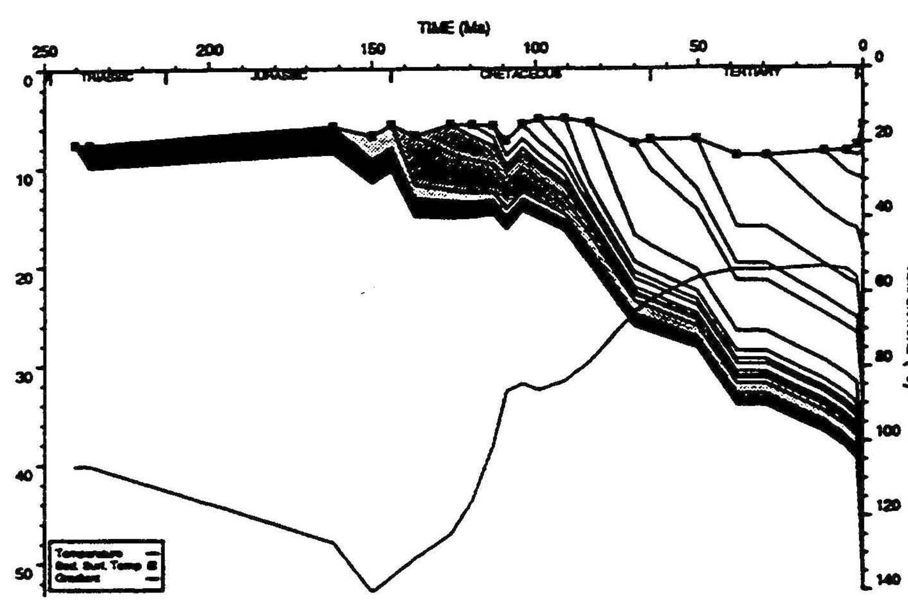
OBSERVED vs COMPUTED MATURITY PLOT : Discorbis 1



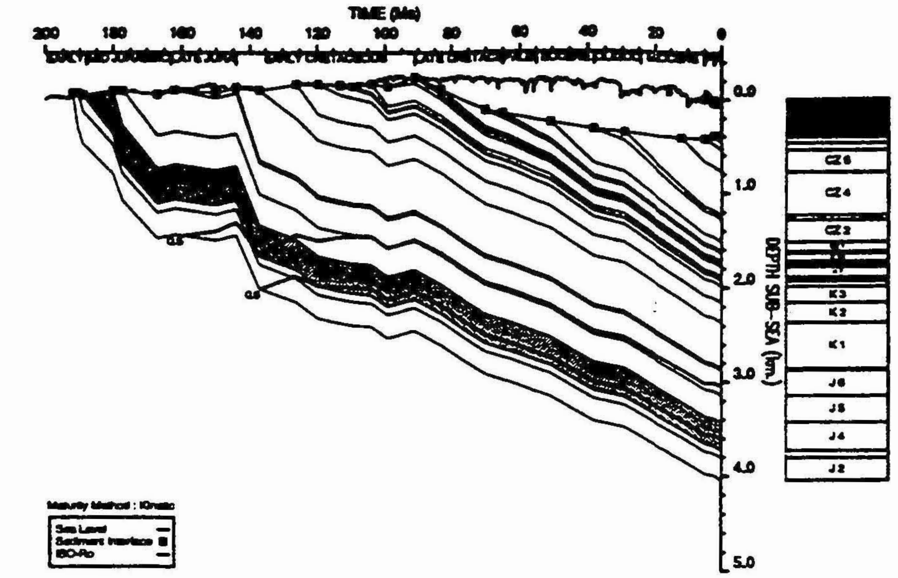
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Discorbis 1



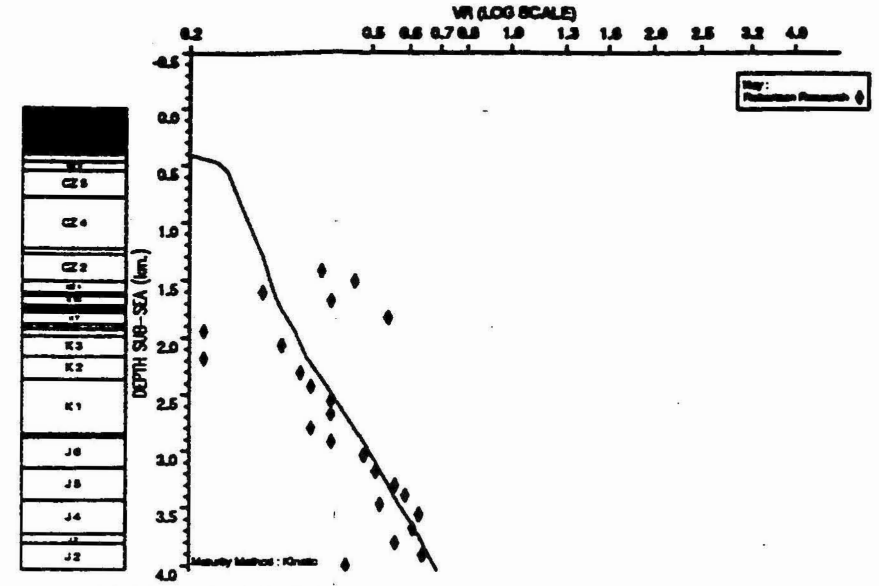
HYDROCARBON GENERATION PLOT : Discorbis 1



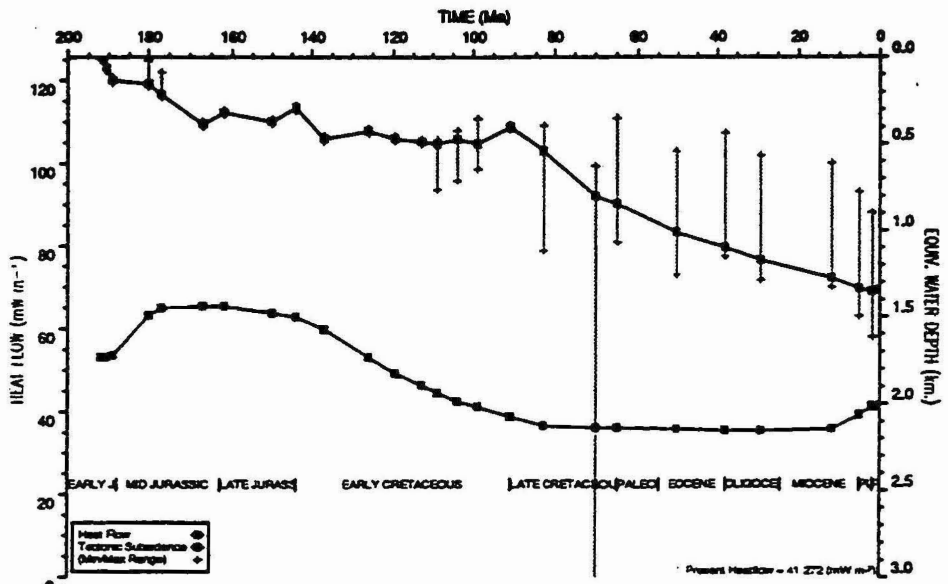
BED TEMPERATURE PLOT : Discorbis 1



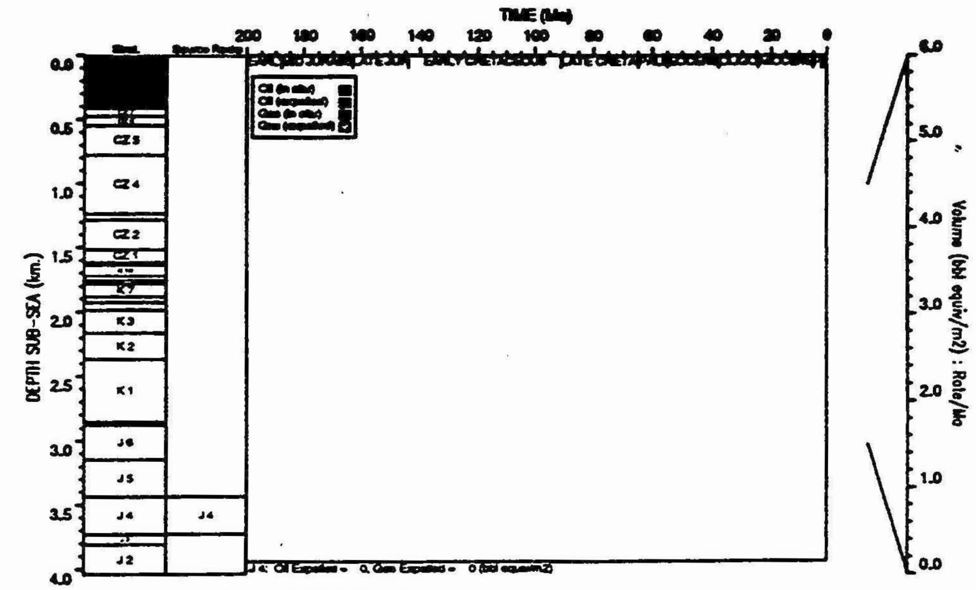
GEOHISTORY PLOT : East Mermaid 1



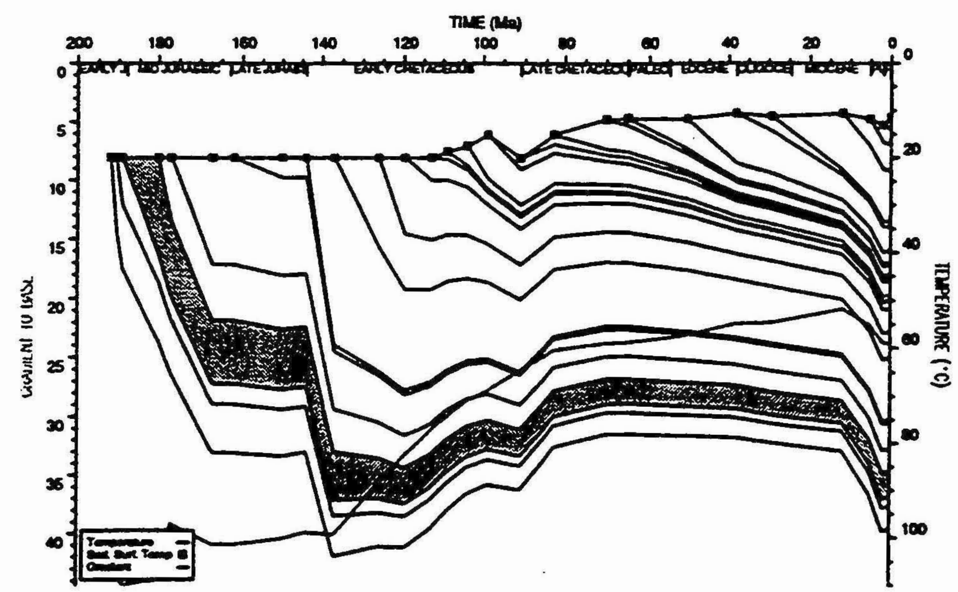
OBSERVED vs COMPUTED MATURITY PLOT : East Mermaid 1



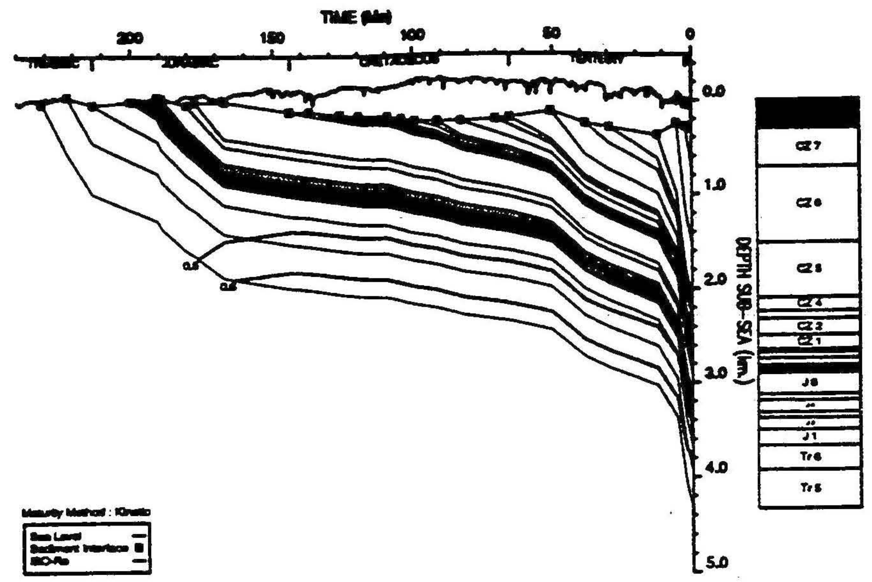
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : East Mermaid 1



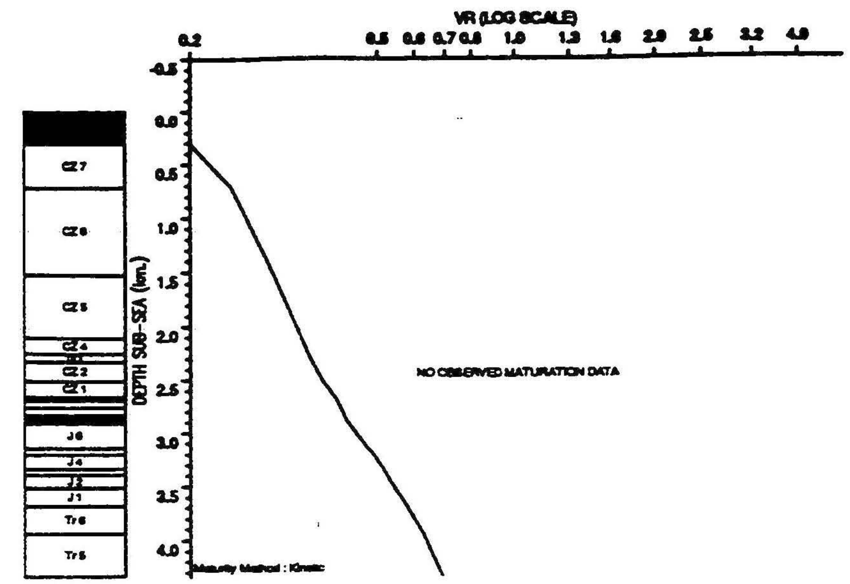
HYDROCARBON GENERATION PLOT : East Mermaid 1



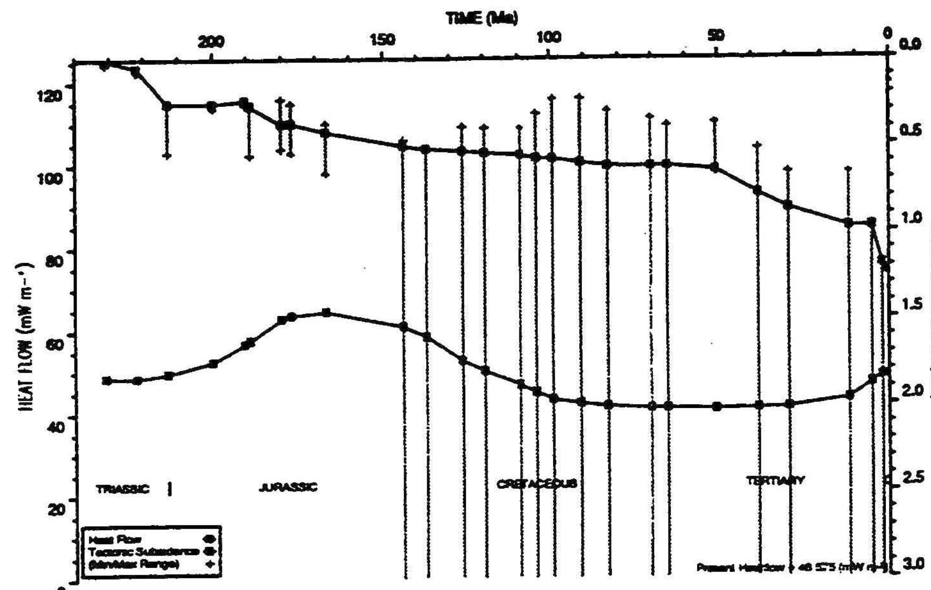
BED TEMPERATURE PLOT : East Mermaid 1



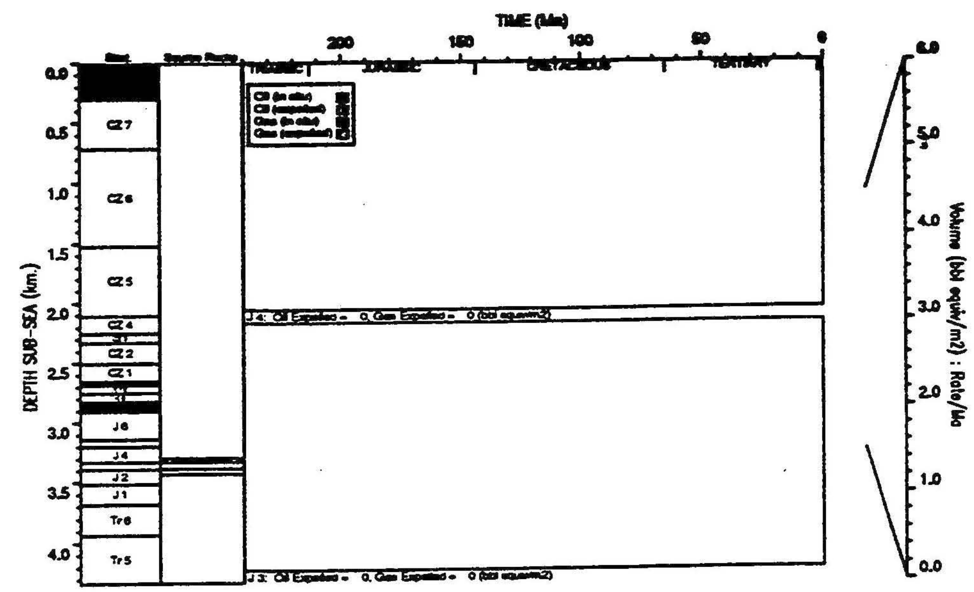
GEOHISTORY PLOT : Gandara 1



OBSERVED vs COMPUTED MATURITY PLOT : Gandara 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Gandara 1



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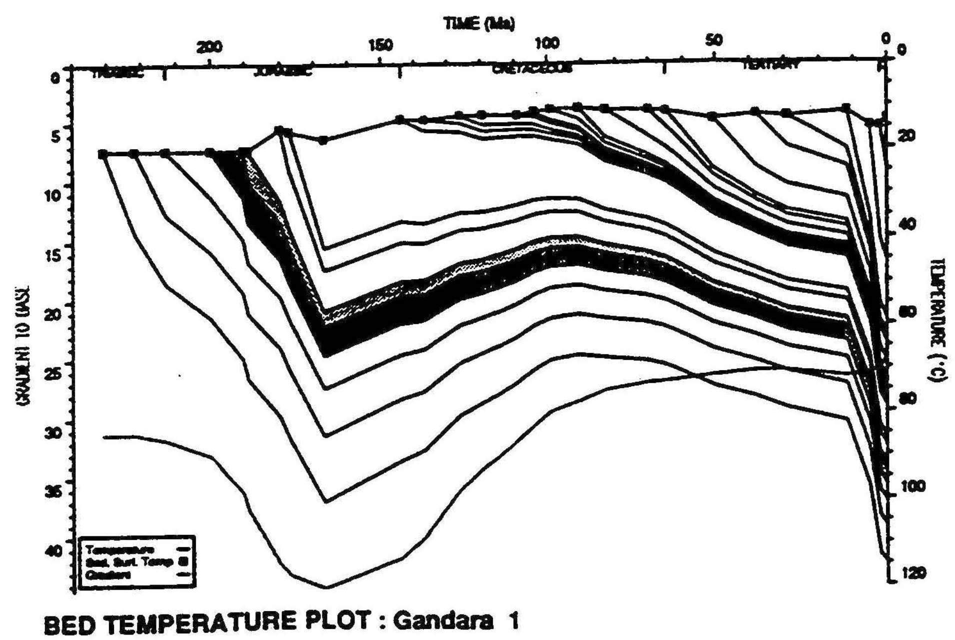

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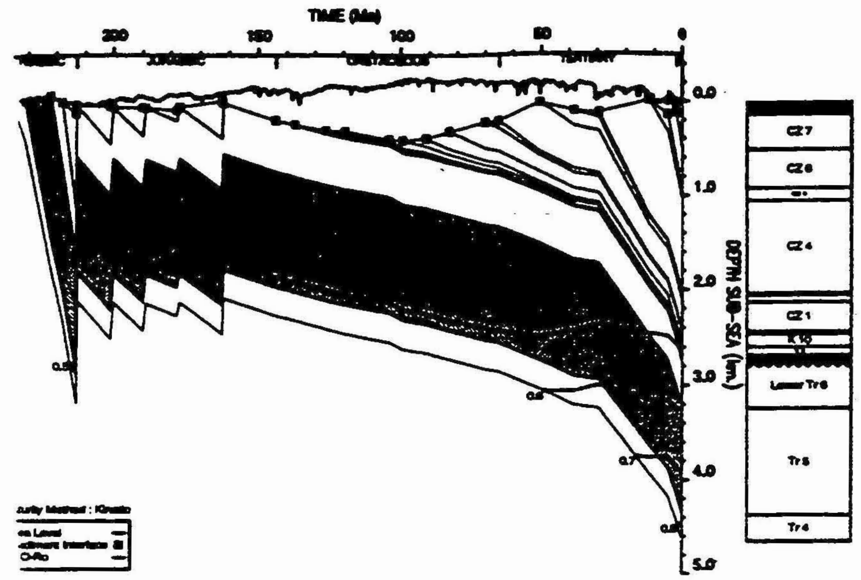
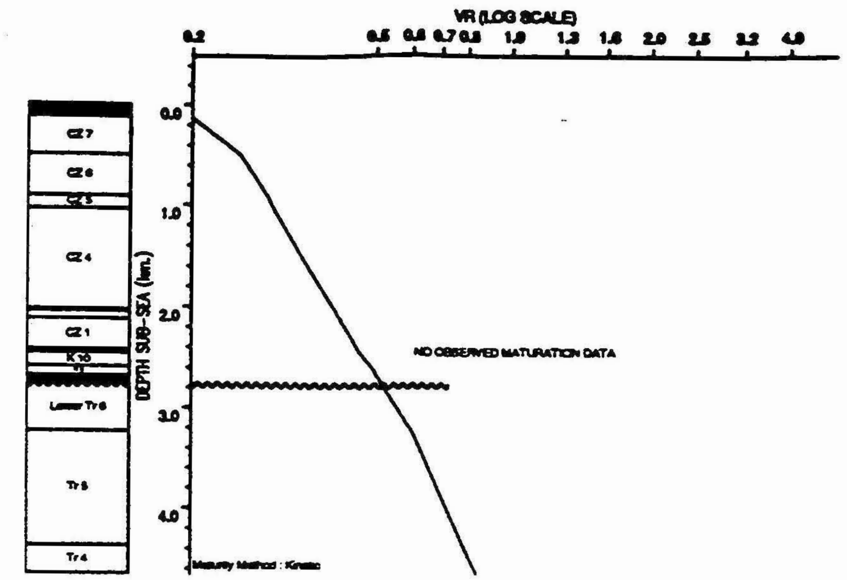
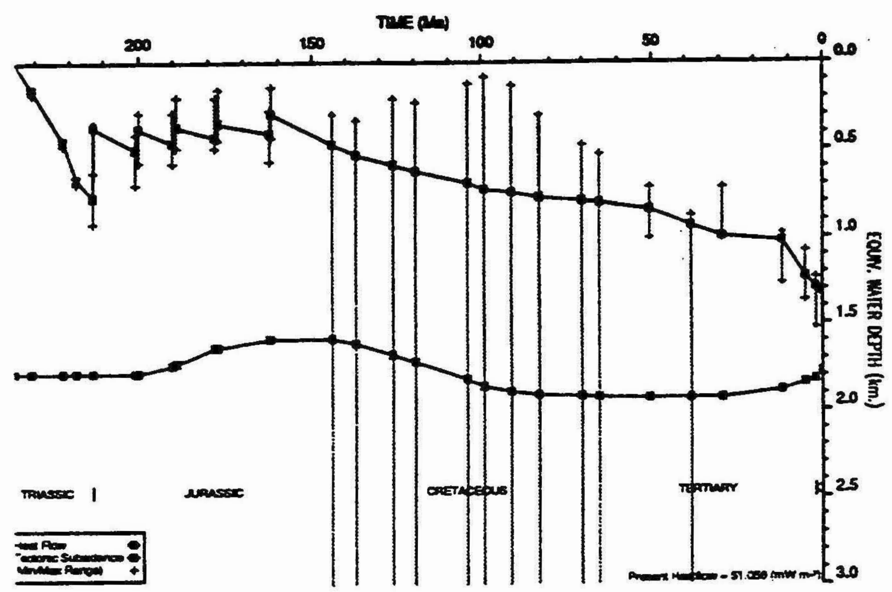


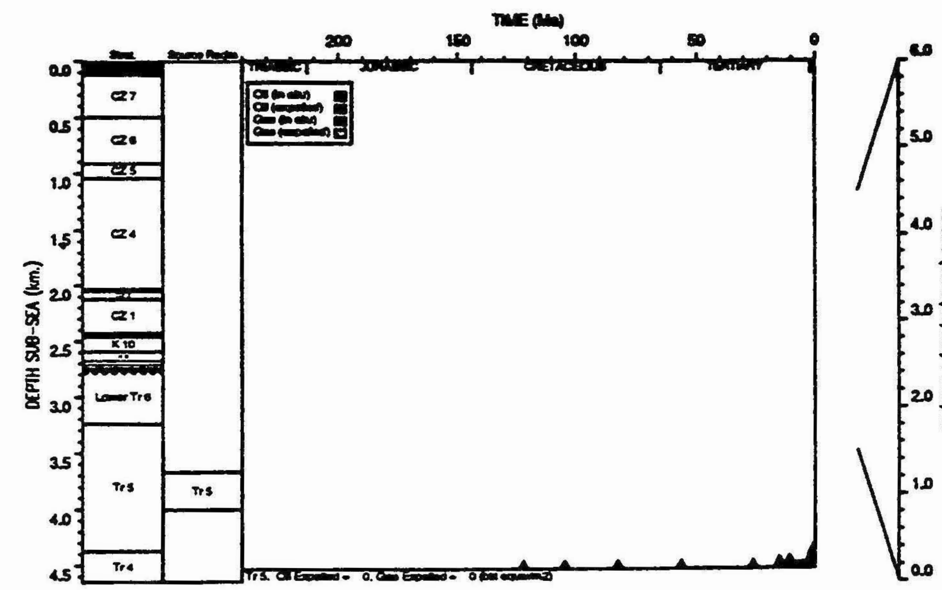
HISTORY PLOT : Goodwyn 6



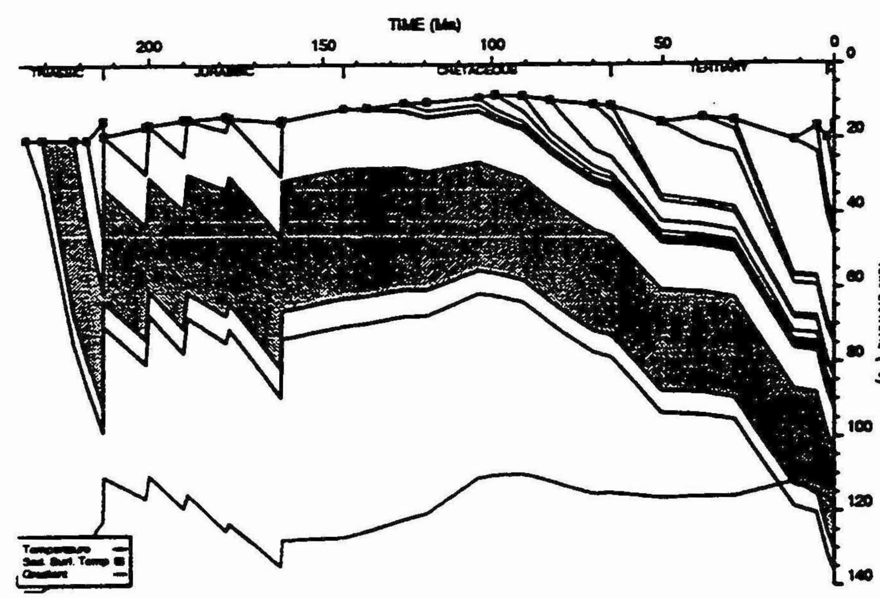
OBSERVED vs COMPUTED MATURITY PLOT : Goodwyn 6



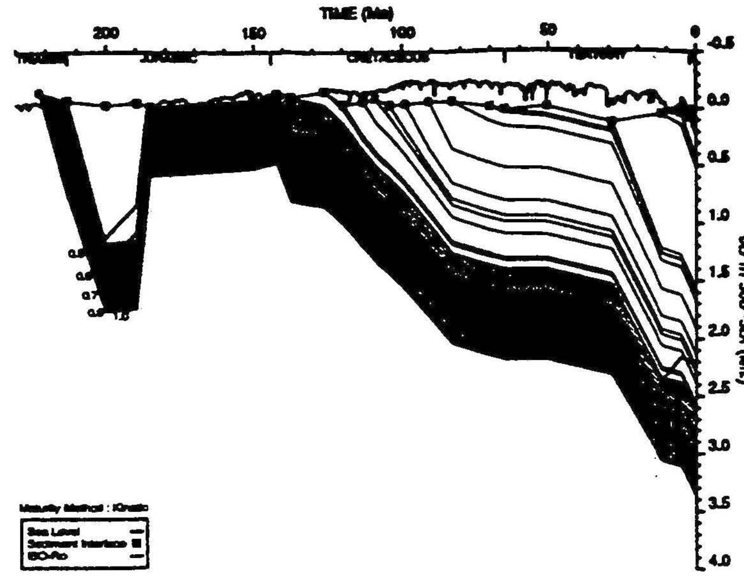
ATFLOW AND TECTONIC SUBSIDENCE PLOT : Goodwyn 6



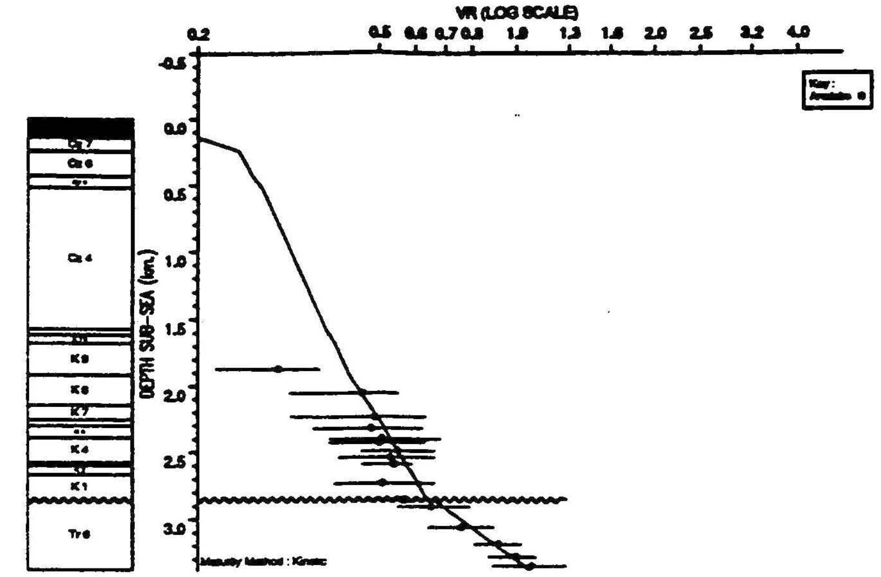
HYDROCARBON GENERATION PLOT : Goodwyn 6



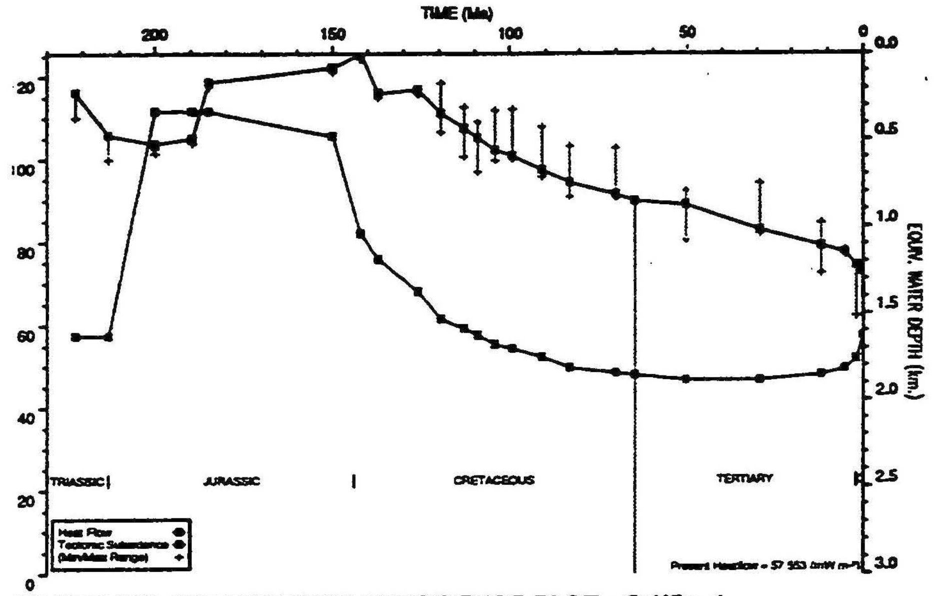
D TEMPERATURE PLOT : Goodwyn 6



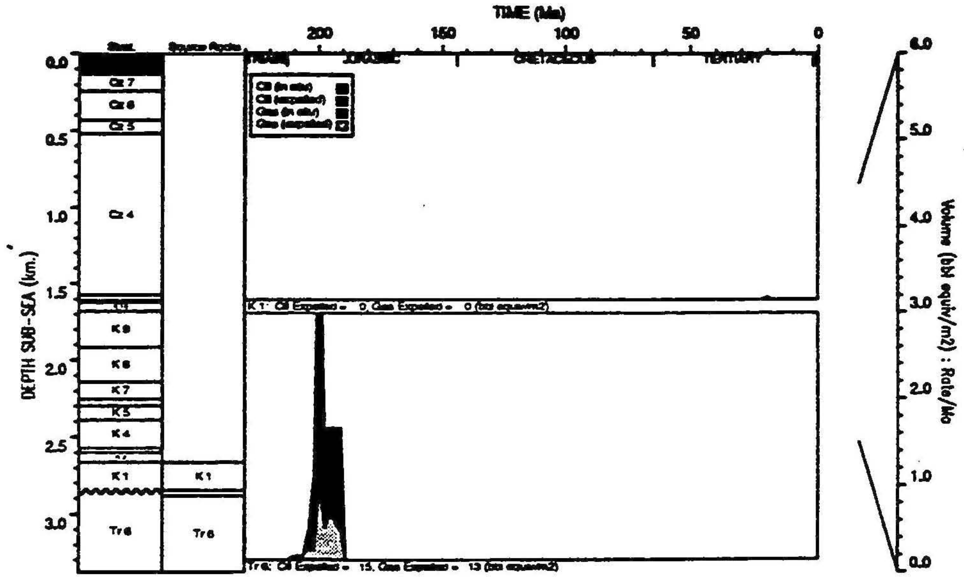
GEOHISTORY PLOT : Griffin 1



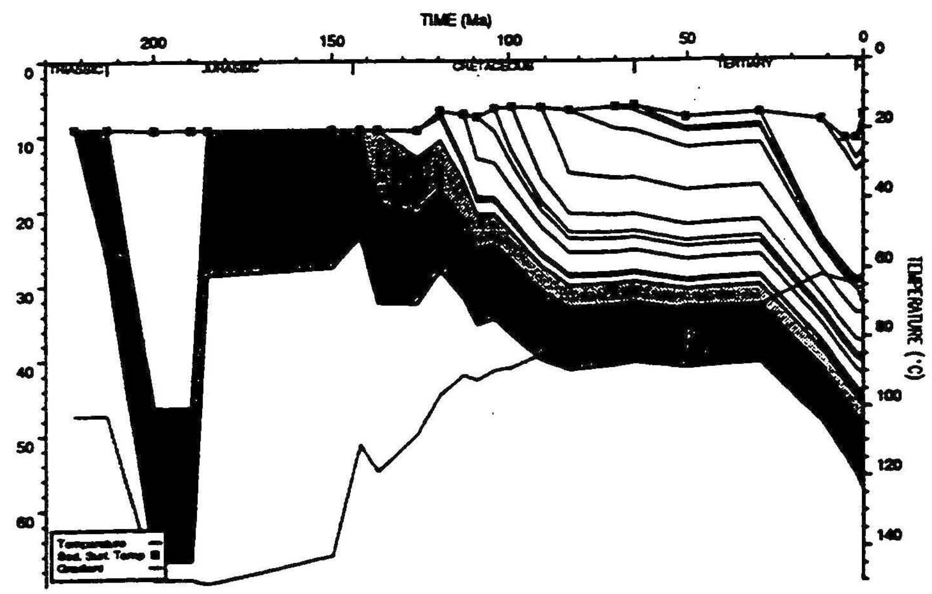
OBSERVED vs COMPUTED MATURITY PLOT : Griffin 1



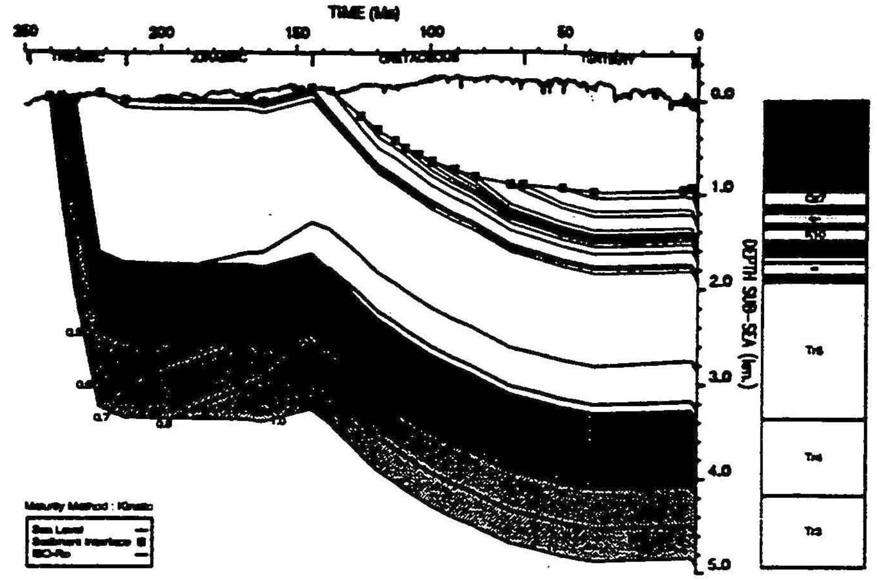
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Griffin 1



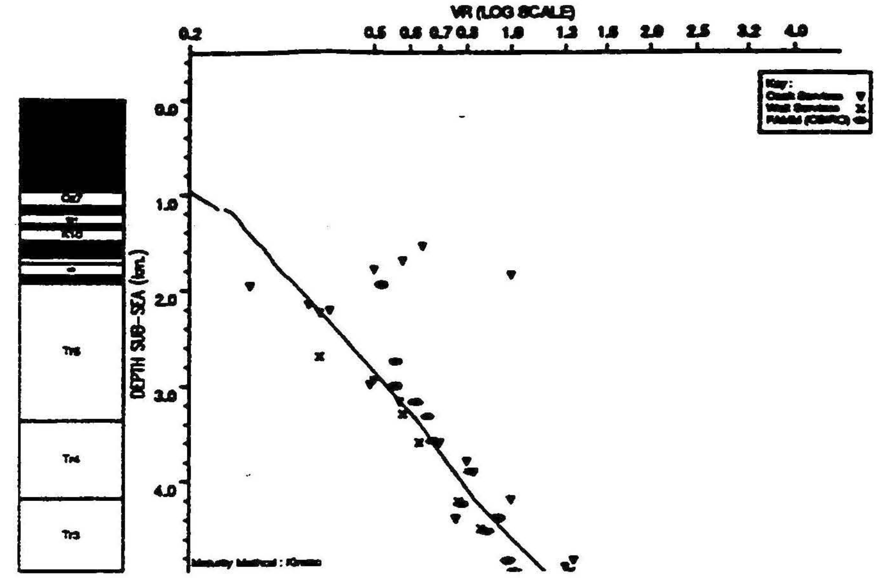
HYDROCARBON GENERATION PLOT : Griffin 1



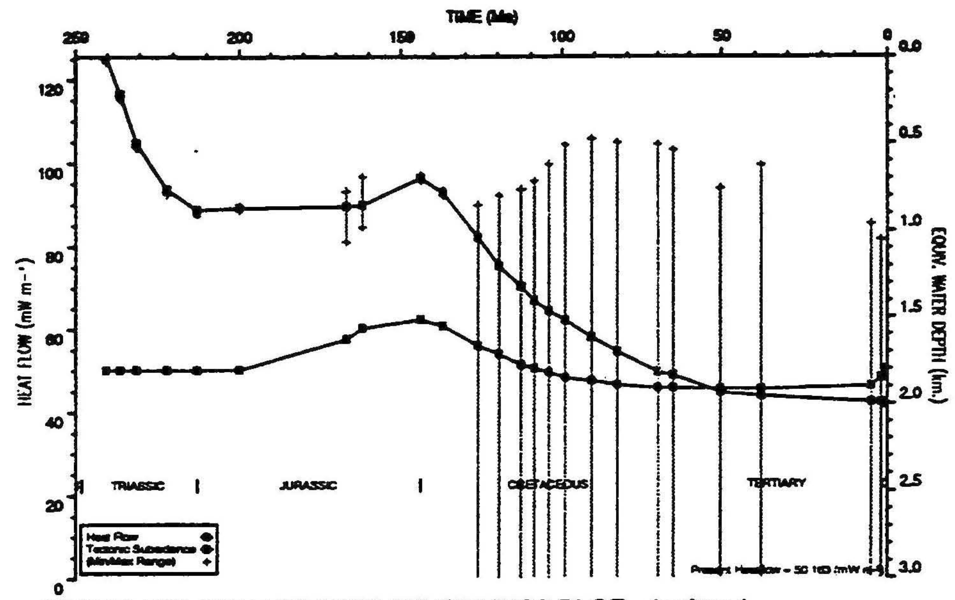
BED TEMPERATURE PLOT : Griffin 1



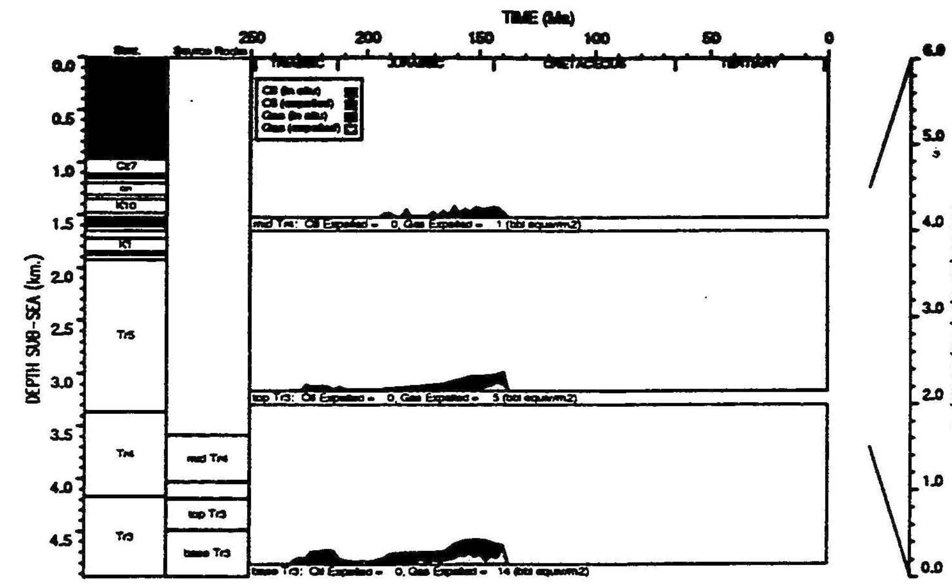
GEOHISTORY PLOT : Jupiter 1



OBSERVED vs COMPUTED MATURITY PLOT : Jupiter 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Jupiter 1



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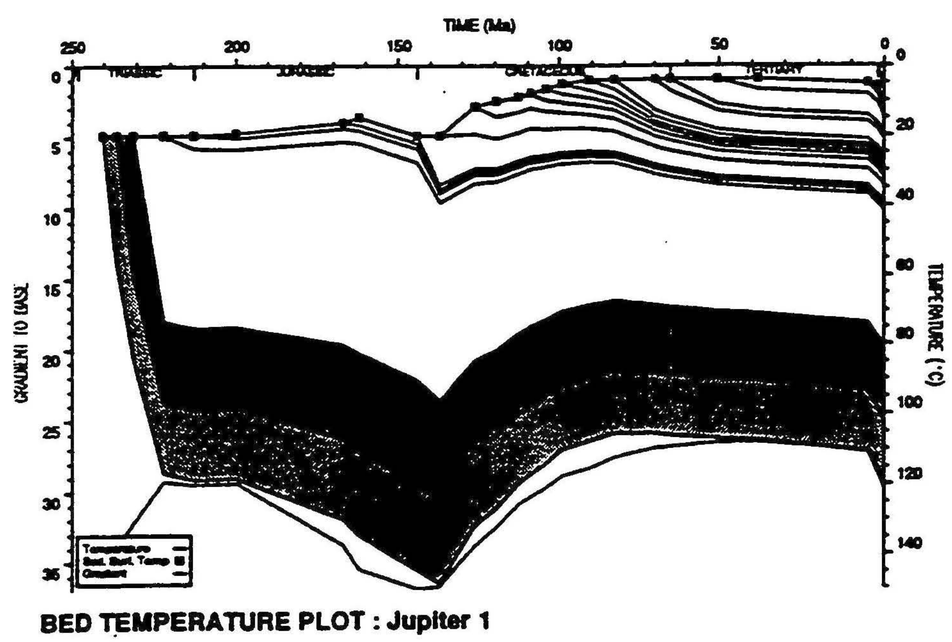

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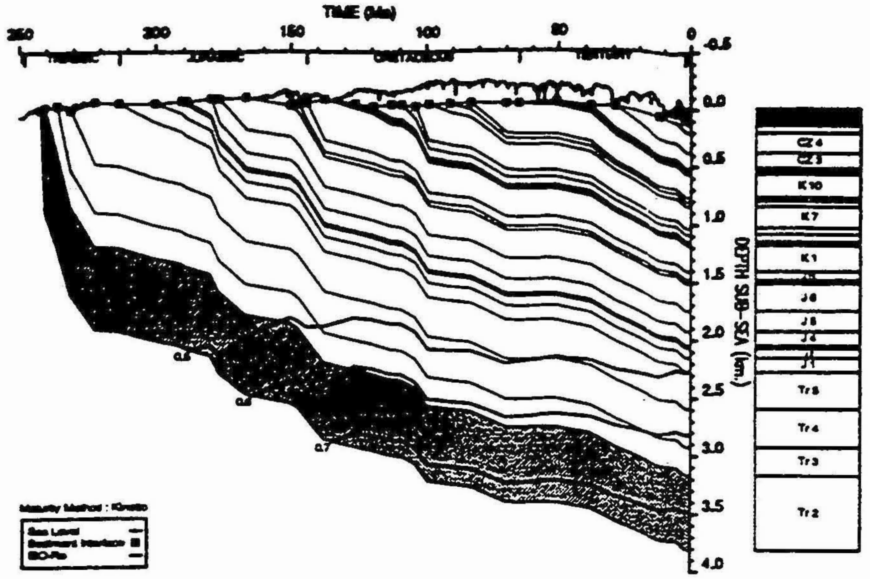
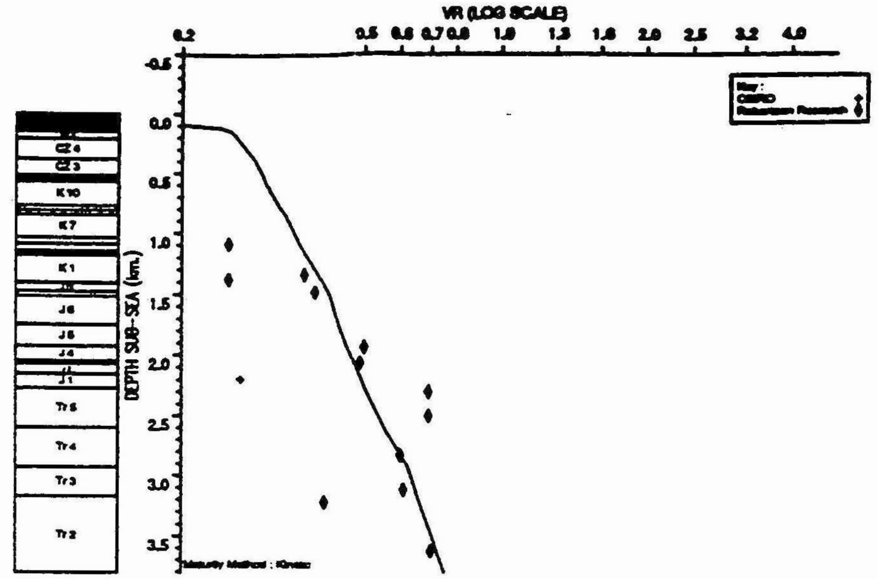
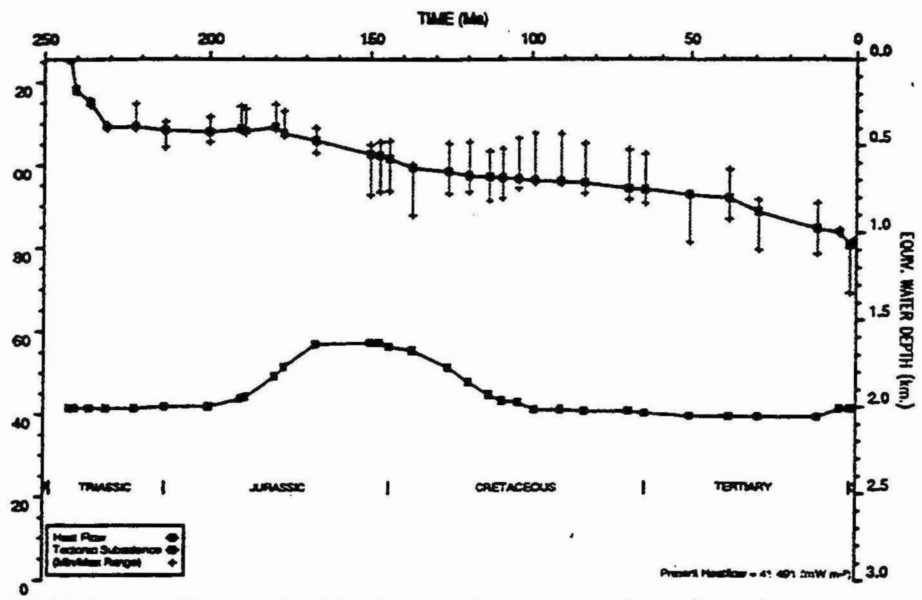


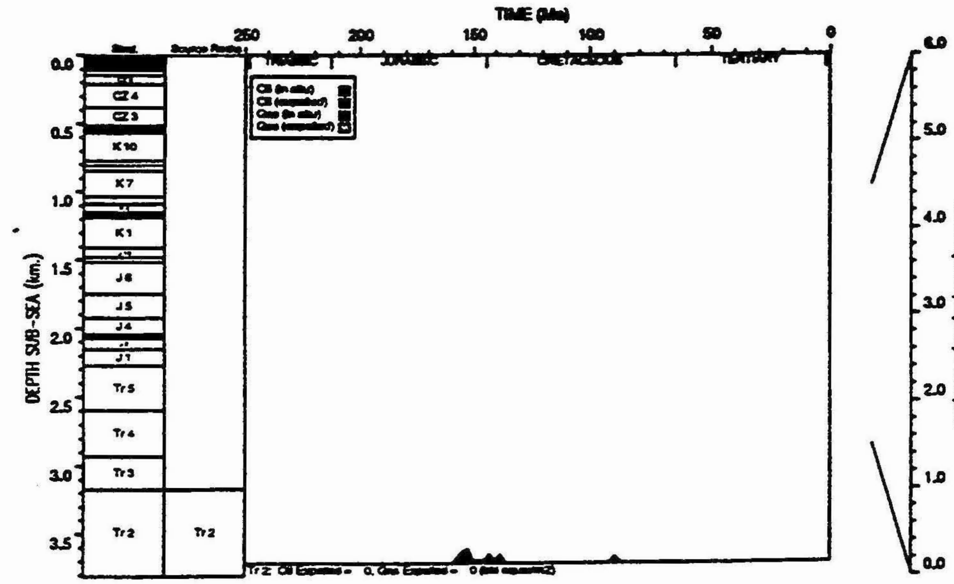
GEOHISTORY PLOT : Keraudren 1



OBSERVED vs COMPUTED MATURITY PLOT : Keraudren 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Keraudren 1



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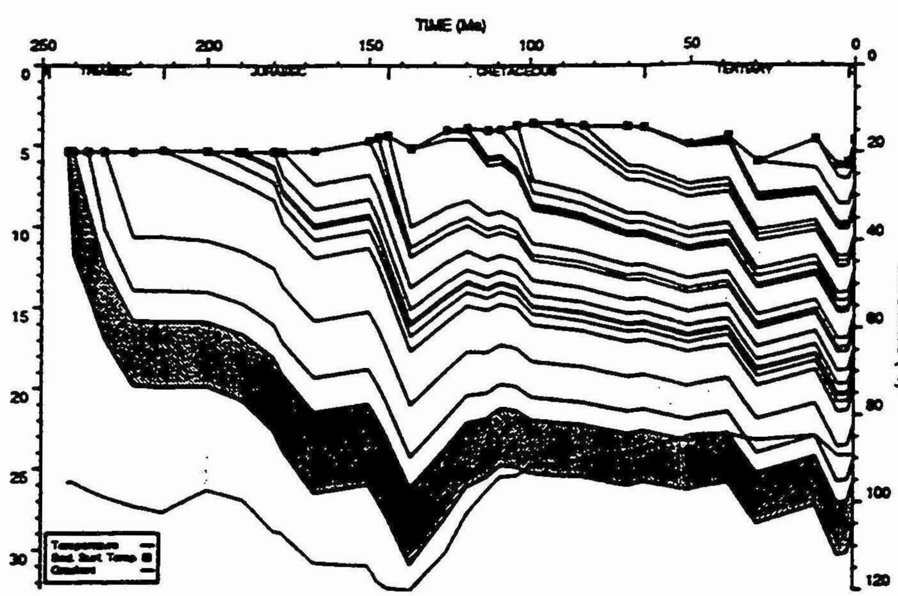

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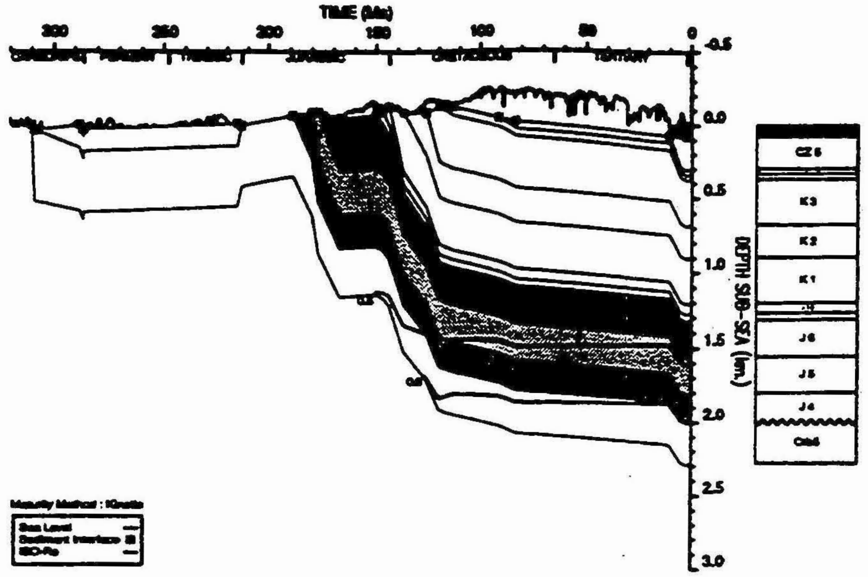
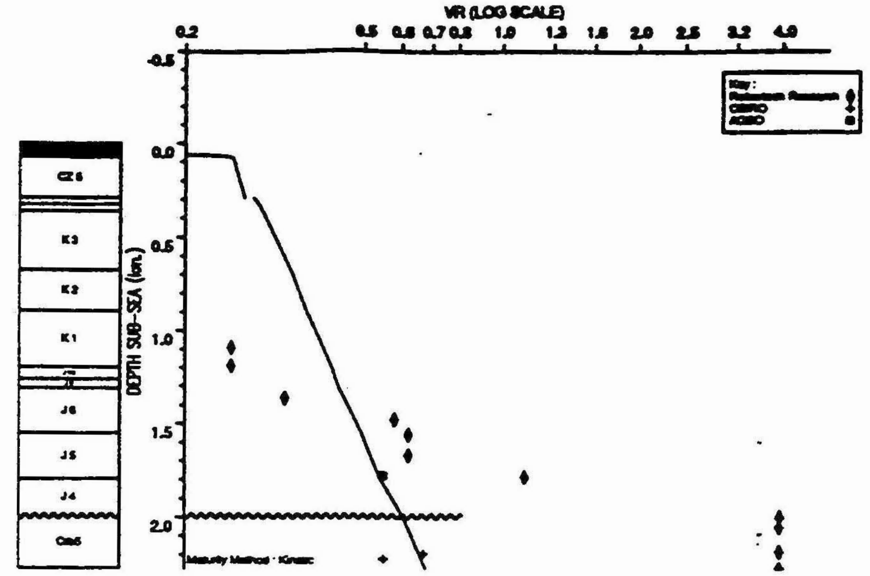


GEOHISTORY PLOT : Lacepede 1A



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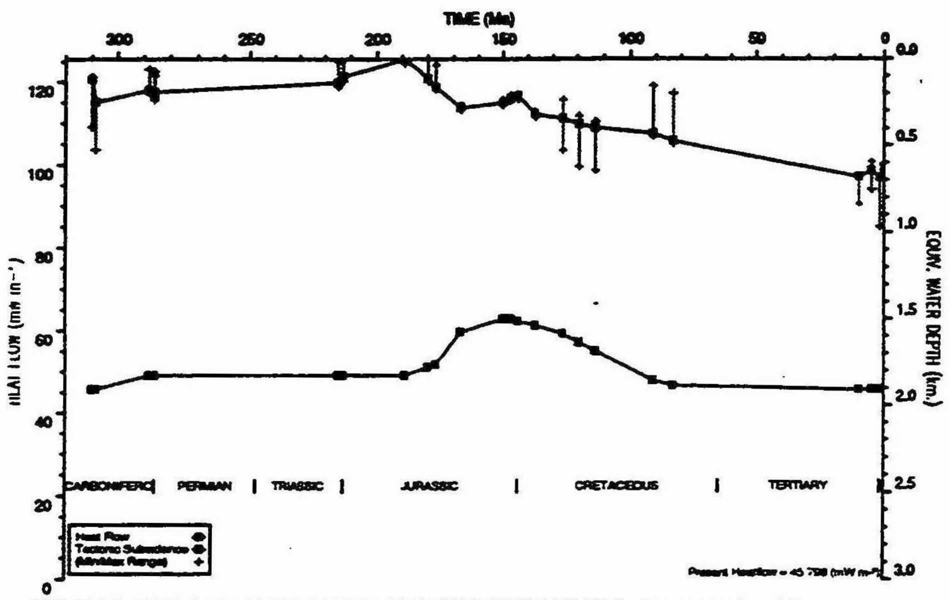

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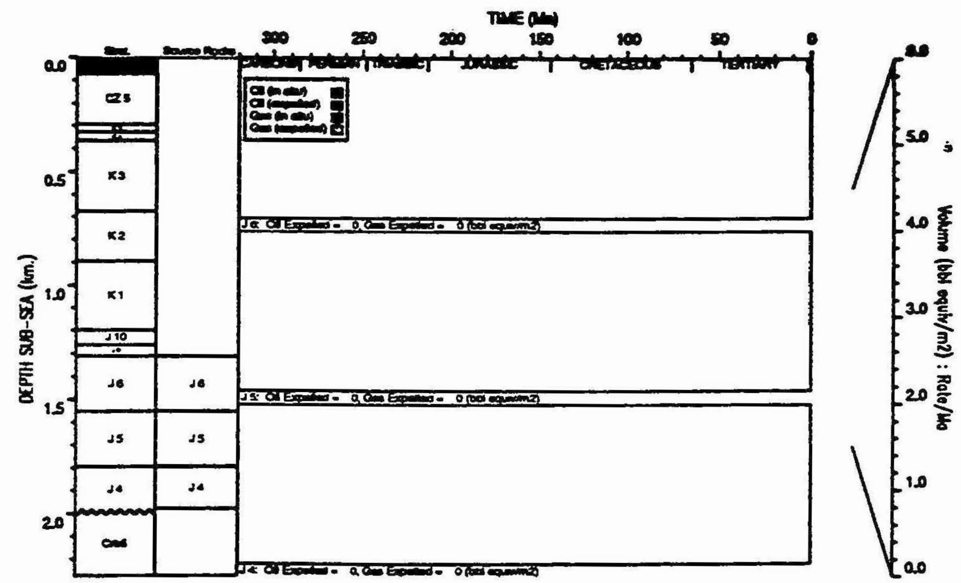

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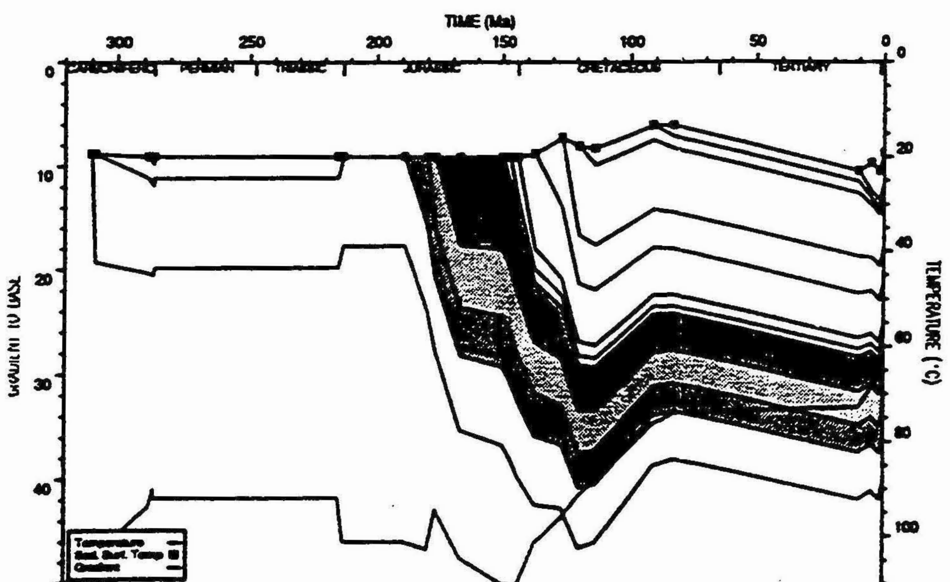

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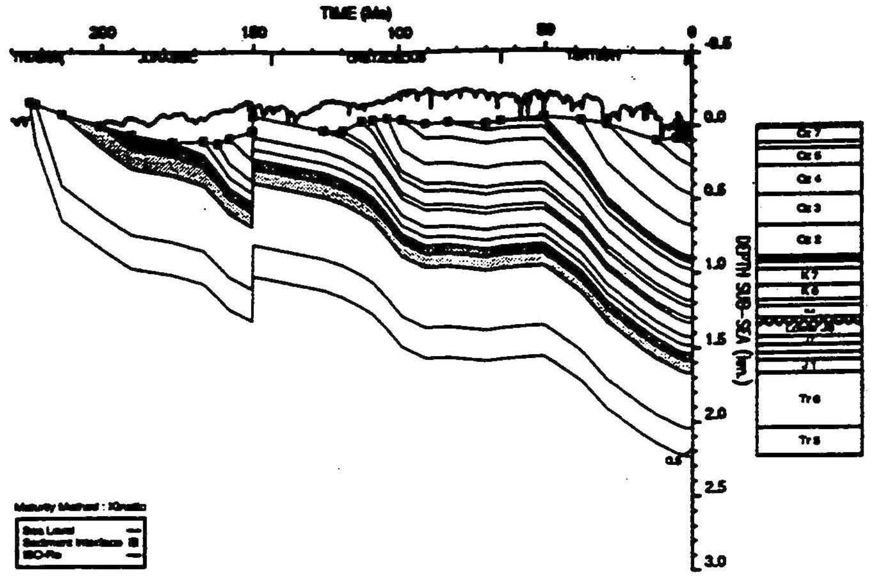
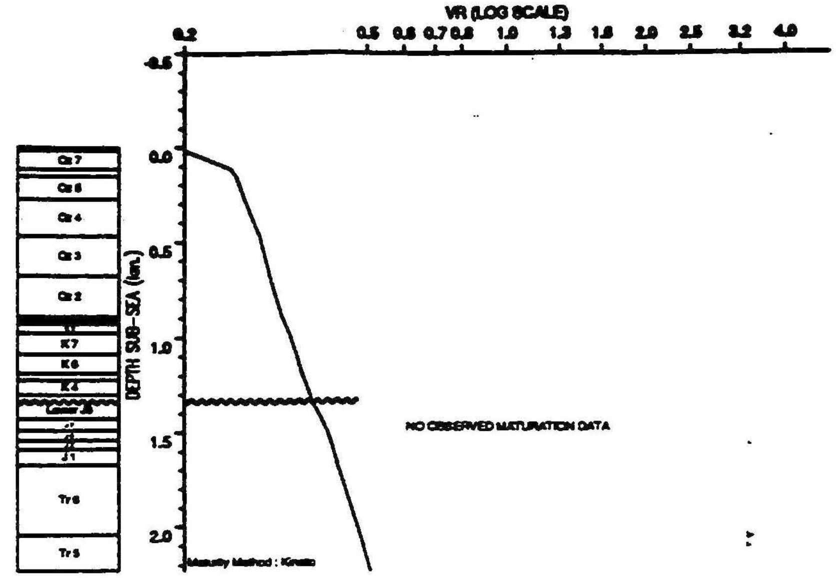
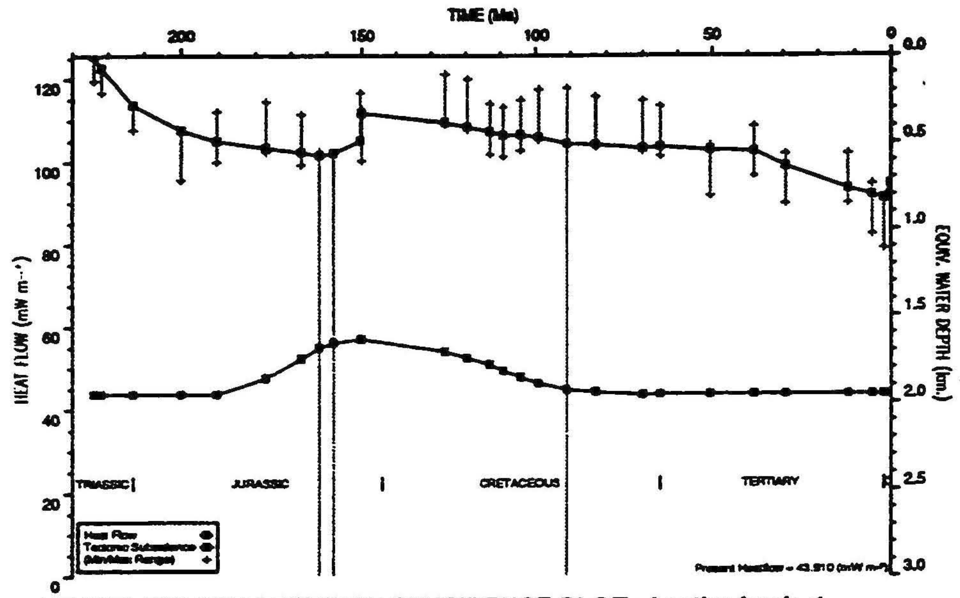


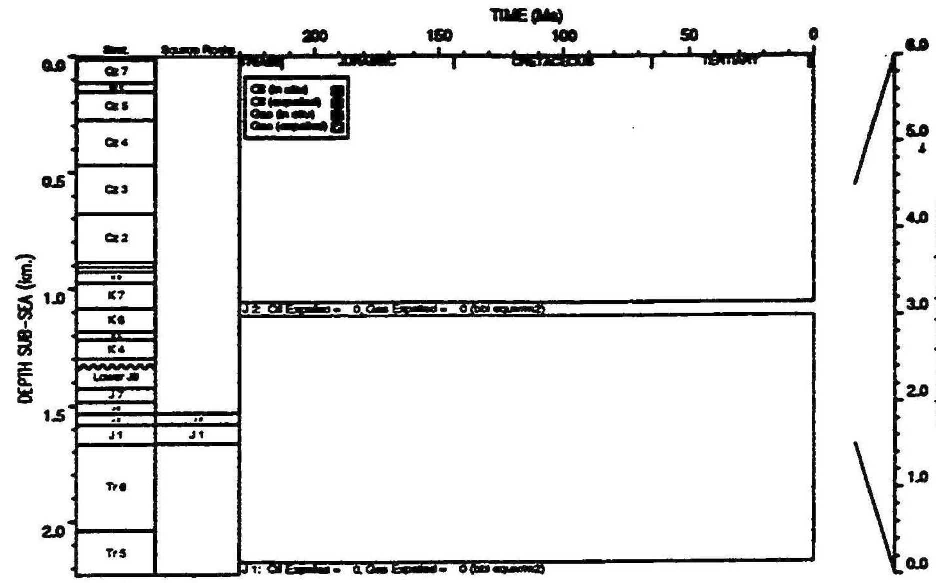
GEOHISTORY PLOT : Leatherback 1



OBSERVED vs COMPUTED MATURITY PLOT : Leatherback 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Leatherback 1



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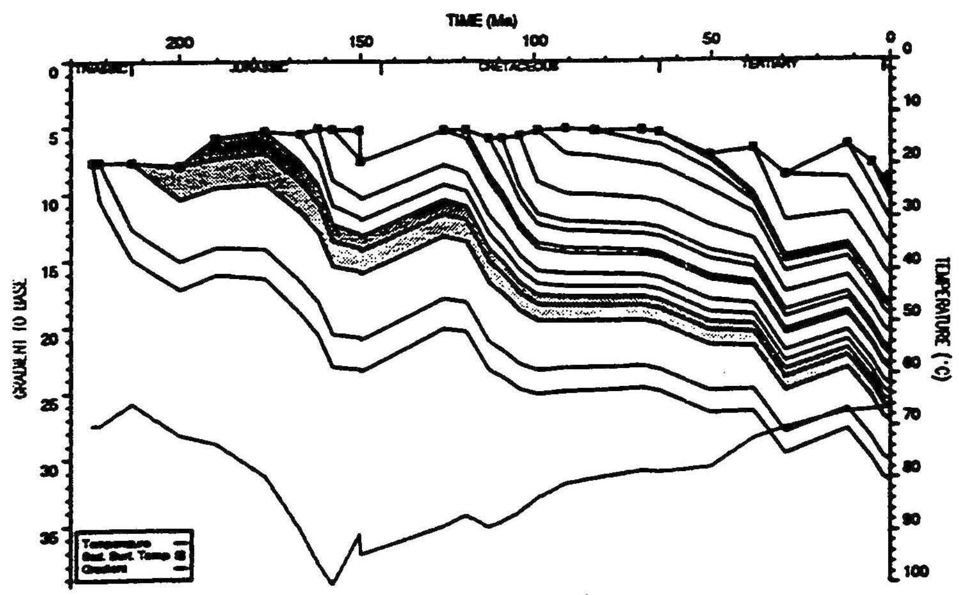

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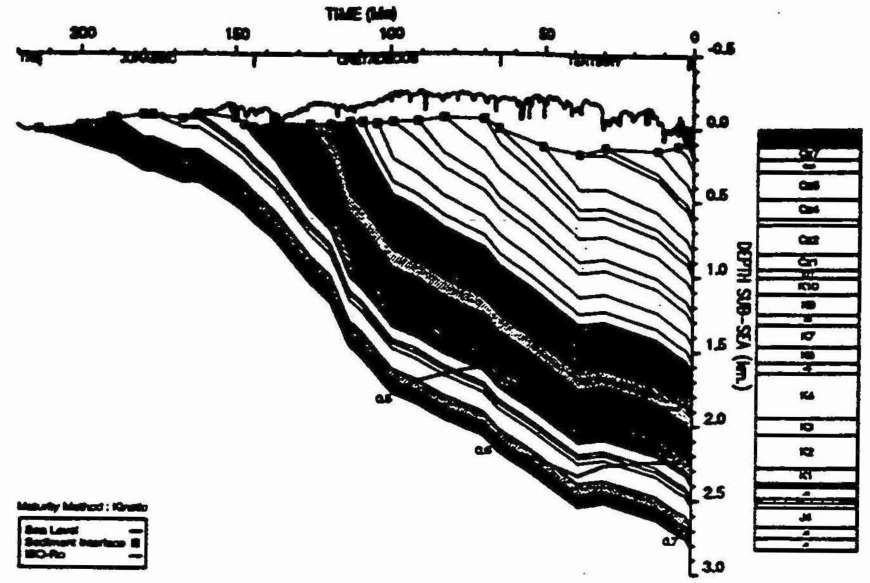
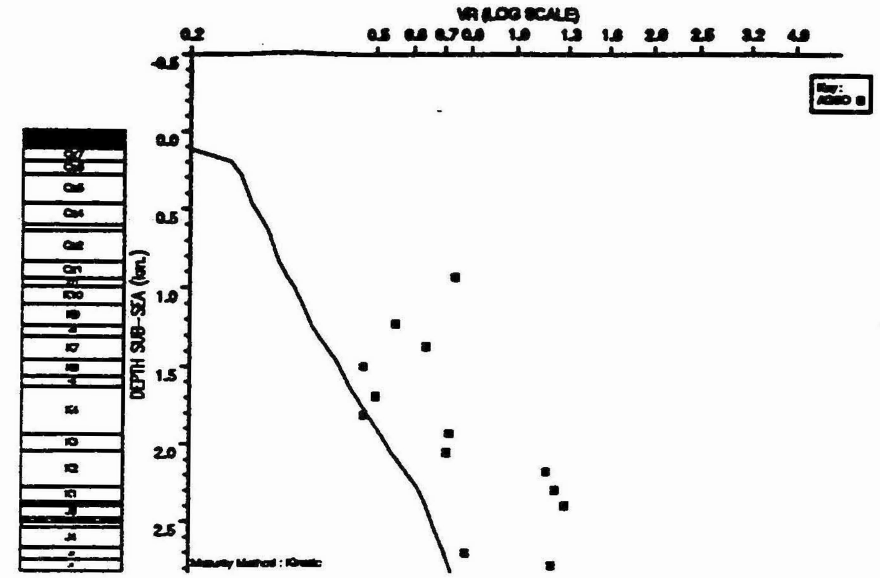
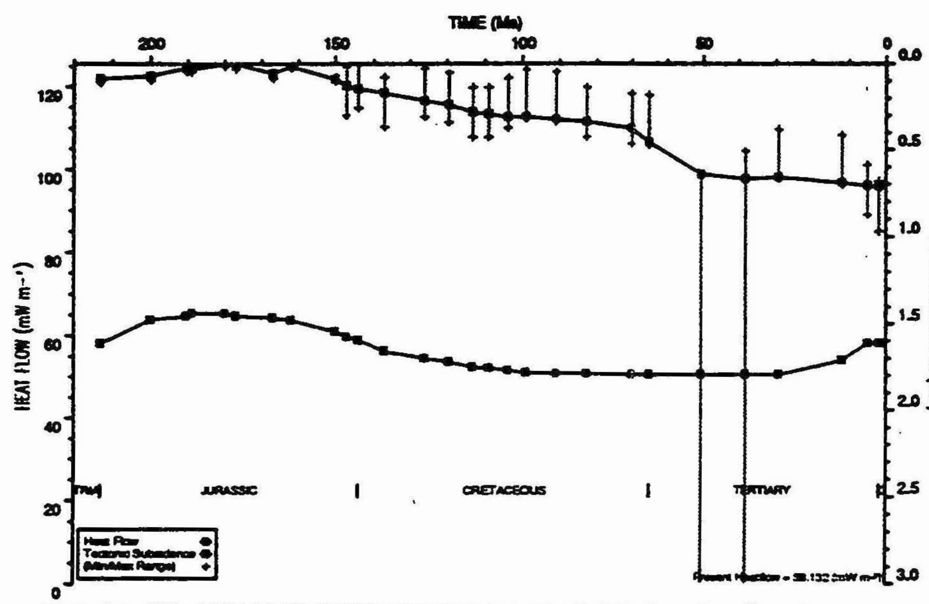


GEOHISTORY PLOT : Lombardina 1



OBSERVED vs COMPUTED MATURITY PLOT : Lombardina 1



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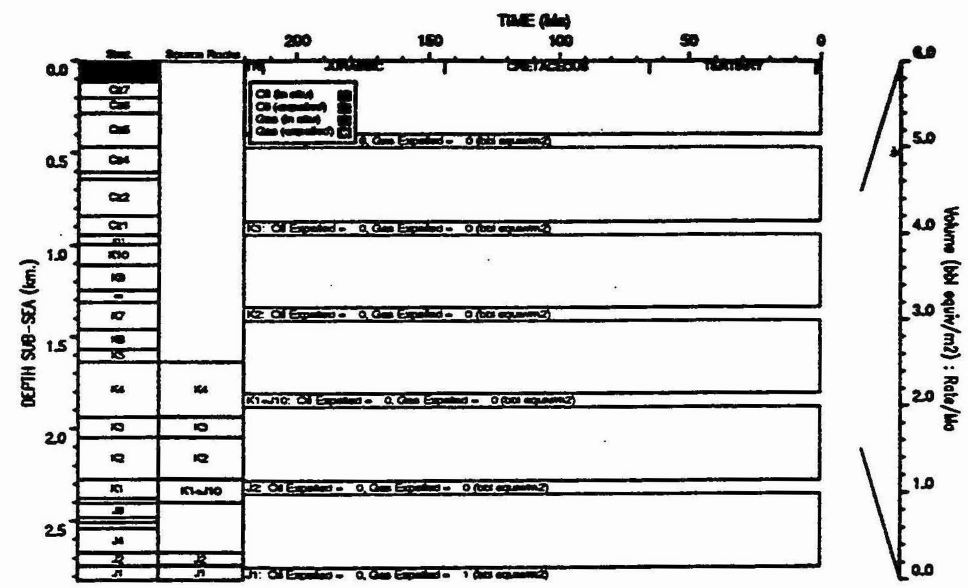

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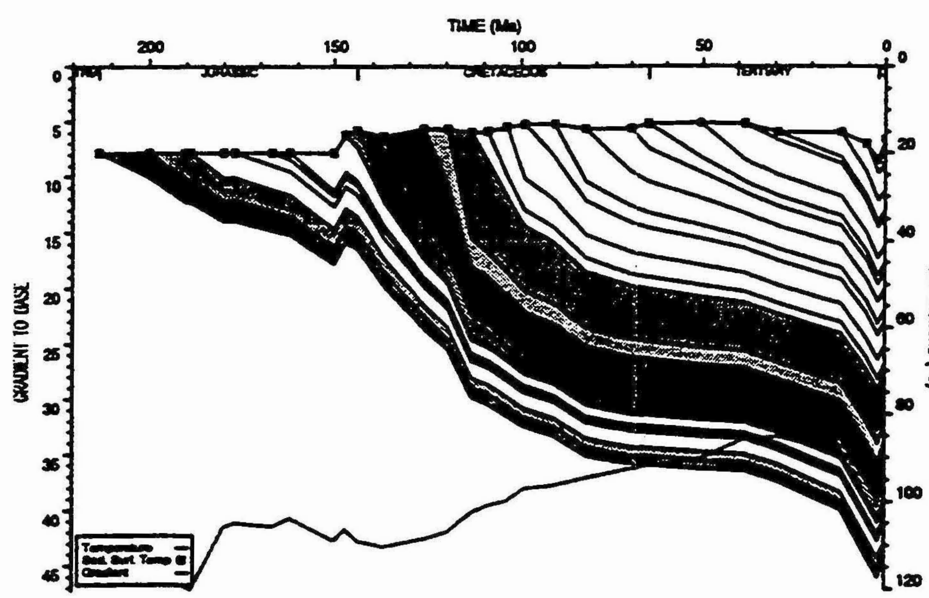

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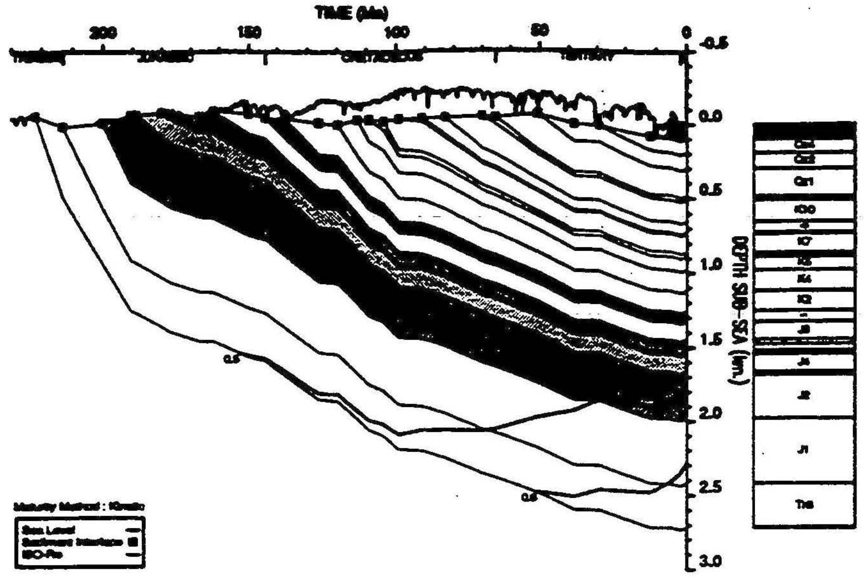
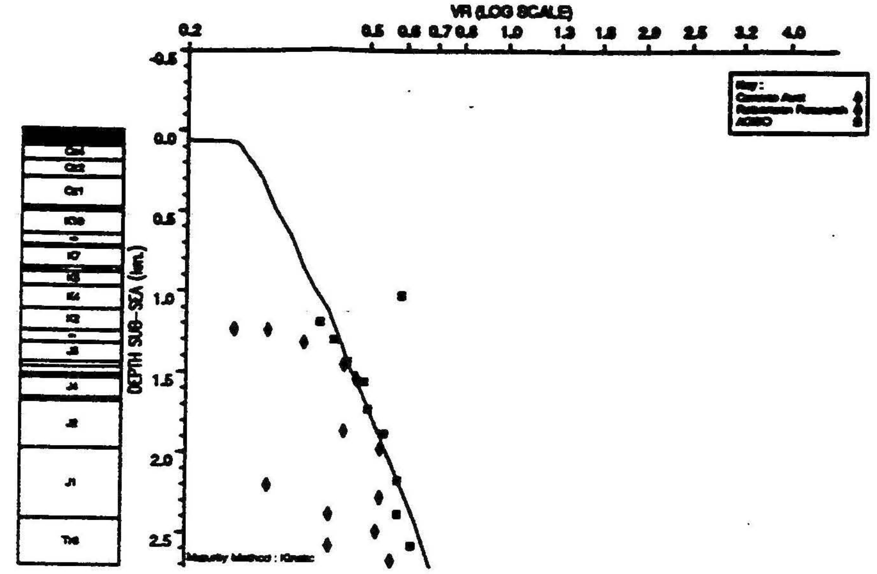
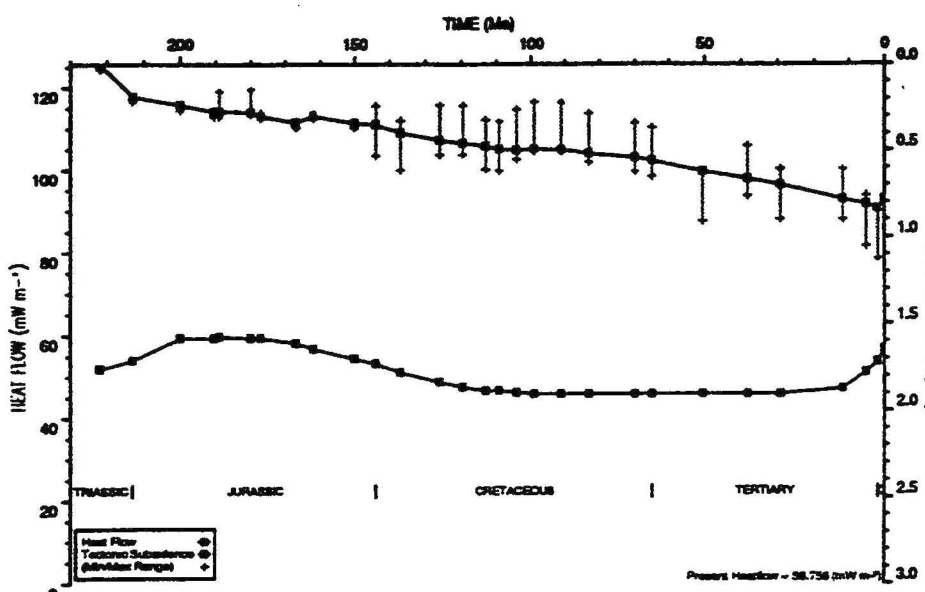


GEOHISTORY PLOT : Lynher 1



OBSERVED vs COMPUTED MATURITY PLOT : Lynher 1



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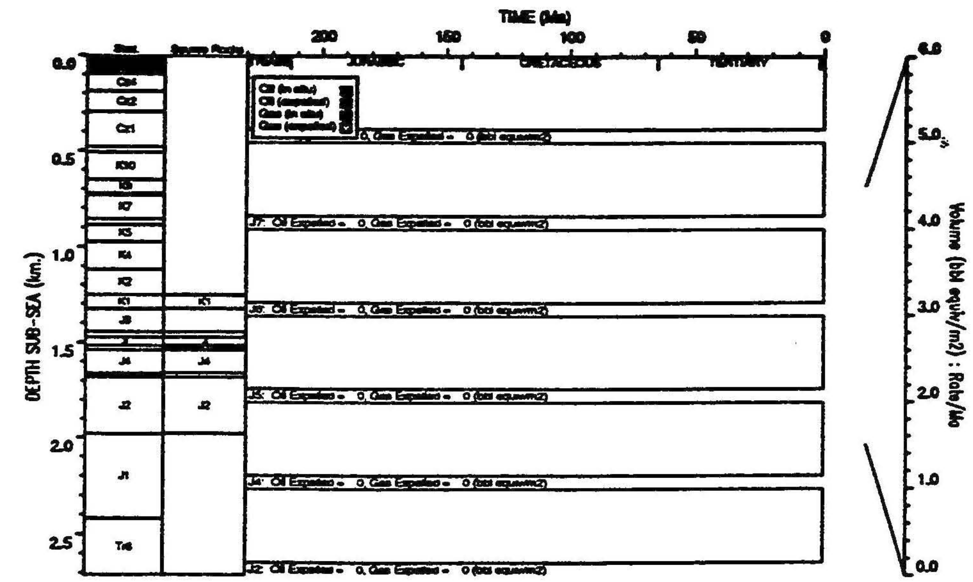

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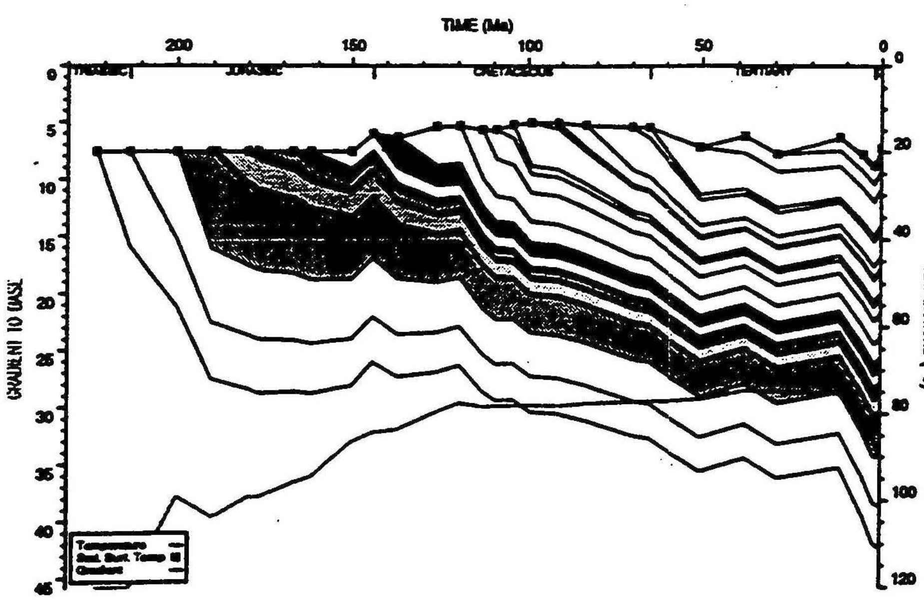

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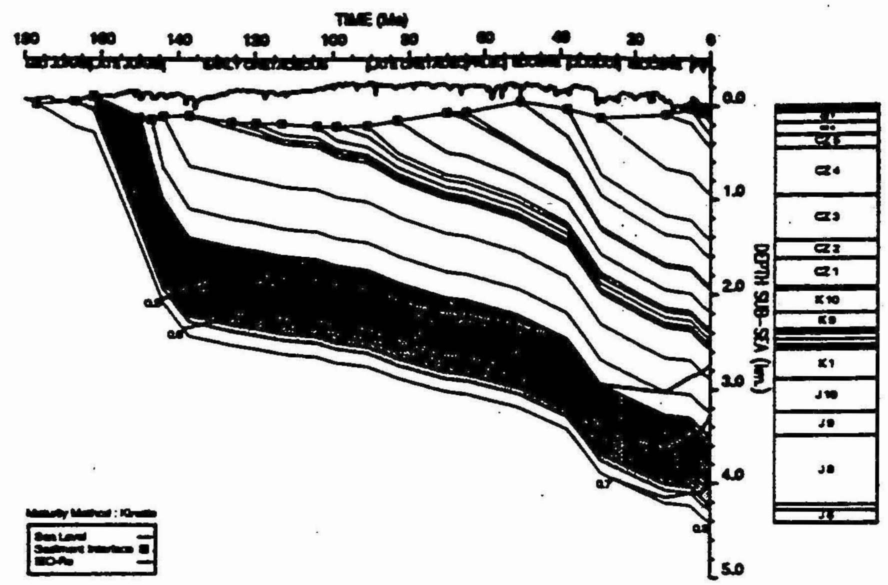
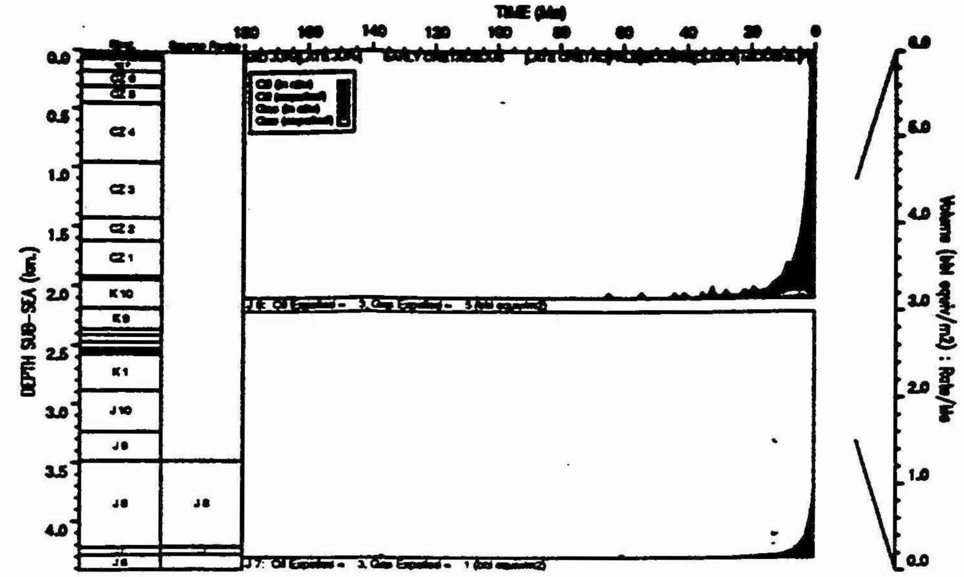


GEOHISTORY PLOT : Madeleine 1



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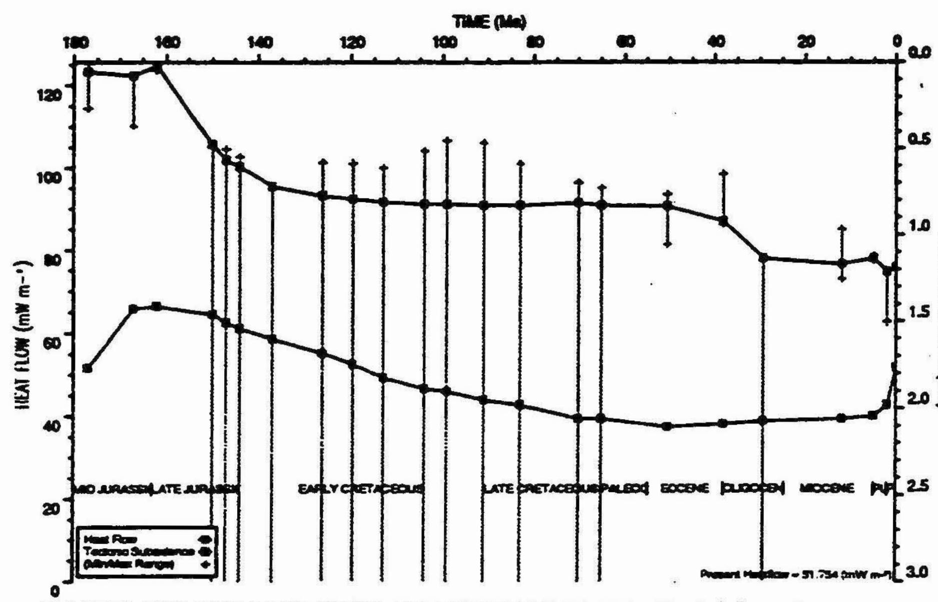

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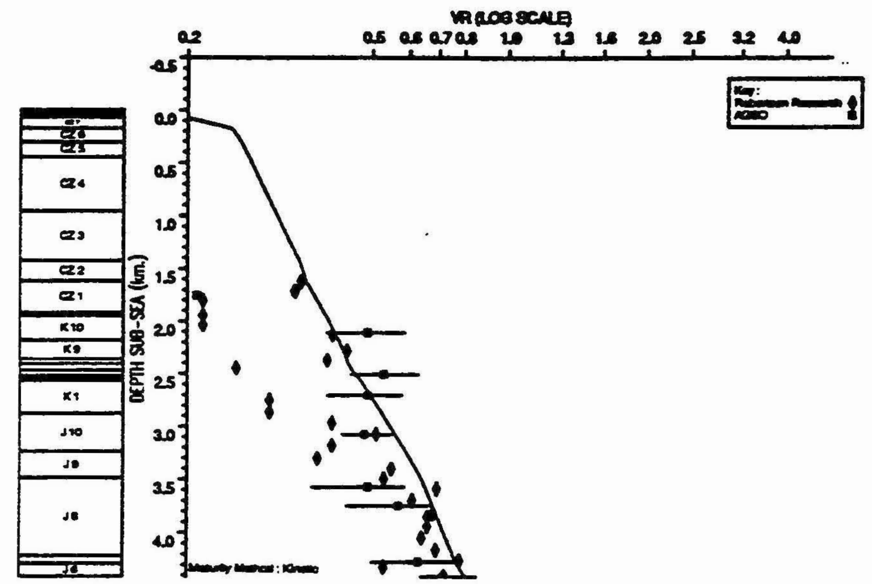
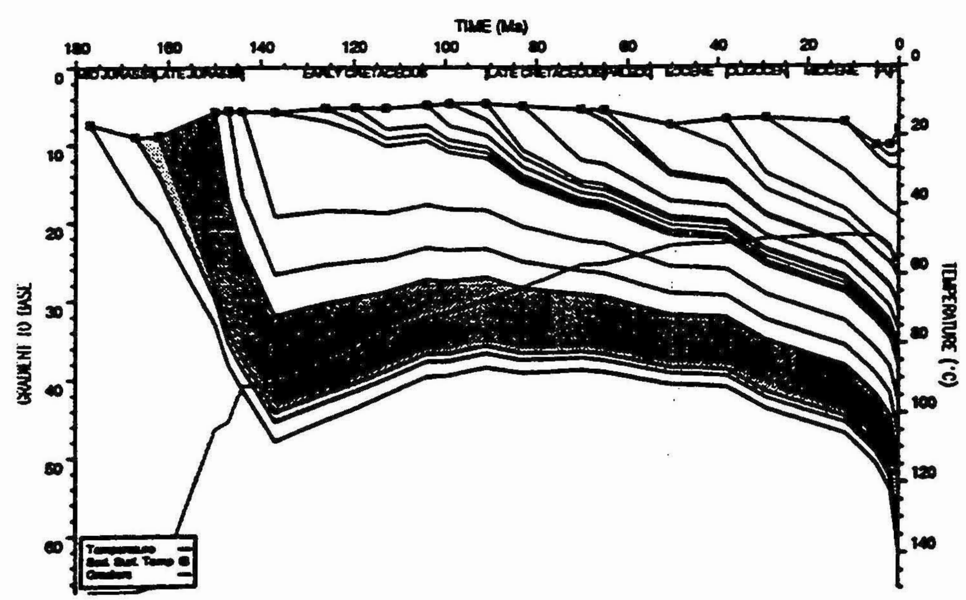


OBSERVED vs COMPUTED MATURITY PLOT : Madeleine 1



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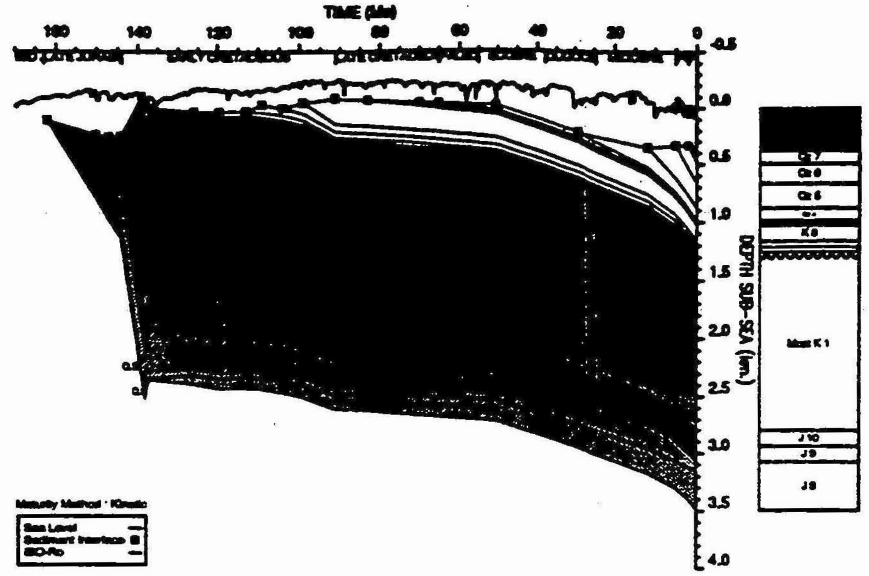
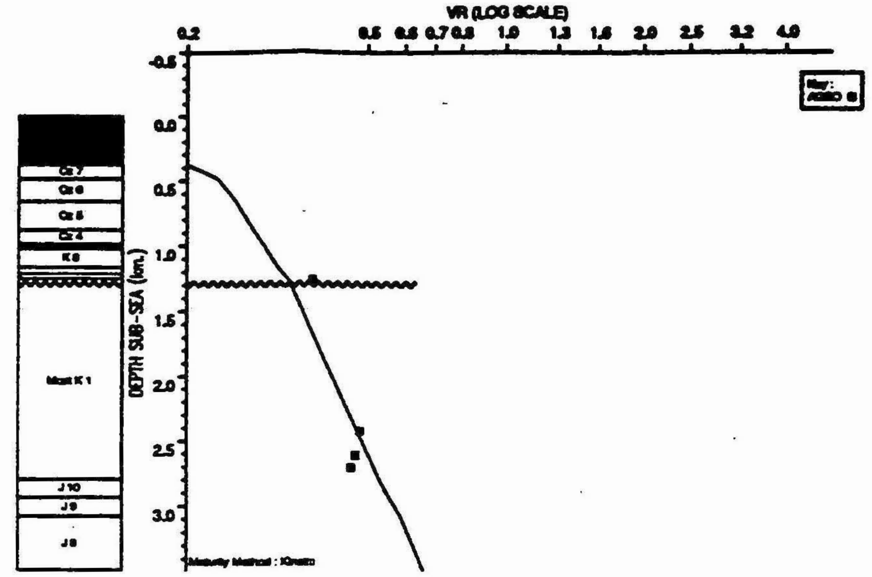
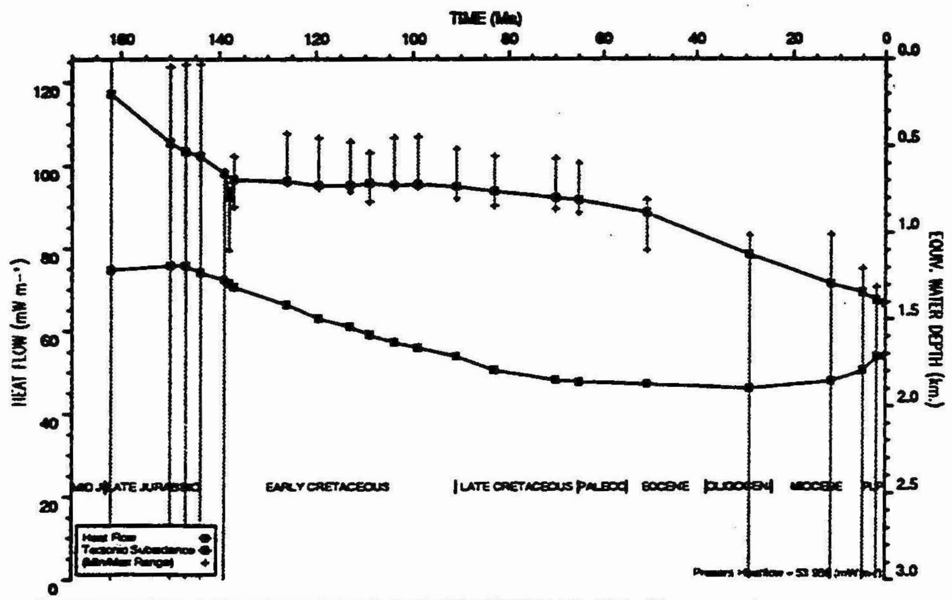


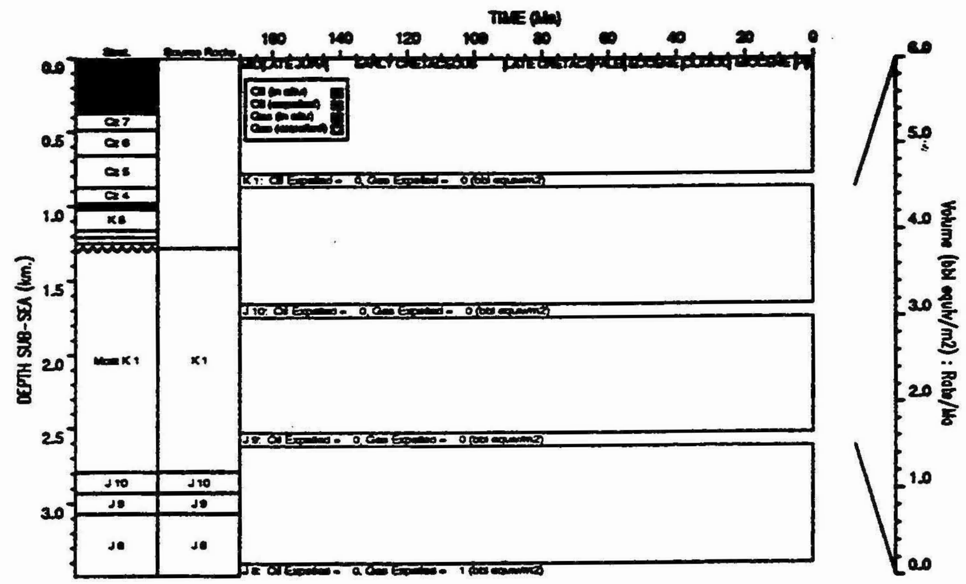
GEOHISTORY PLOT : Novara 1



OBSERVED vs COMPUTED MATURITY PLOT : Novara 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Novara 1



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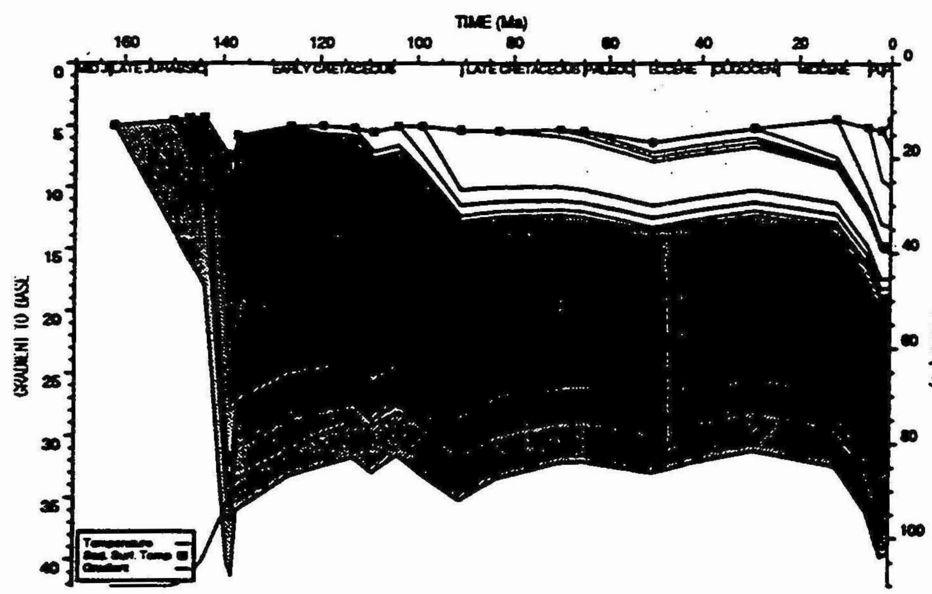
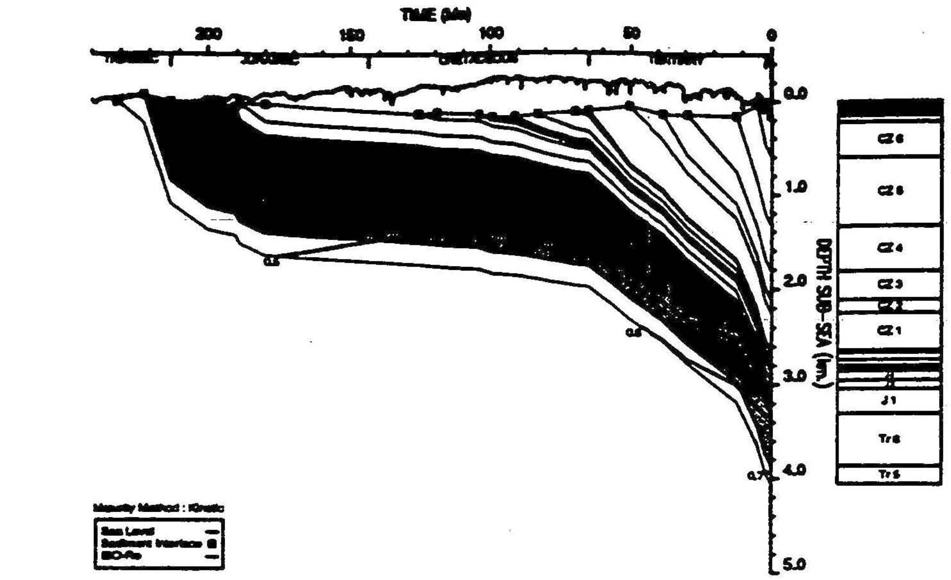
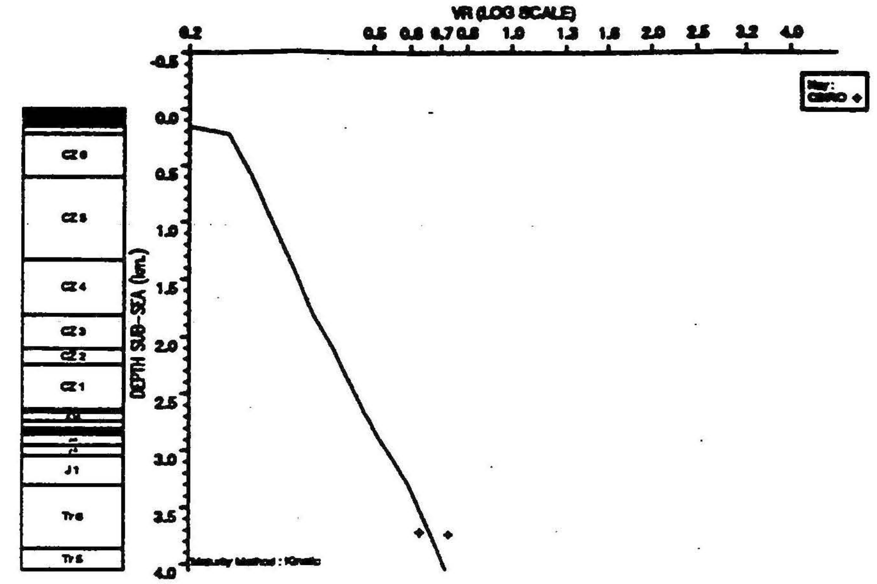


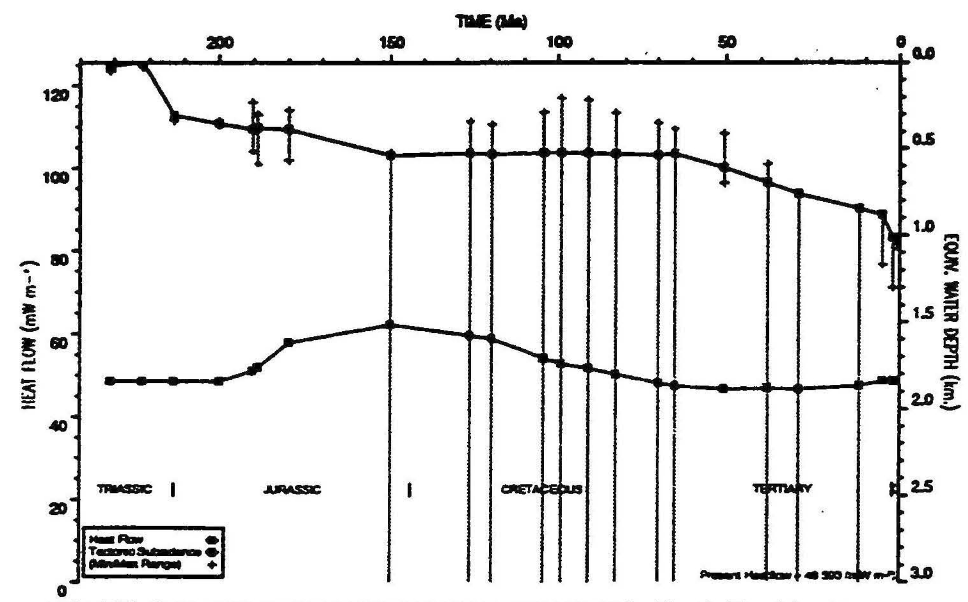
BED TEMPERATURE PLOT : Novara 1



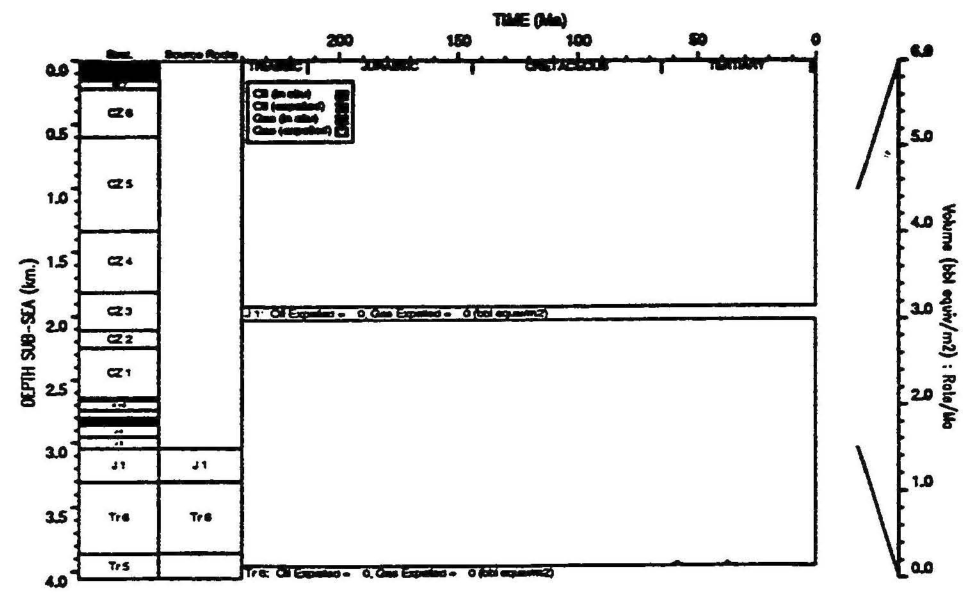
GEOHISTORY PLOT : North Rankin 3



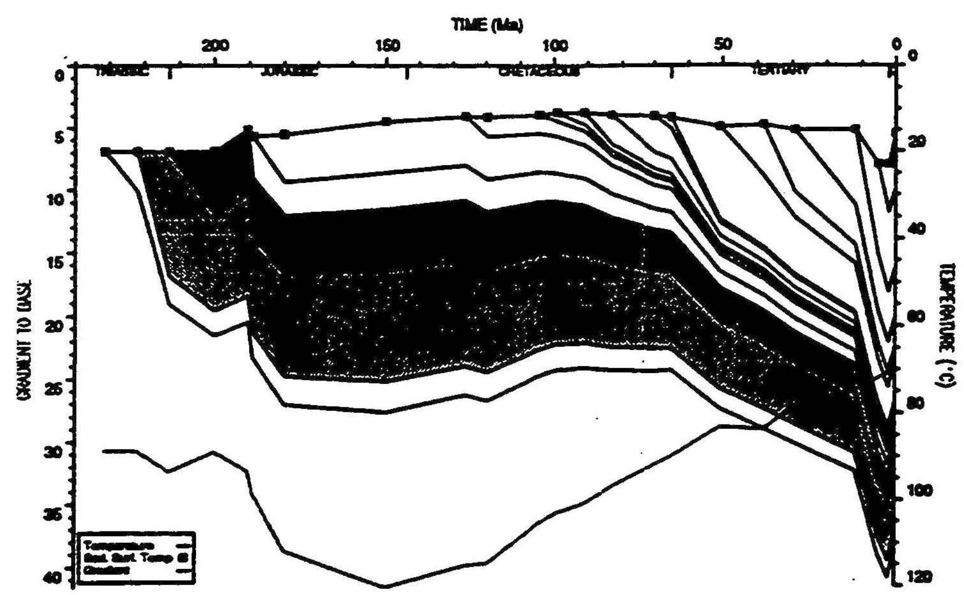
OBSERVED vs COMPUTED MATURITY PLOT : North Rankin 3



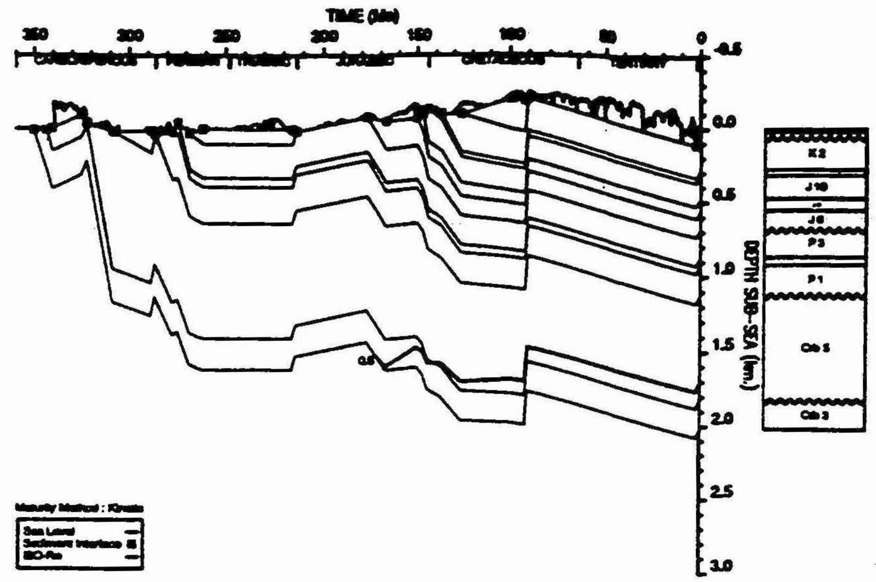
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : North Rankin 3



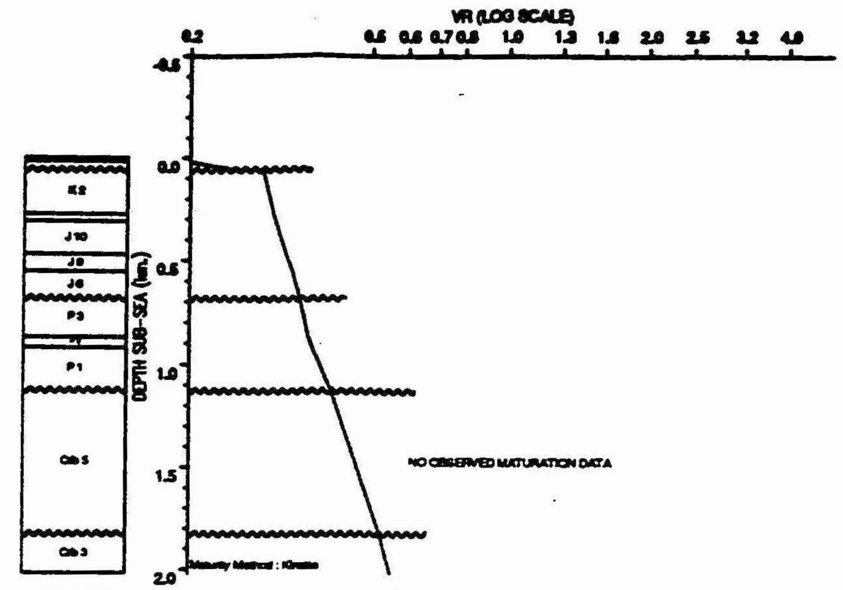
HYDROCARBON GENERATION PLOT : North Rankin 3



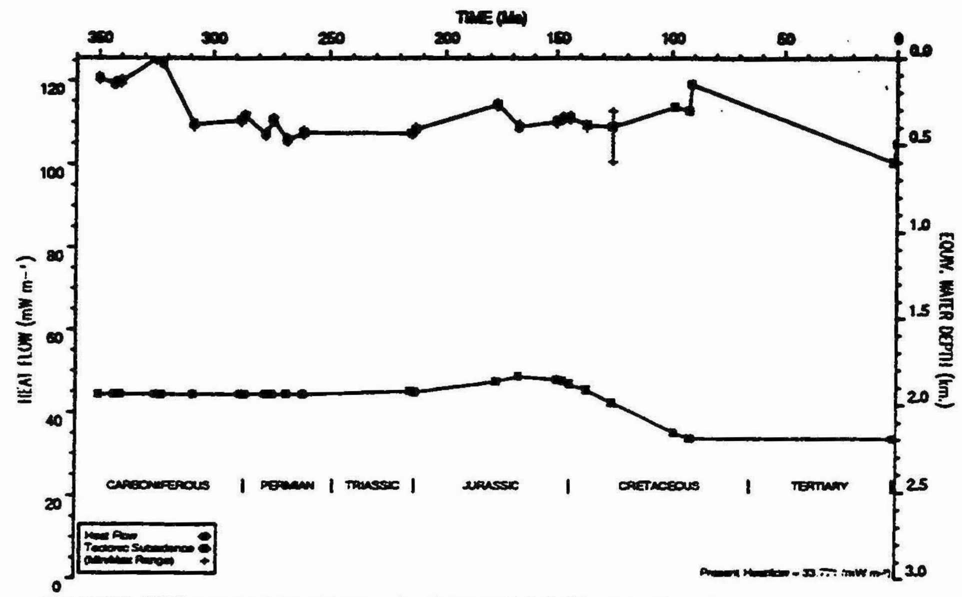
BED TEMPERATURE PLOT : North Rankin 3



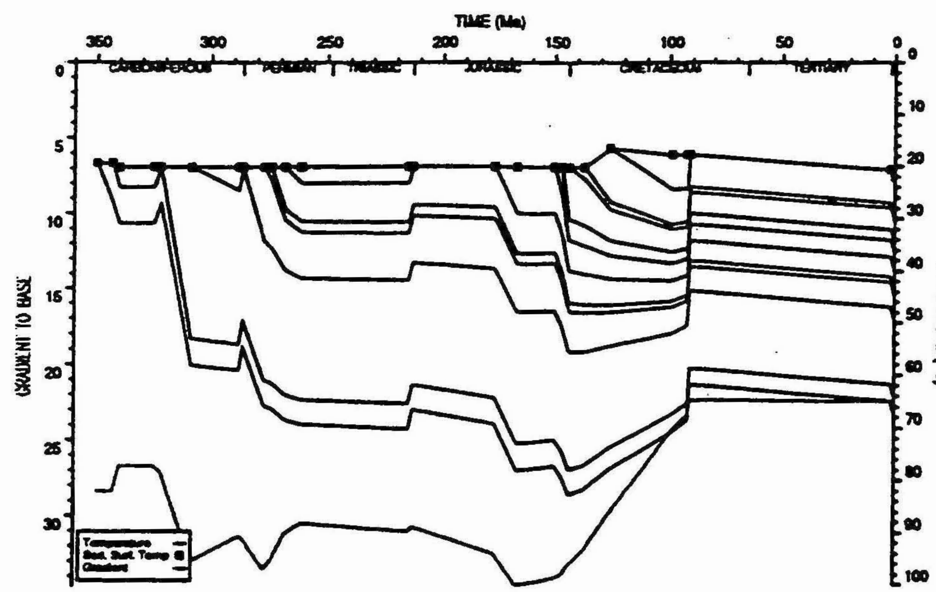
GEOHISTORY PLOT : Pearl 1



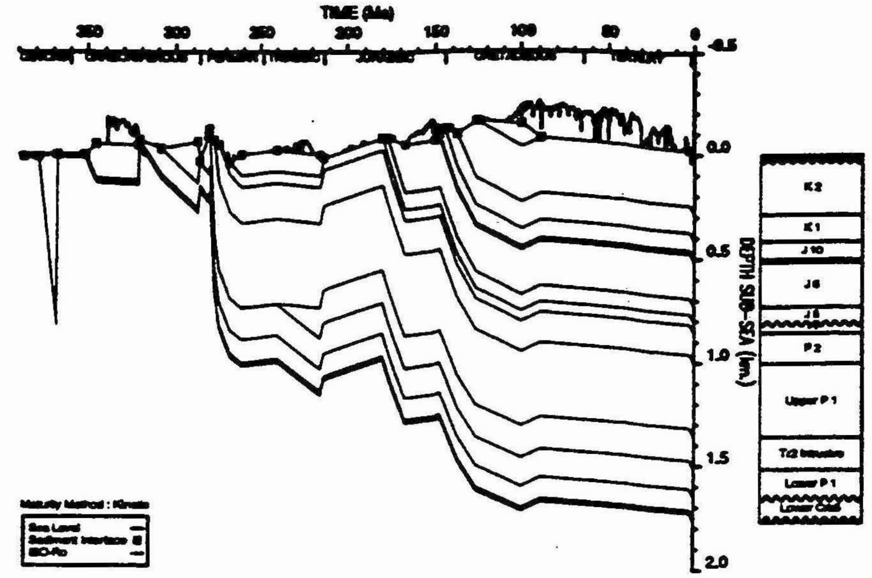
OBSERVED vs COMPUTED MATURITY PLOT : Pearl 1



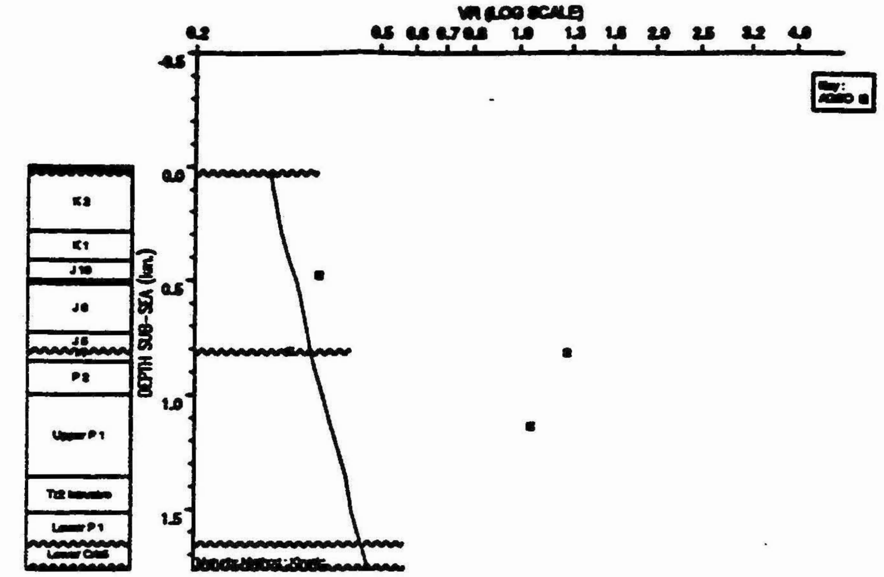
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Pearl 1



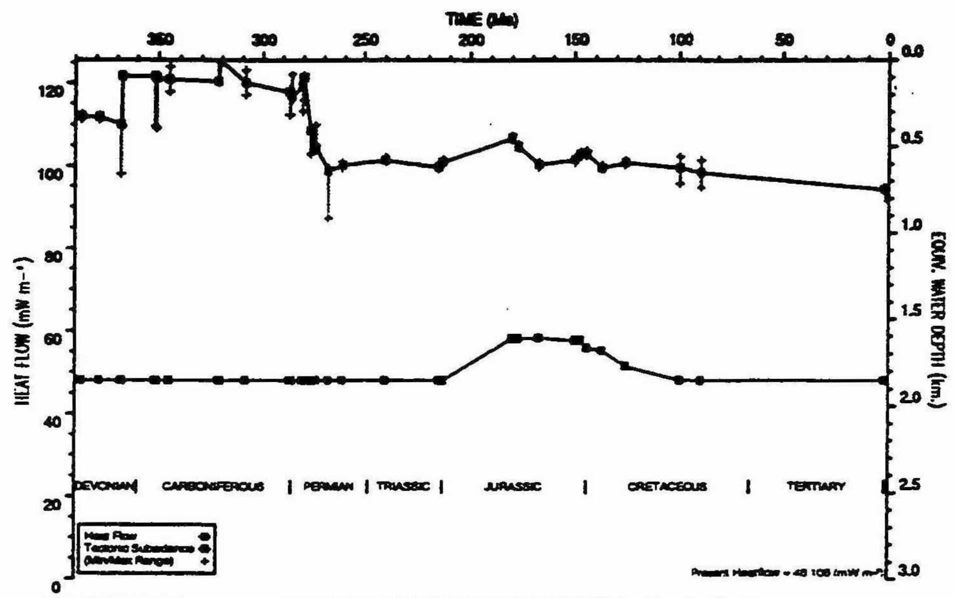
BED TEMPERATURE PLOT : Pearl 1



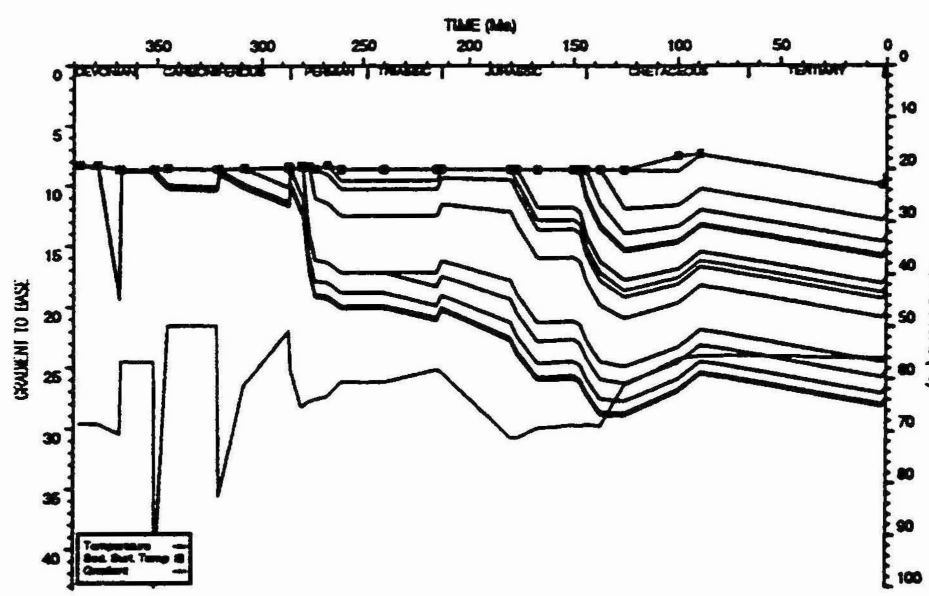
GEOHISTORY PLOT : Perindi 1



OBSERVED vs COMPUTED MATURITY PLOT : Perindi 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Perindi 1



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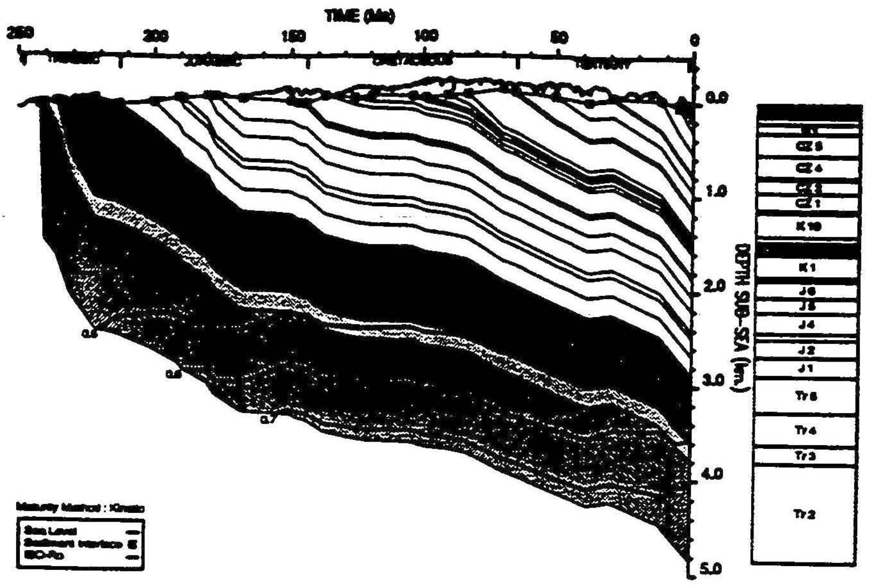
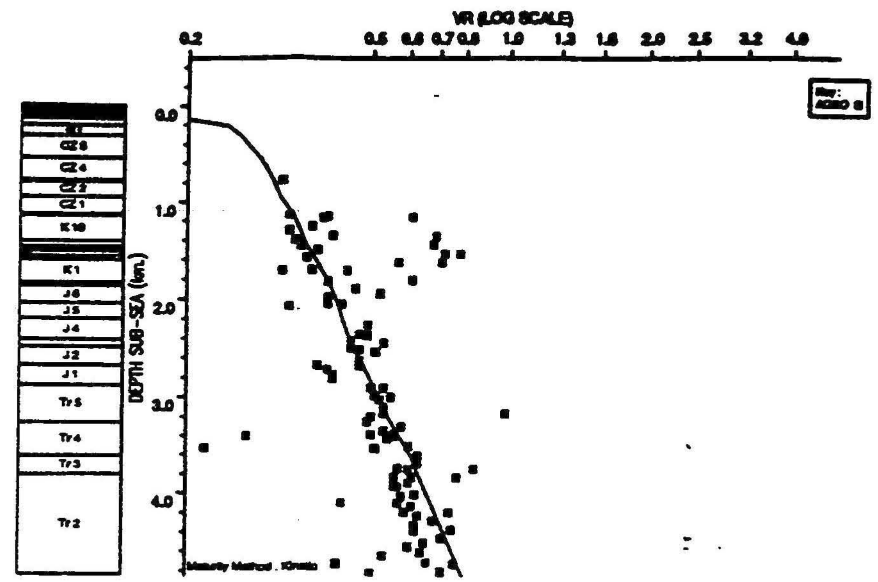
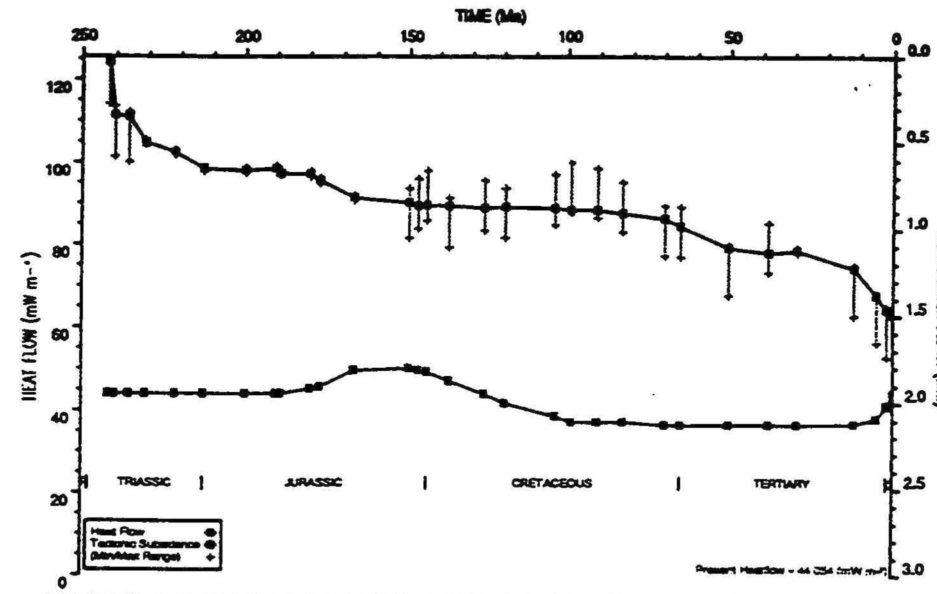


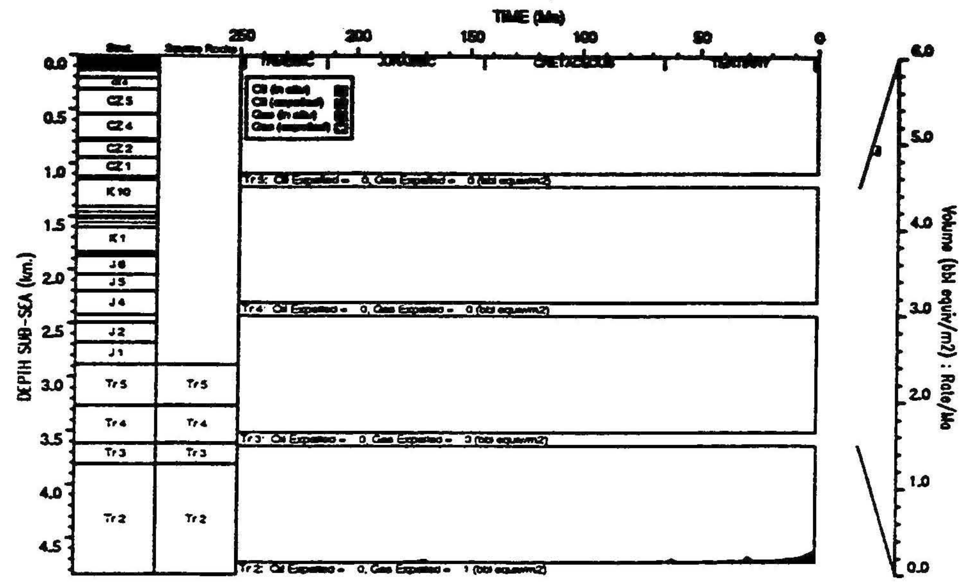
GEOHISTORY PLOT : Phoenix 1



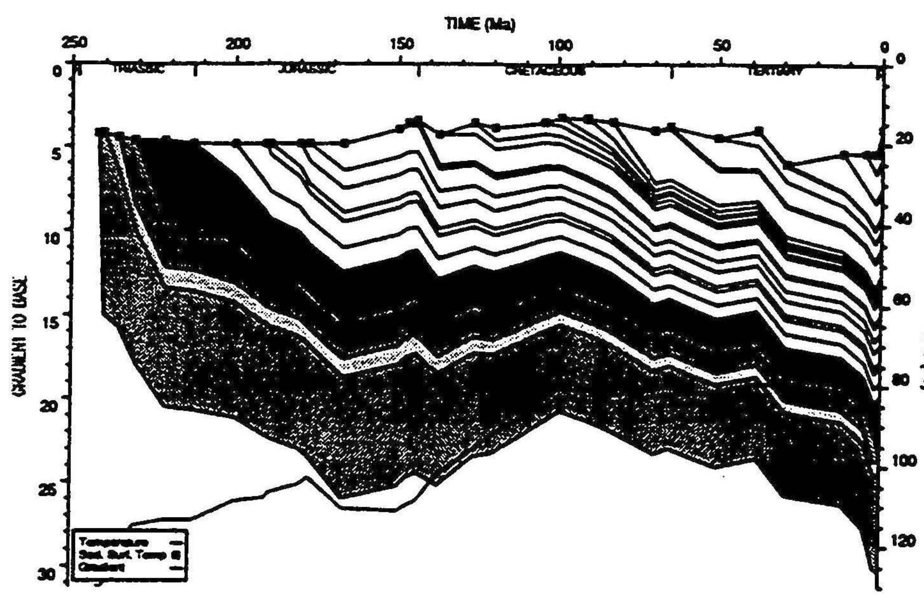
OBSERVED vs COMPUTED MATURITY PLOT : Phoenix 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Phoenix 1



HYDROCARBON GENERATION PLOT : Phoenix 1



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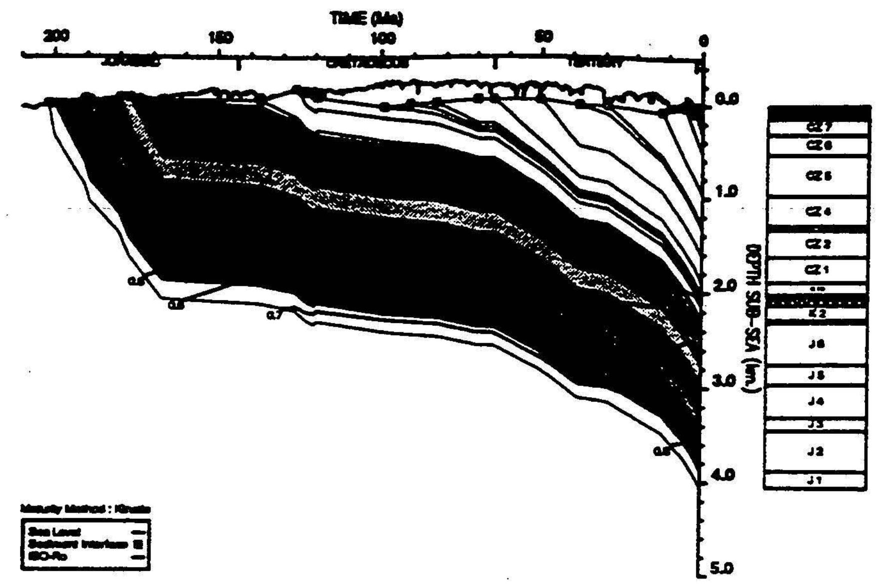
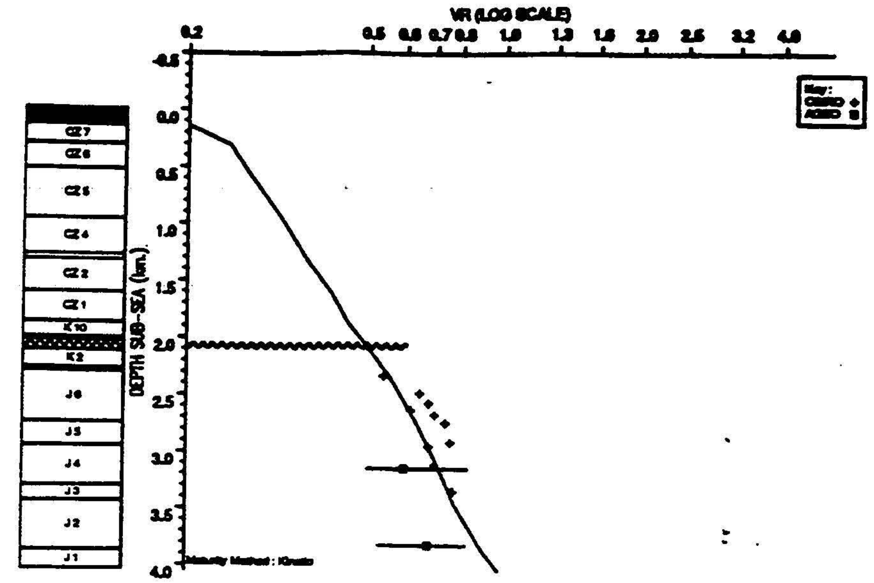
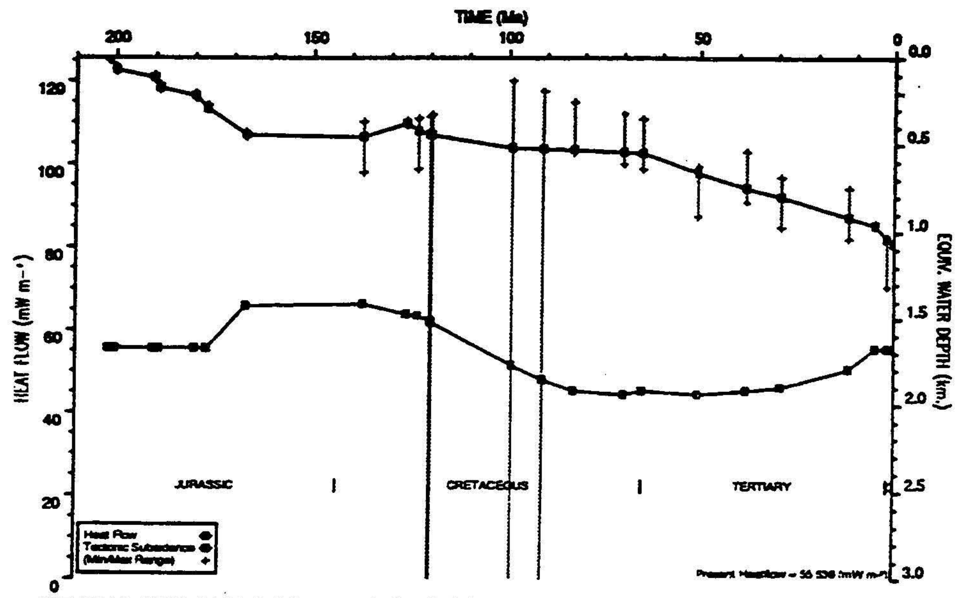


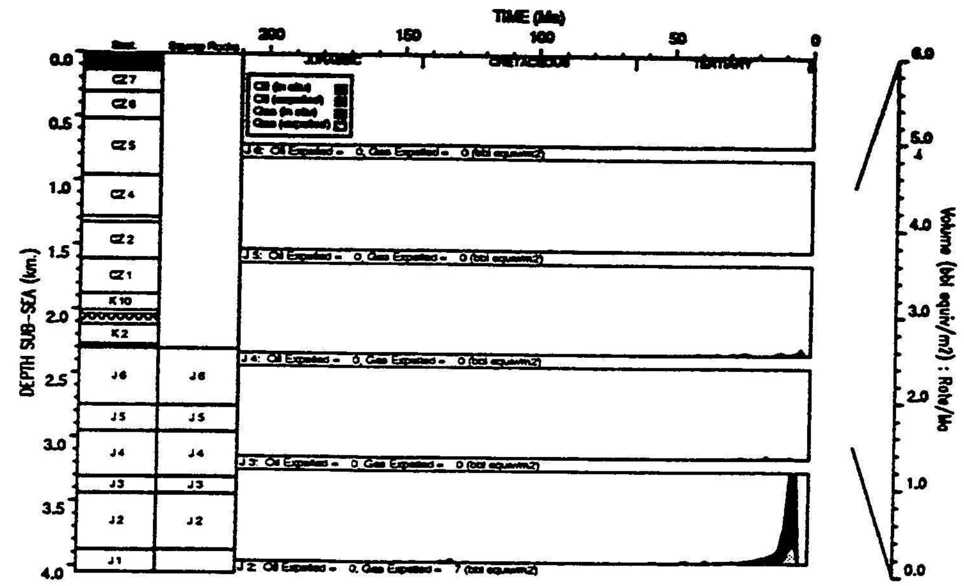
GEOHISTORY PLOT : Picard 1



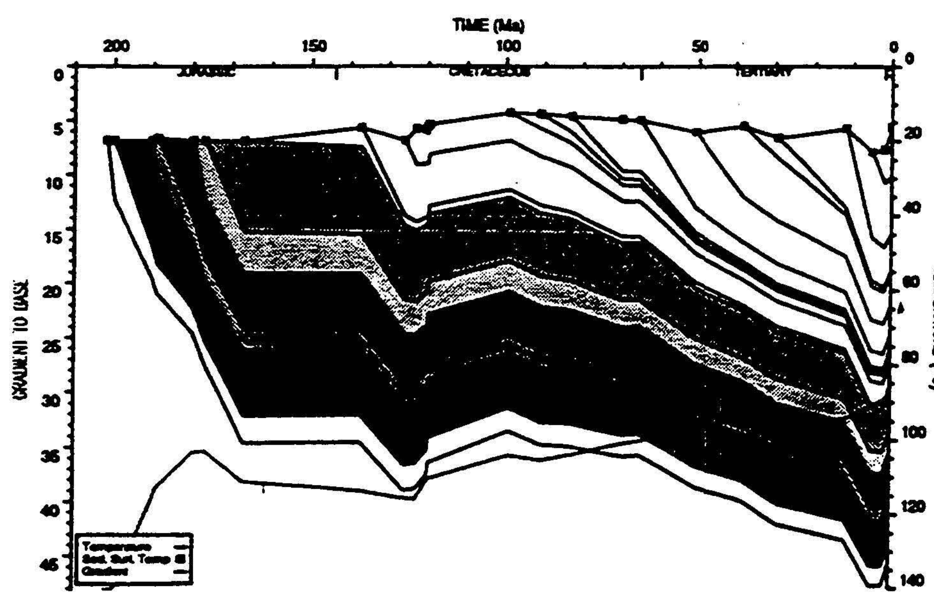
OBSERVED vs COMPUTED MATURITY PLOT : Picard 1



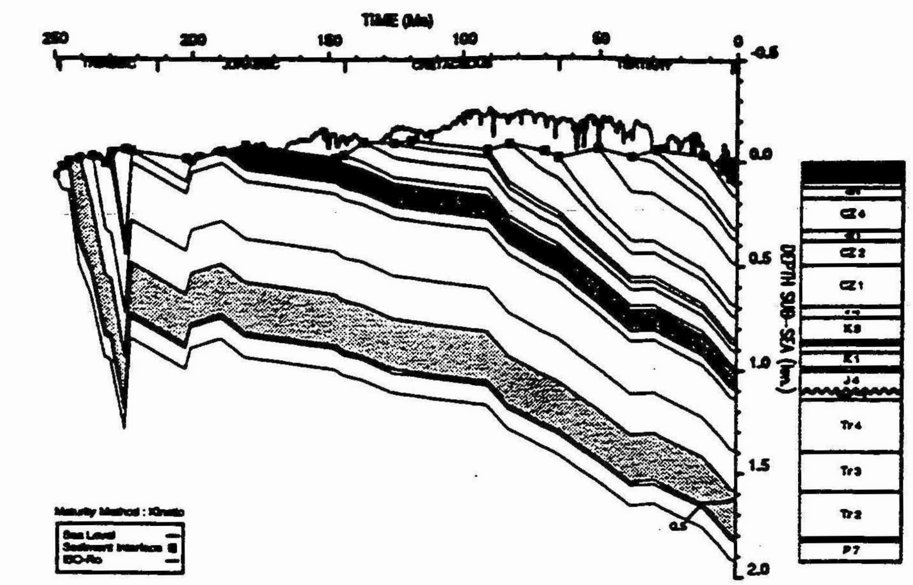
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Picard 1



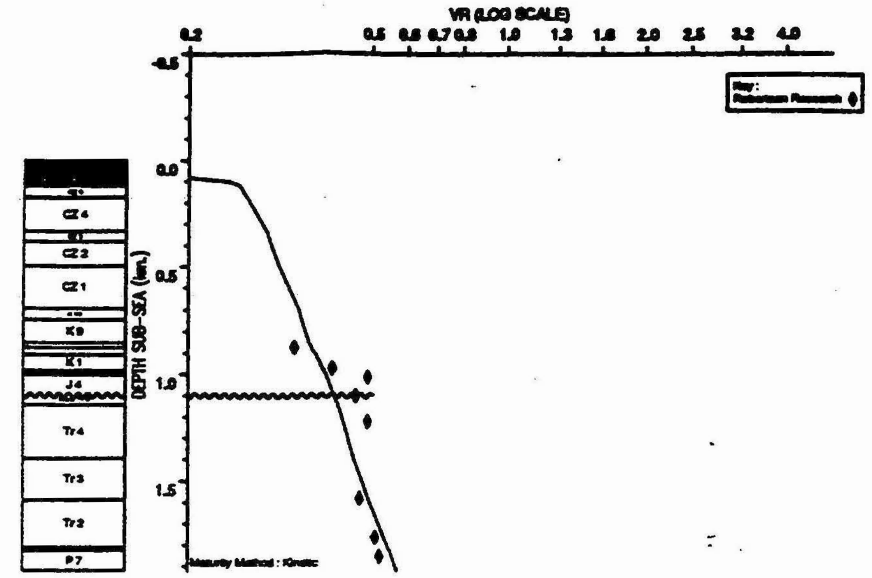
HYDROCARBON GENERATION PLOT : Picard 1



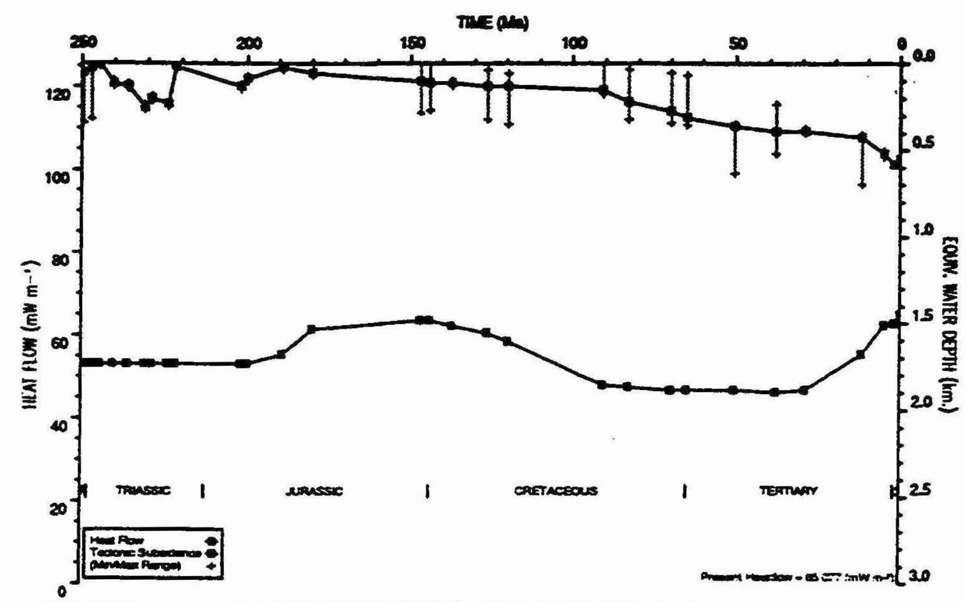
BED TEMPERATURE PLOT : Picard 1



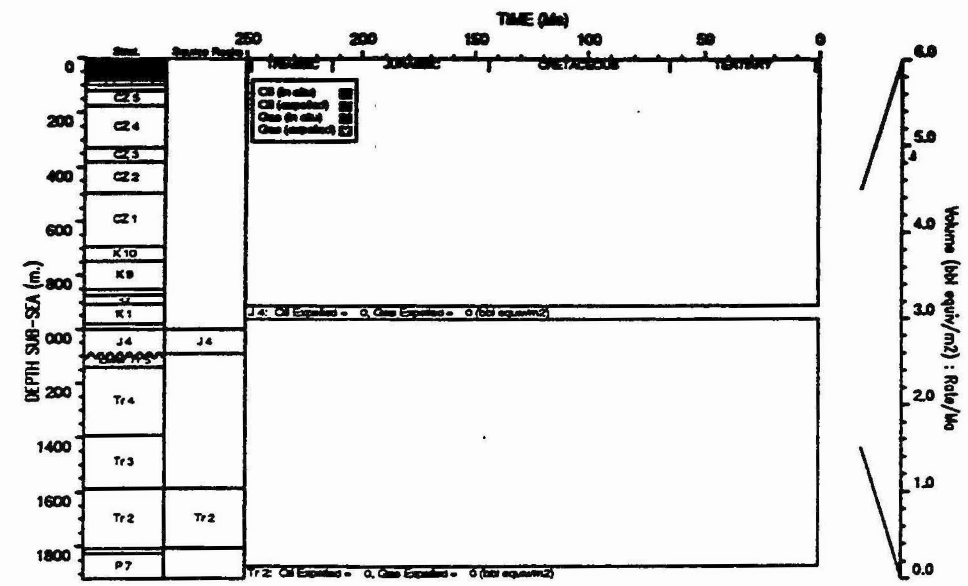
GEOHISTORY PLOT : Poissonnier 1



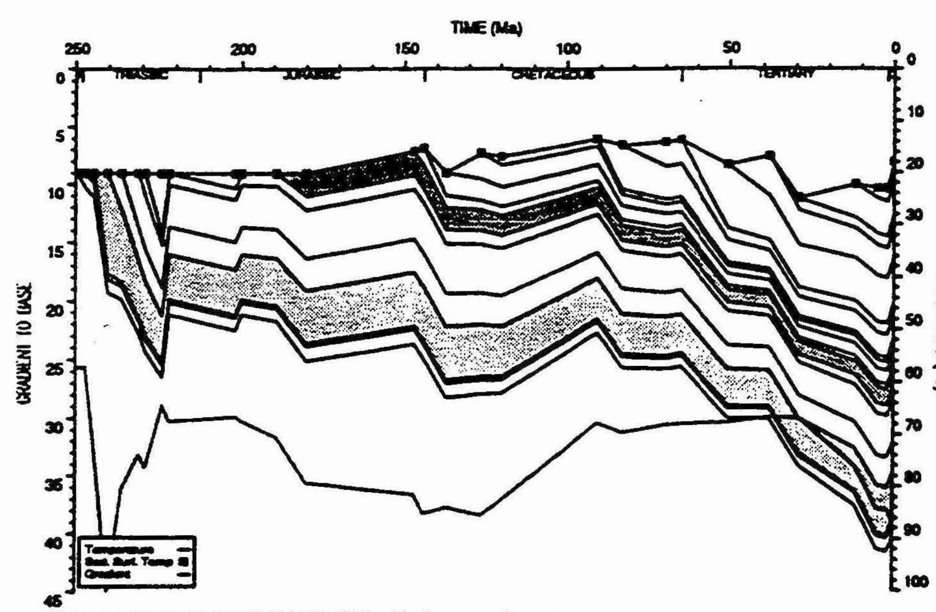
OBSERVED vs COMPUTED MATURITY PLOT : Poissonnier 1



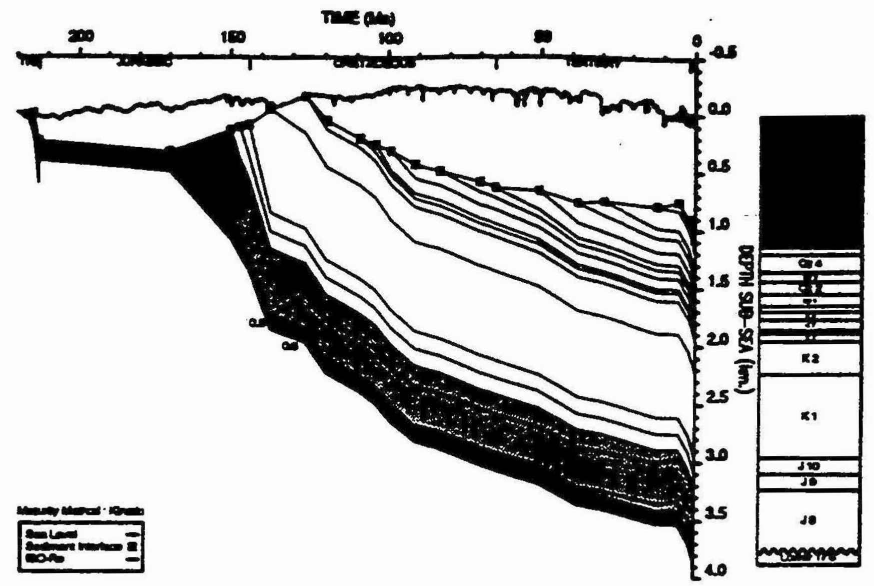
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Poissonnier 1



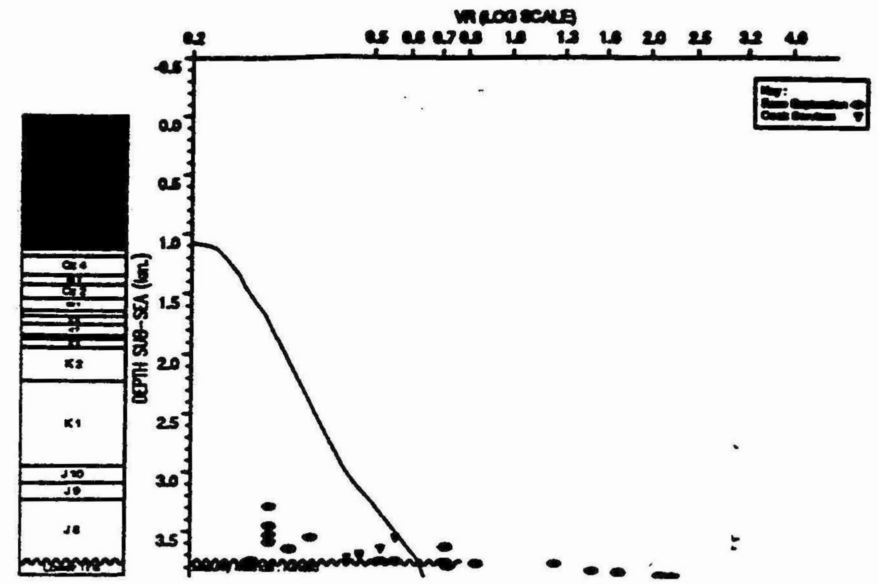
HYDROCARBON GENERATION PLOT : Poissonnier 1



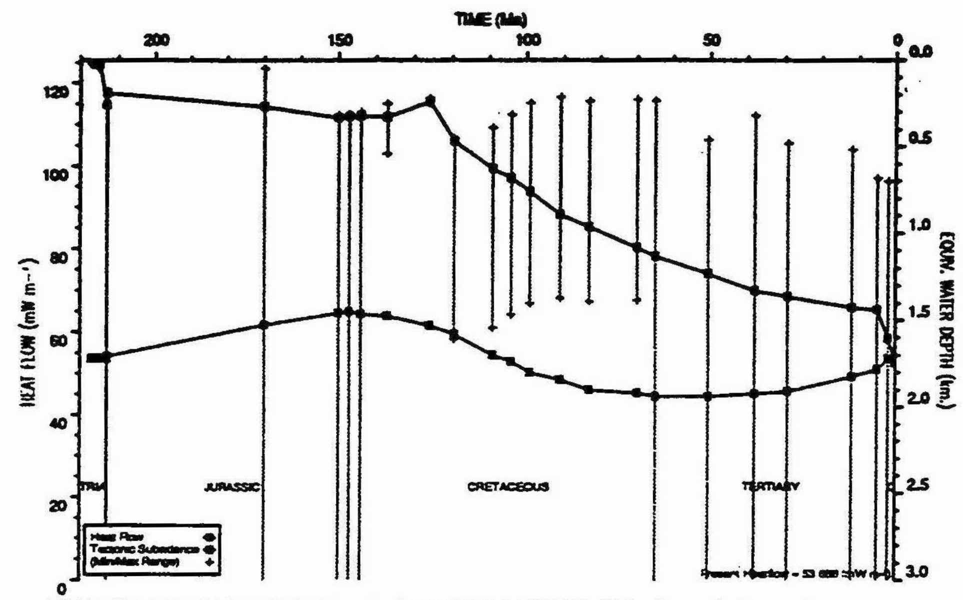
BED TEMPERATURE PLOT : Poissonnier 1



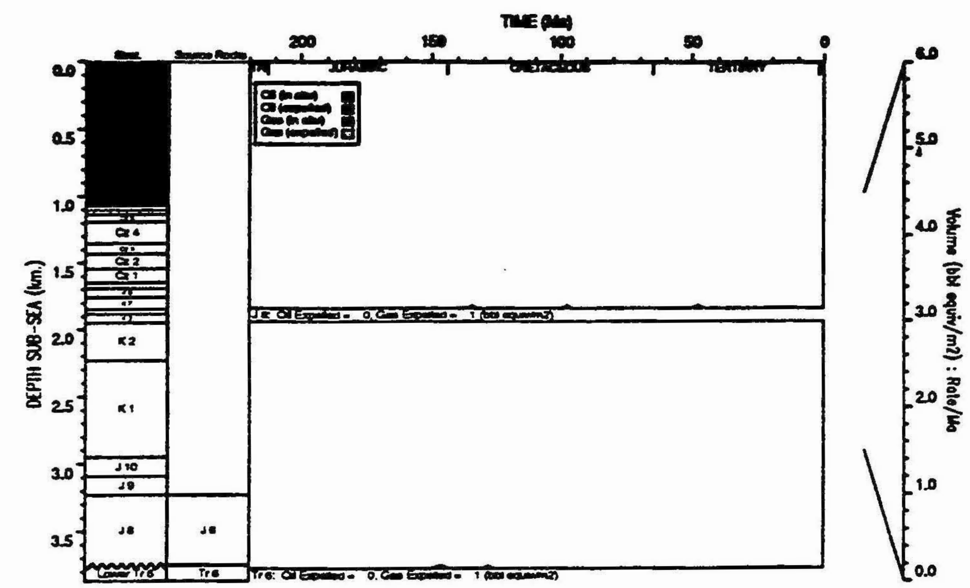
GEOHISTORY PLOT : Resolution 1



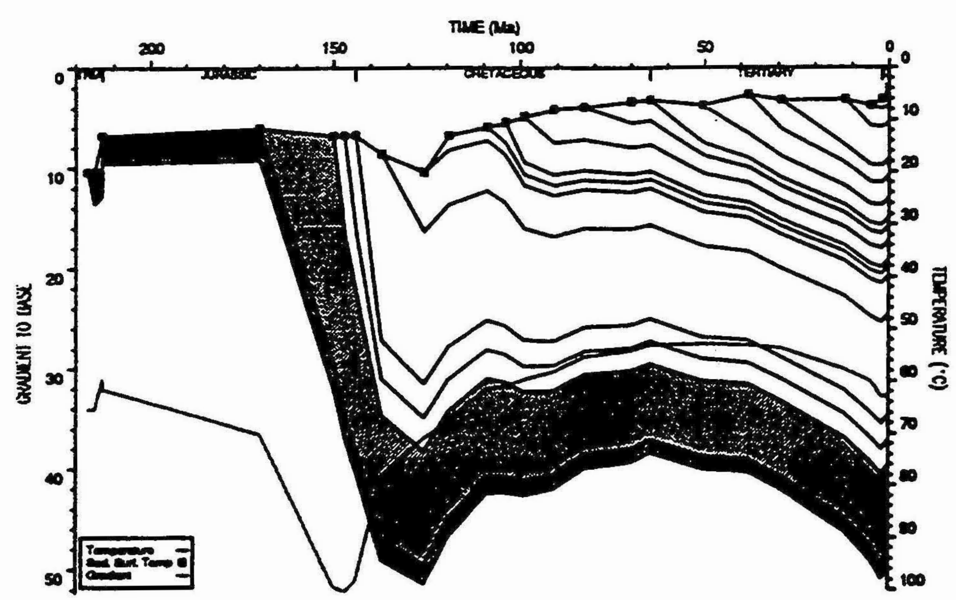
OBSERVED vs COMPUTED MATURITY PLOT : Resolution 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Resolution 1



HYDROCARBON GENERATION PLOT : Resolution 1



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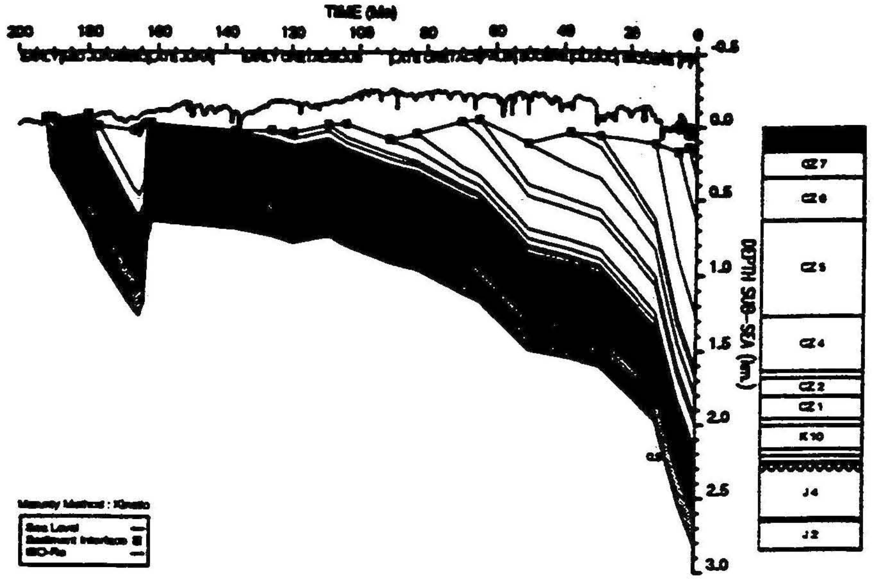
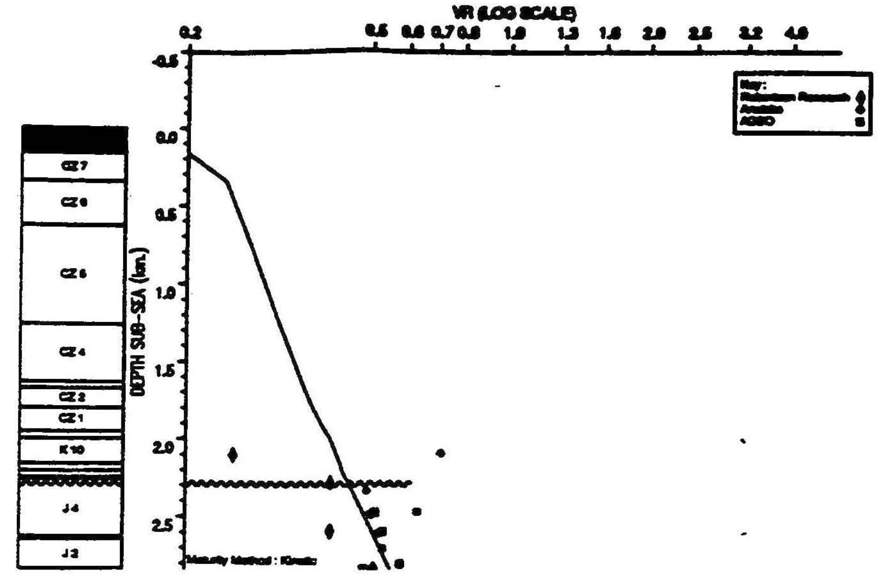
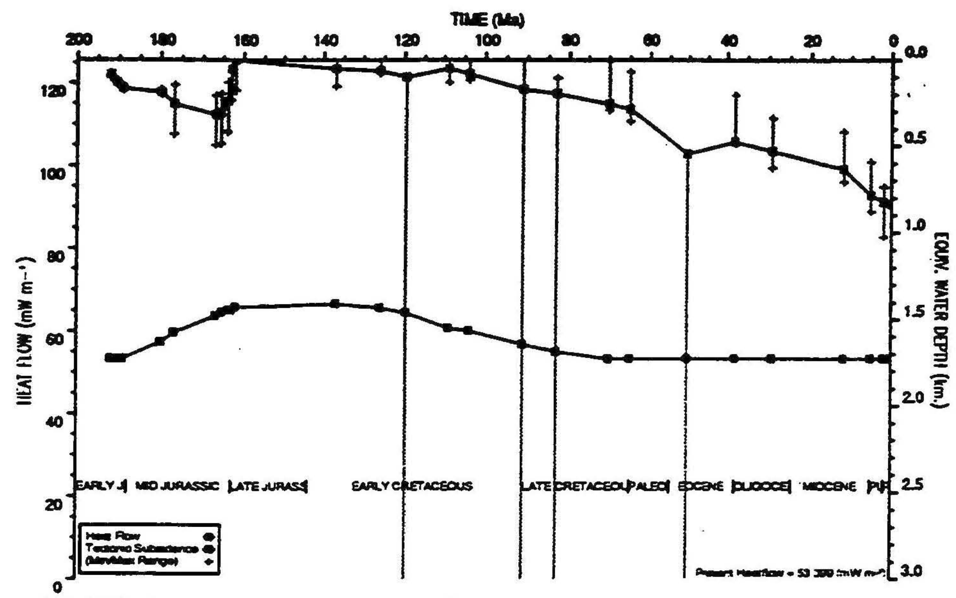


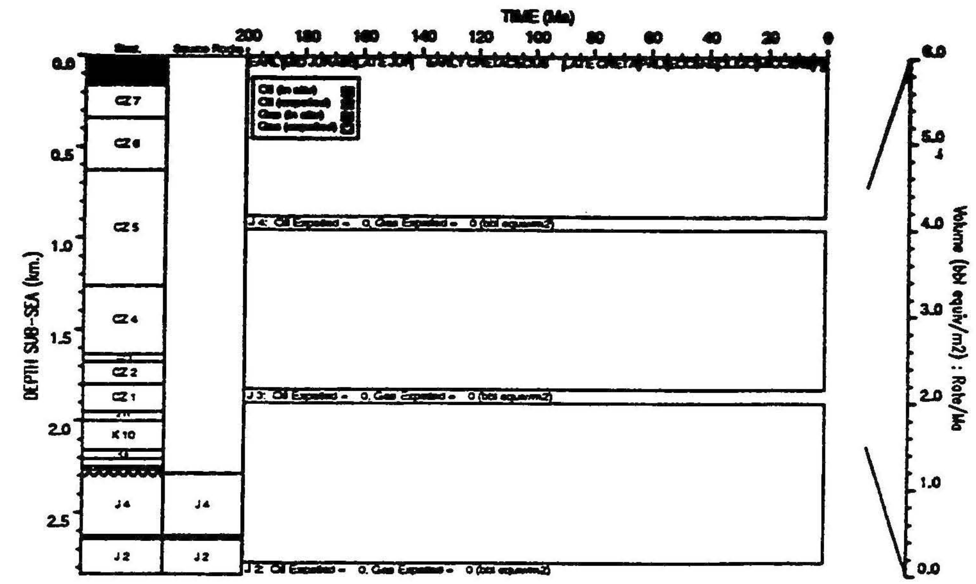
GEOHISTORY PLOT : Ronsard 1



OBSERVED vs COMPUTED MATURITY PLOT : Ronsard 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Ronsard 1



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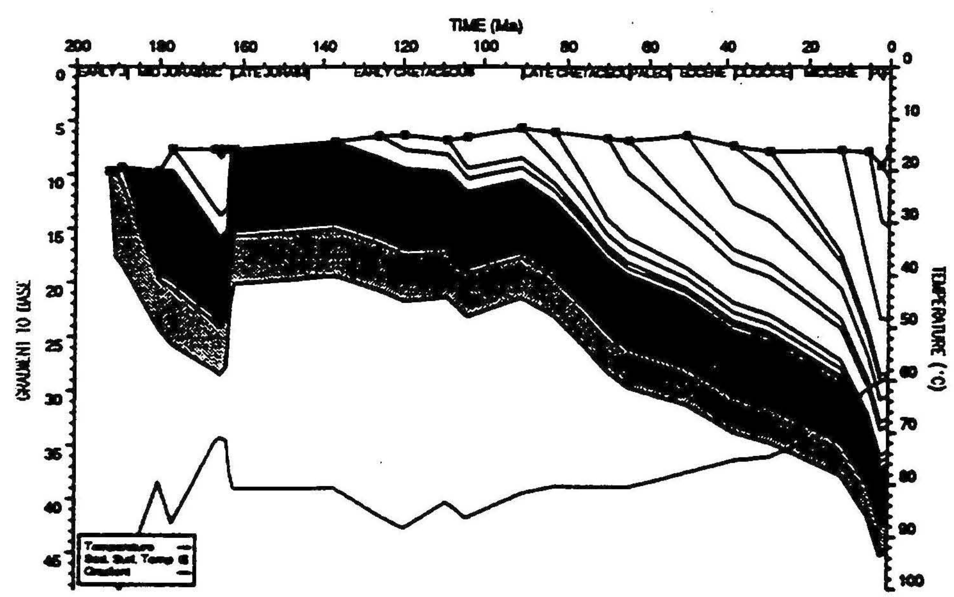

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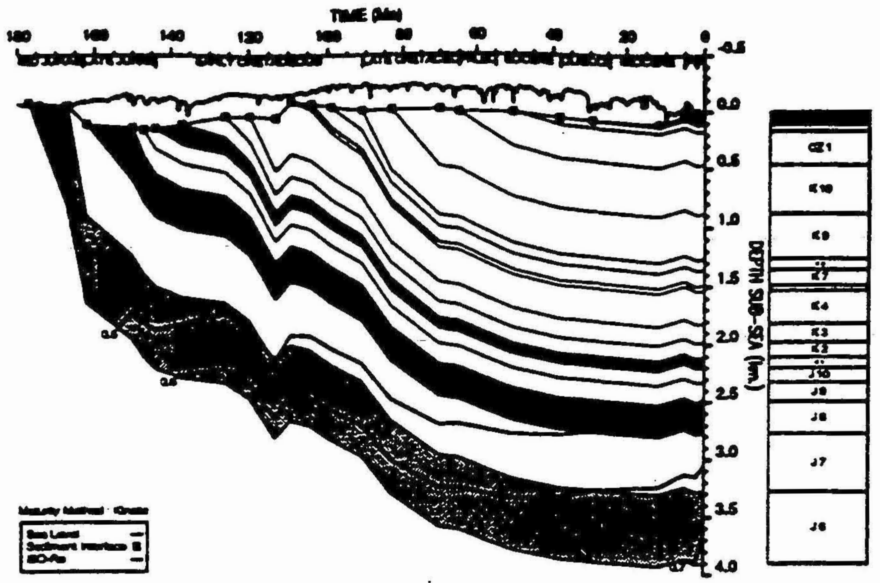
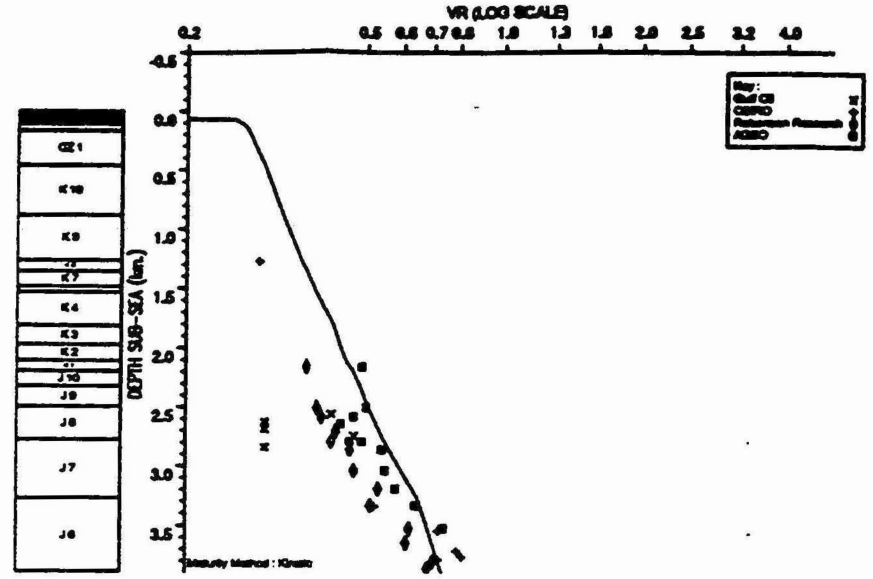
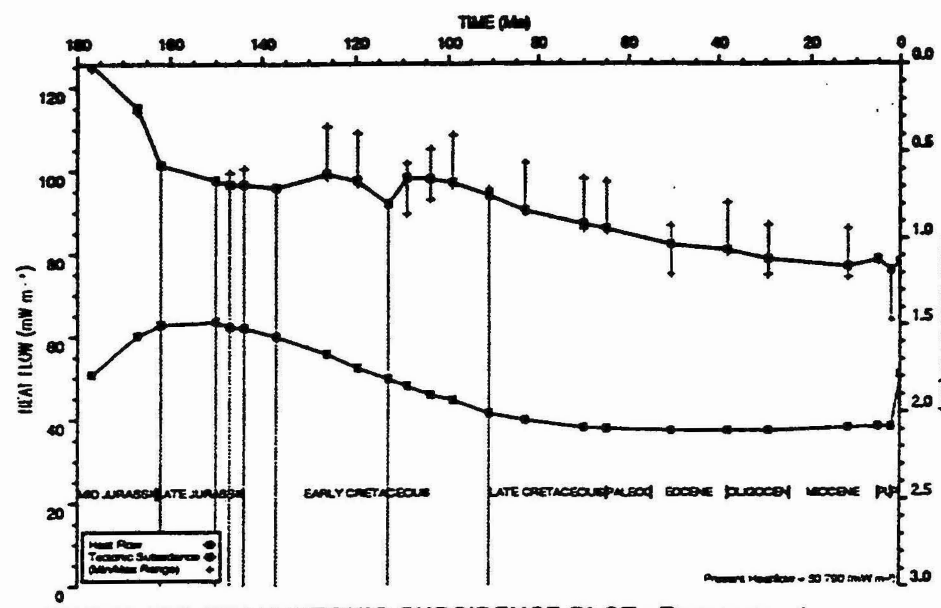


GEOHISTORY PLOT : Rosemary 1



OBSERVED vs COMPUTED MATURITY PLOT : Rosemary 1



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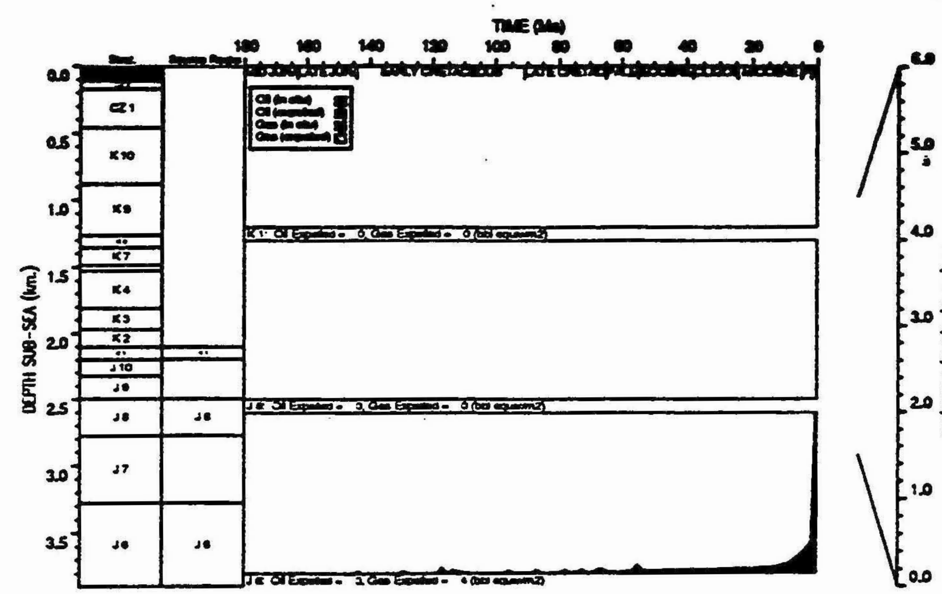

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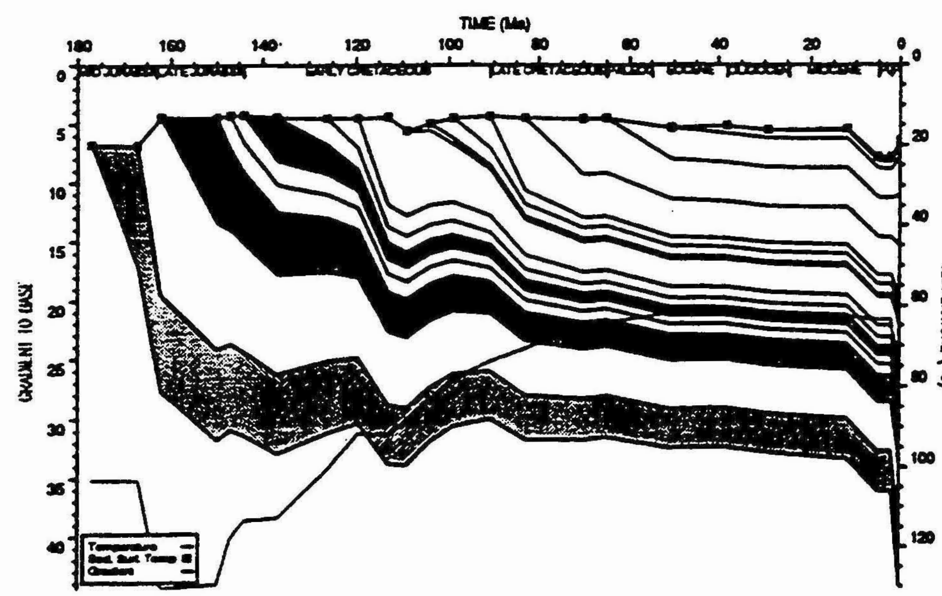

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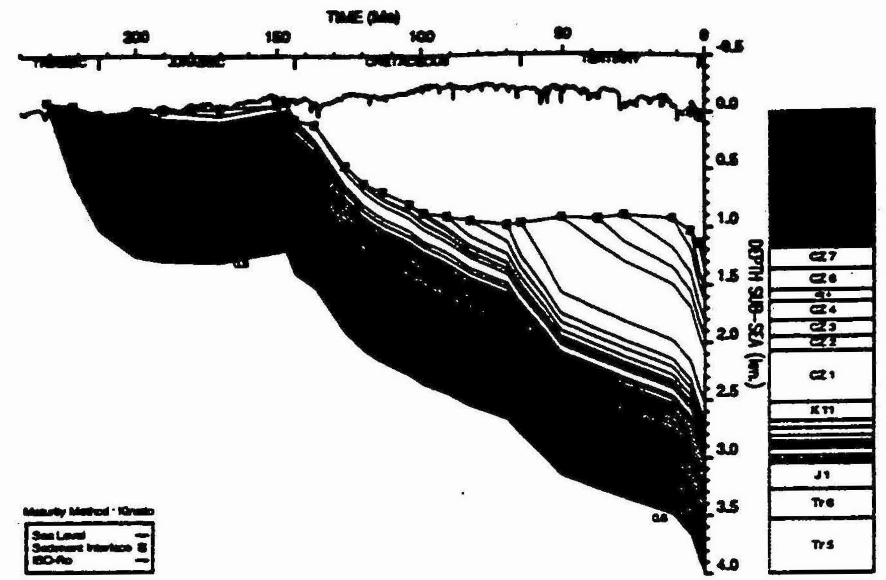
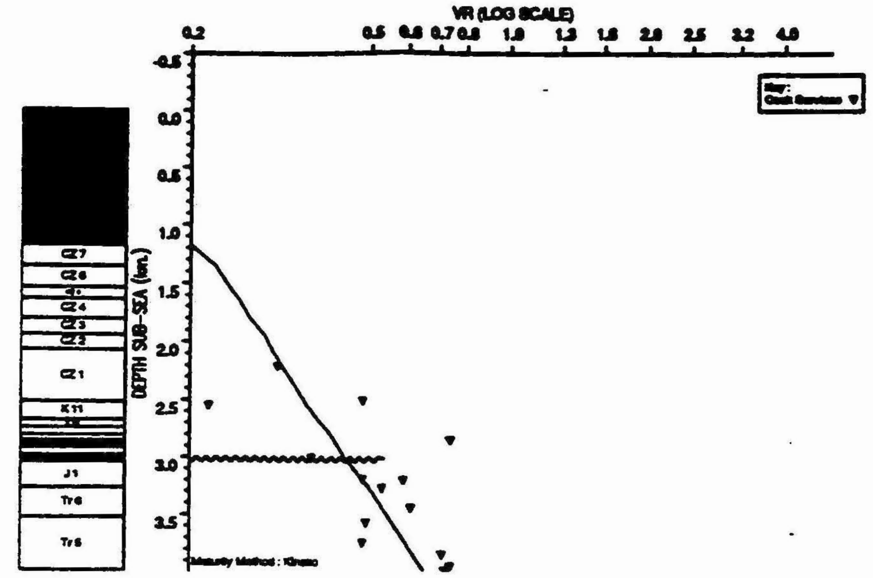
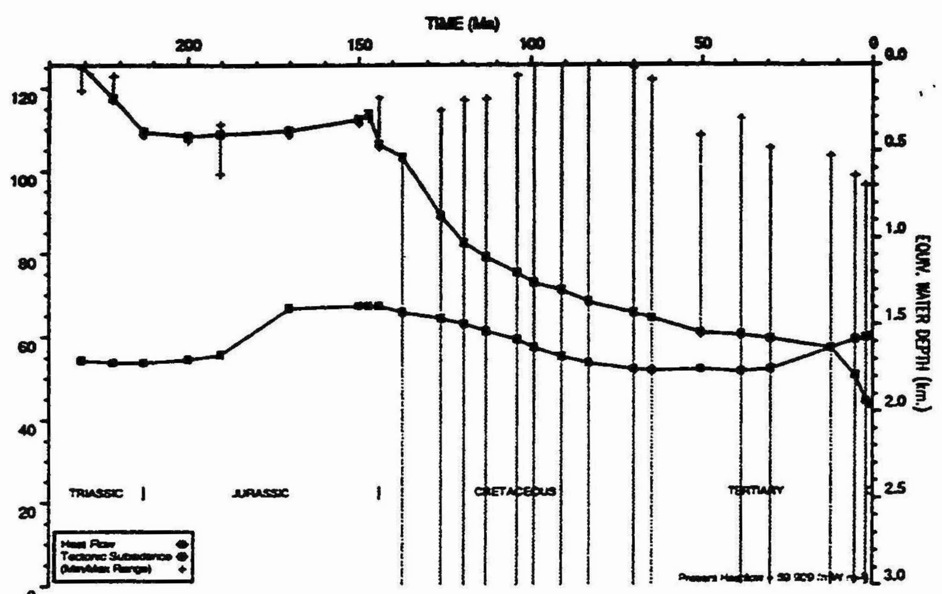


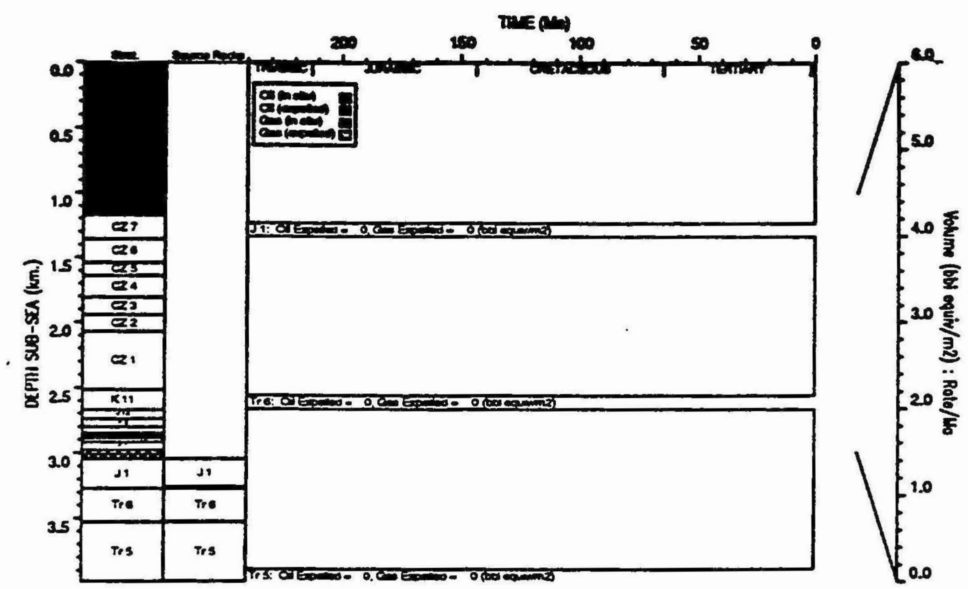
GEOHISTORY PLOT : Saturn 1



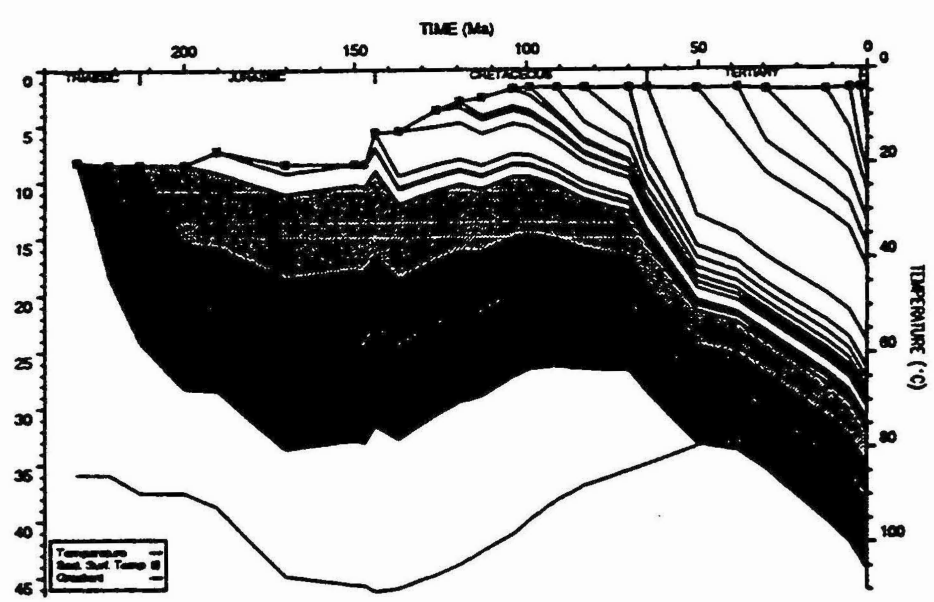
OBSERVED vs COMPUTED MATURITY PLOT : Saturn 1



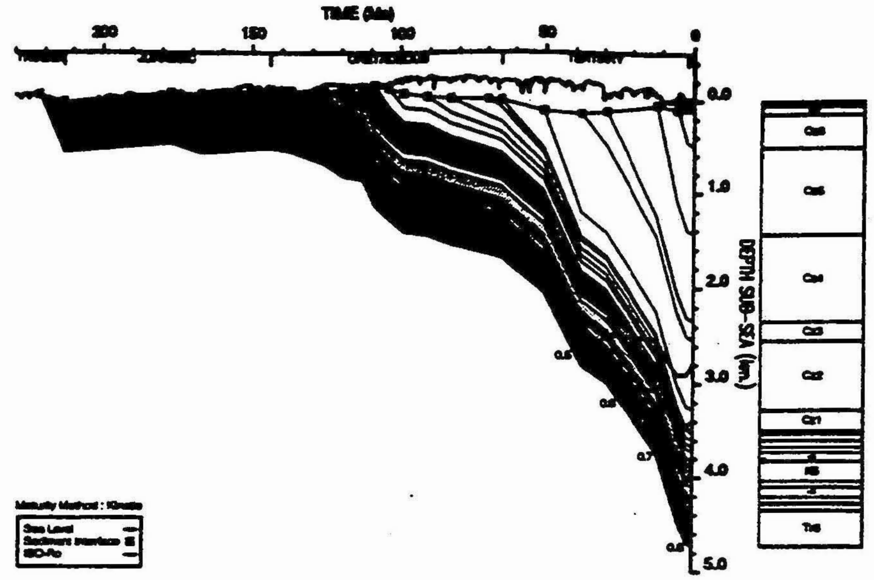
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Saturn 1



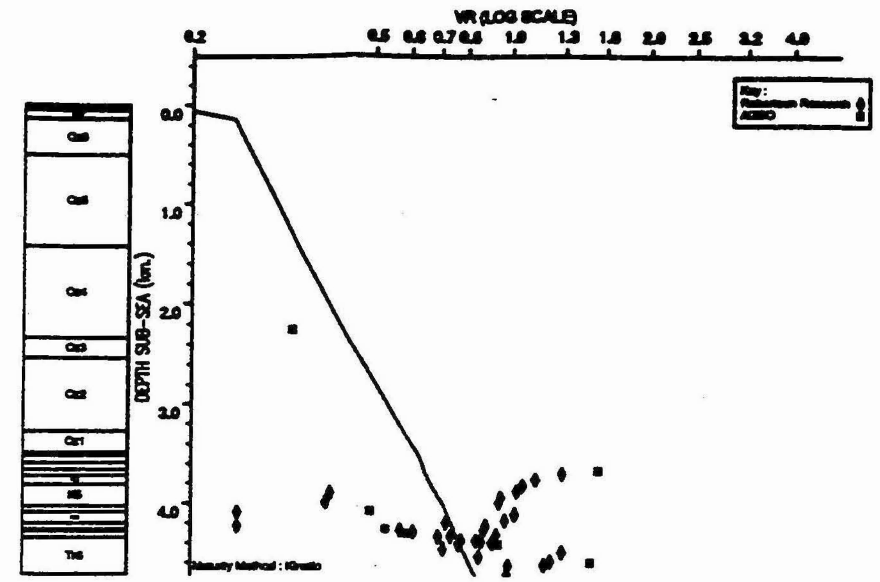
HYDROCARBON GENERATION PLOT : Saturn 1



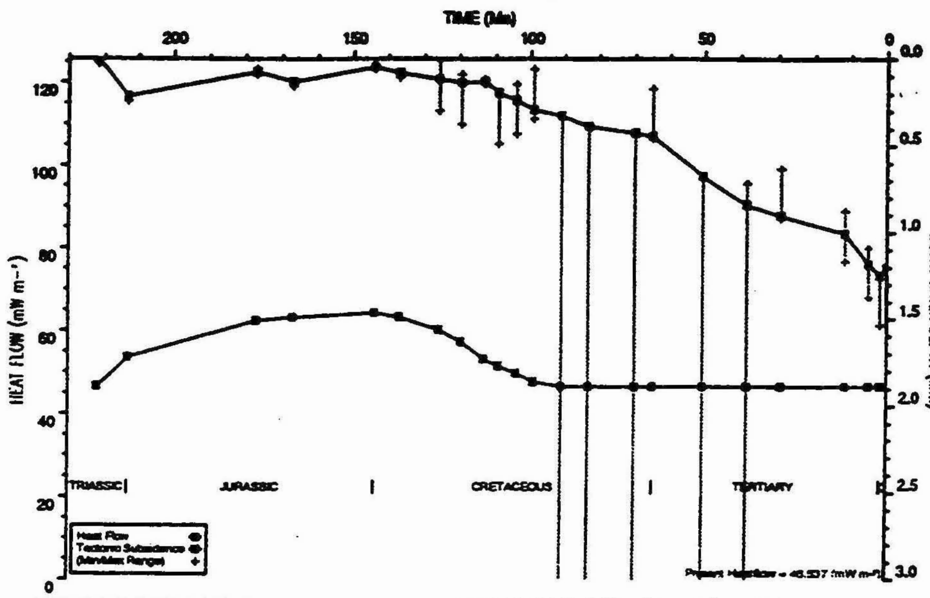
BED TEMPERATURE PLOT : Saturn 1



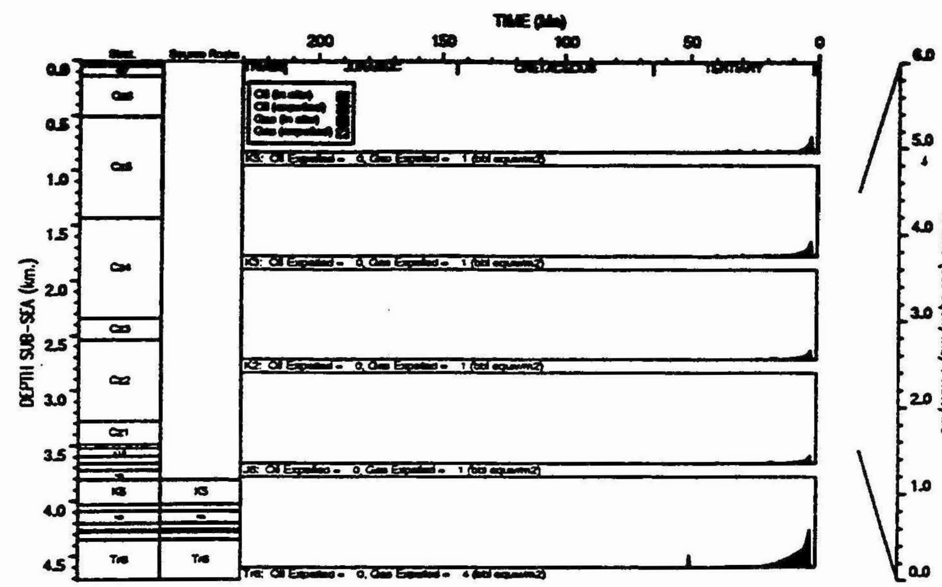
GEOHISTORY PLOT : Scott Reef 1



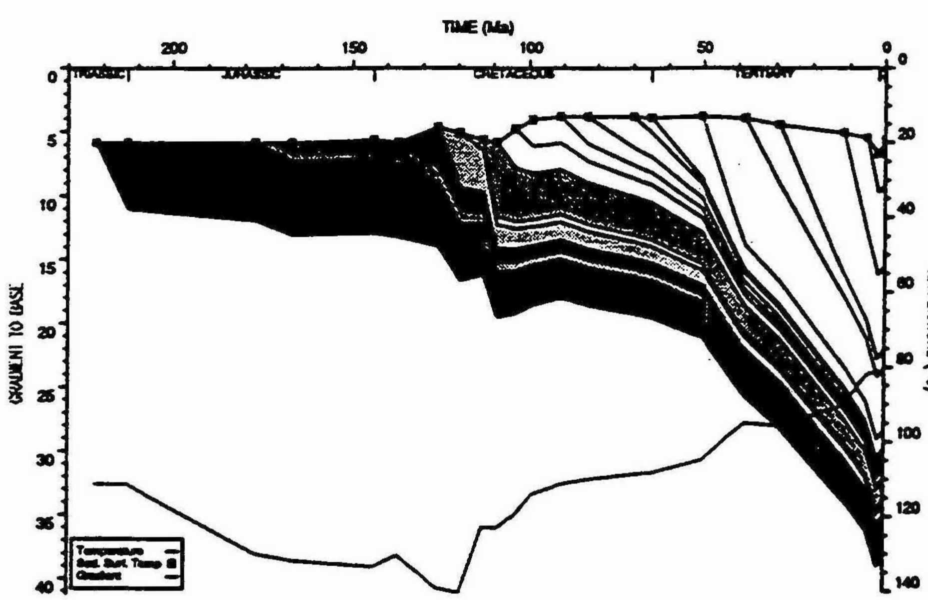
OBSERVED vs COMPUTED MATURITY PLOT : Scott Reef 1



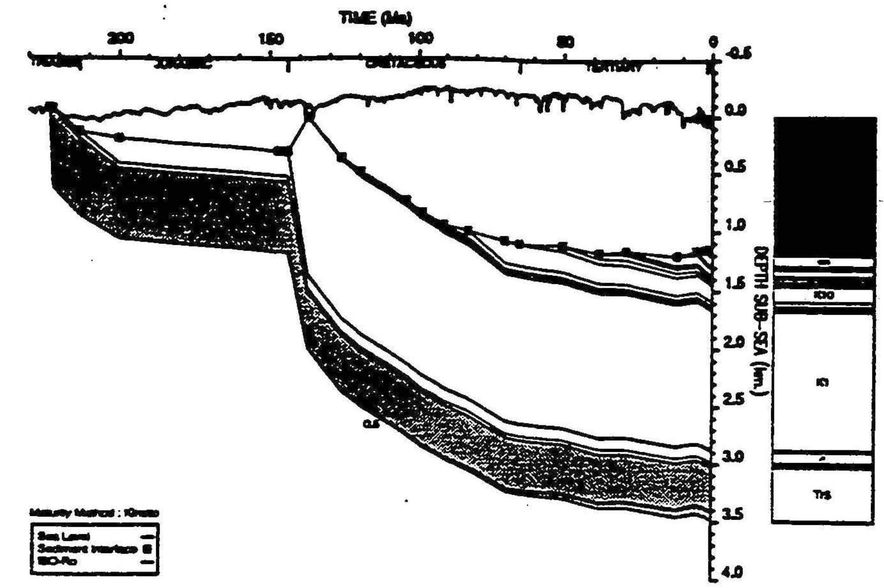
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Scott Reef 1



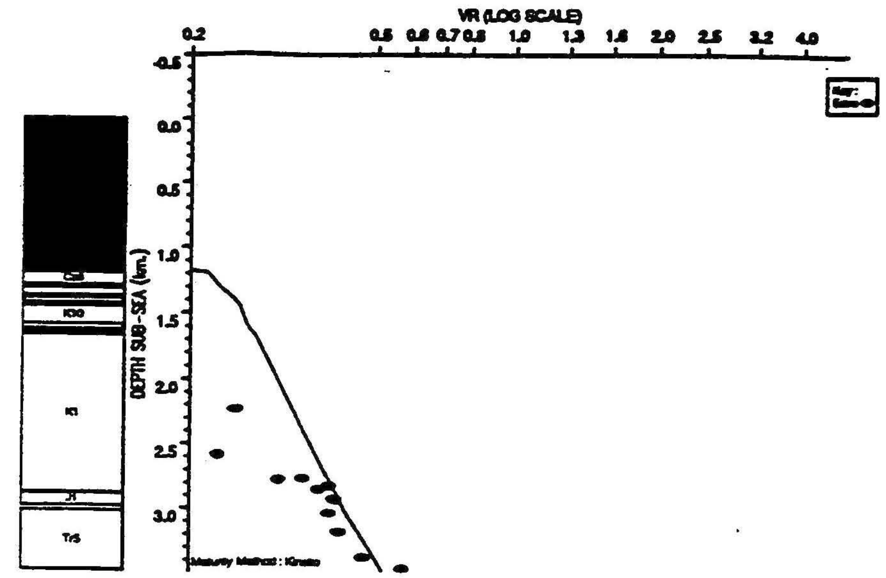
HYDROCARBON GENERATION PLOT : Scott Reef 1



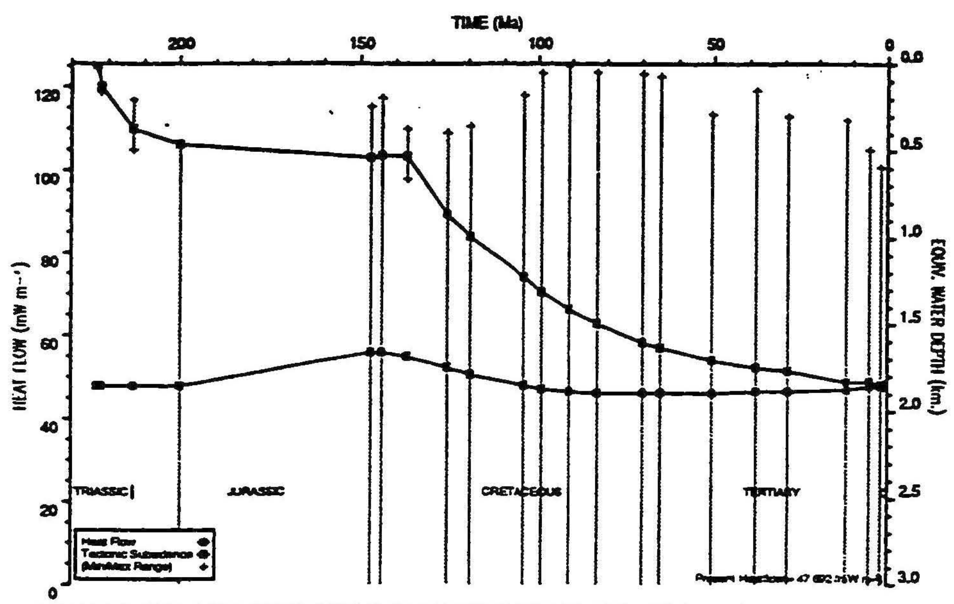
BED TEMPERATURE PLOT : Scott Reef 1



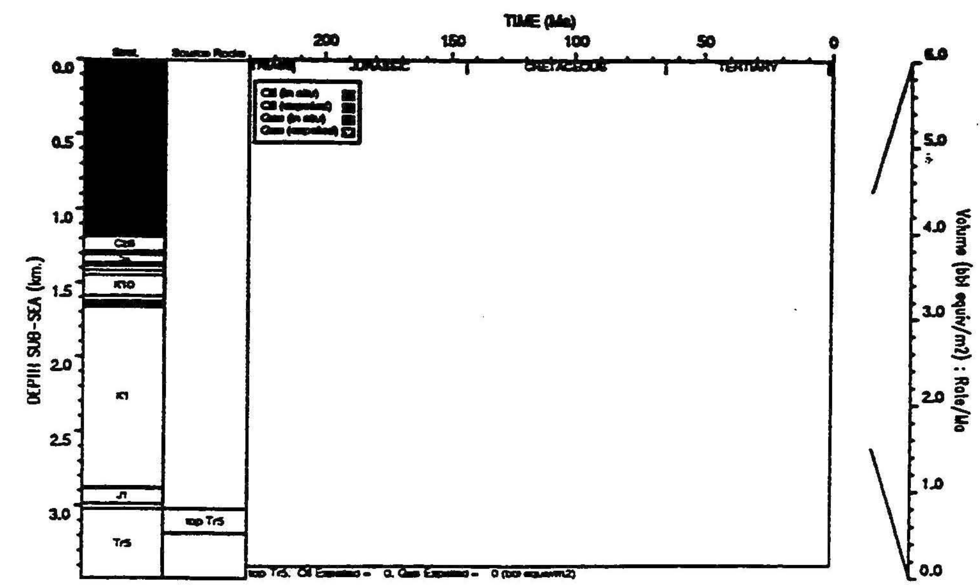
GEOHISTORY PLOT : Sirius 1



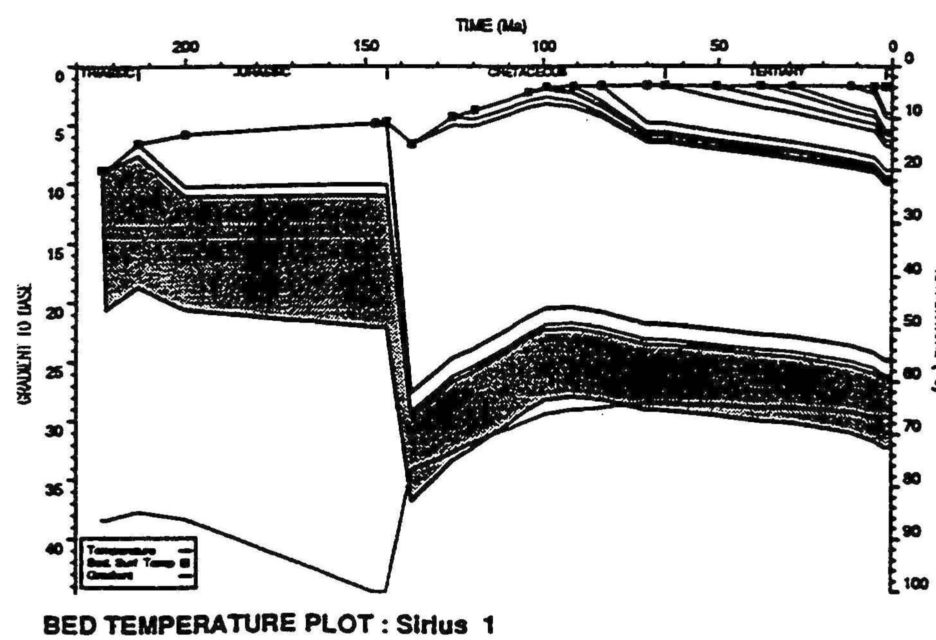
OBSERVED vs COMPUTED MATURITY PLOT : Sirius 1



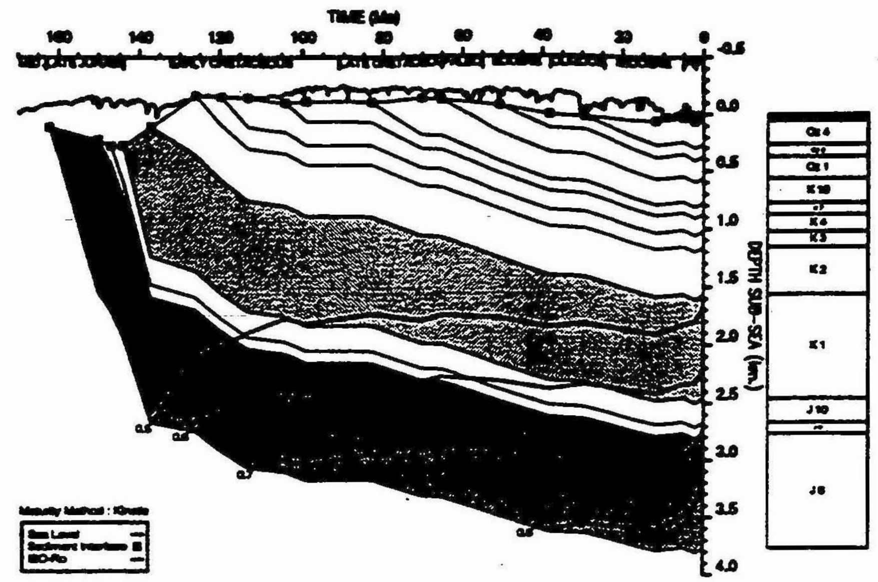
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Sirius 1



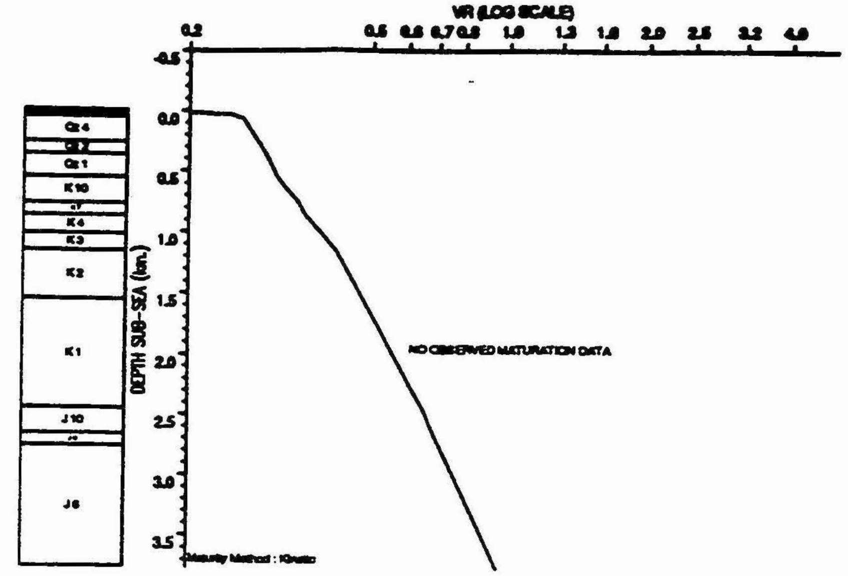
HYDROCARBON GENERATION PLOT : Sirius 1



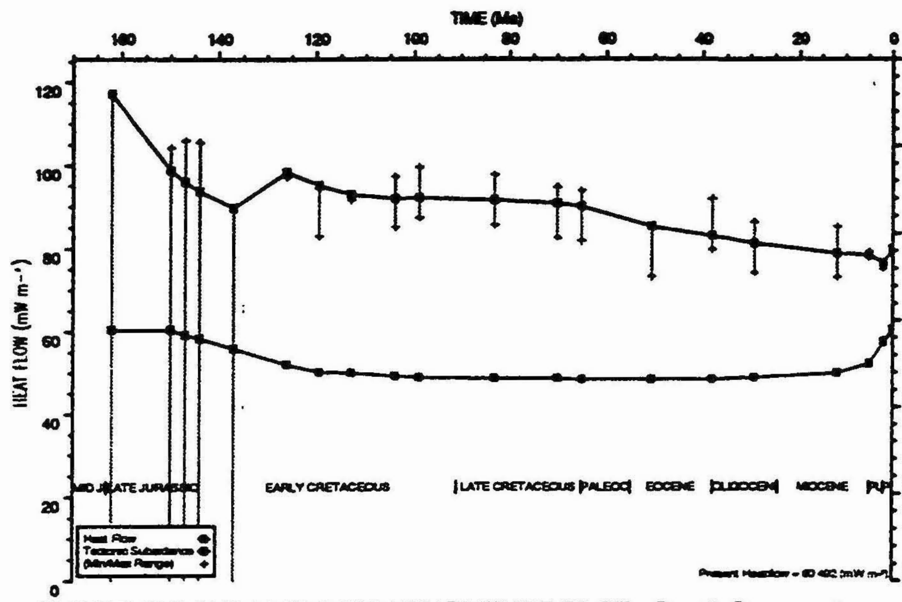
BED TEMPERATURE PLOT : Sirius 1



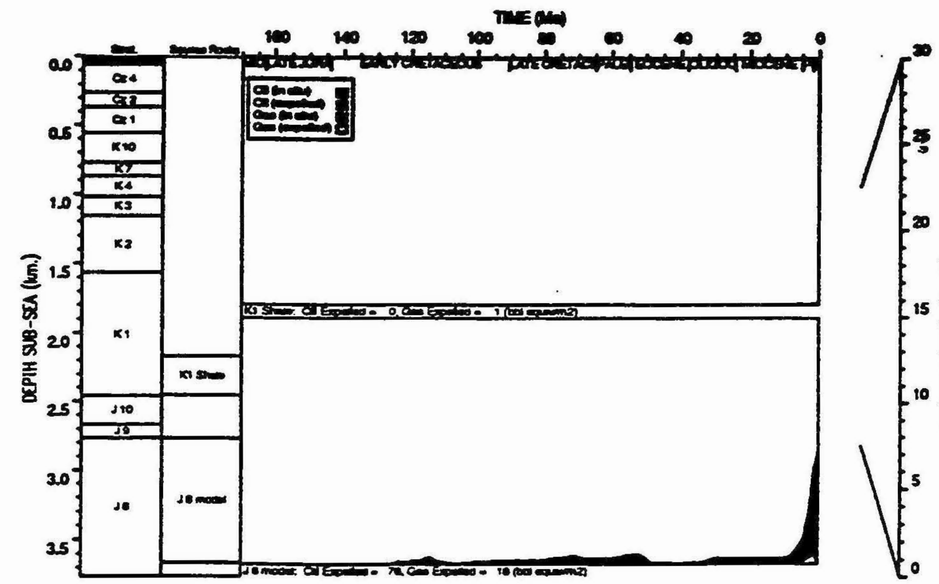
GEOHISTORY PLOT : South Pepper 1



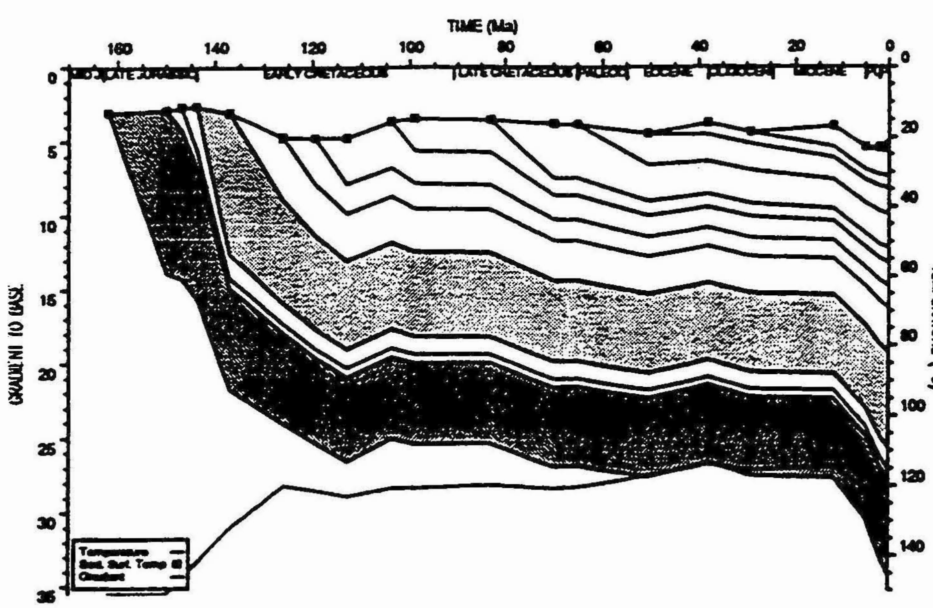
OBSERVED vs COMPUTED MATURITY PLOT : South Pepper 1



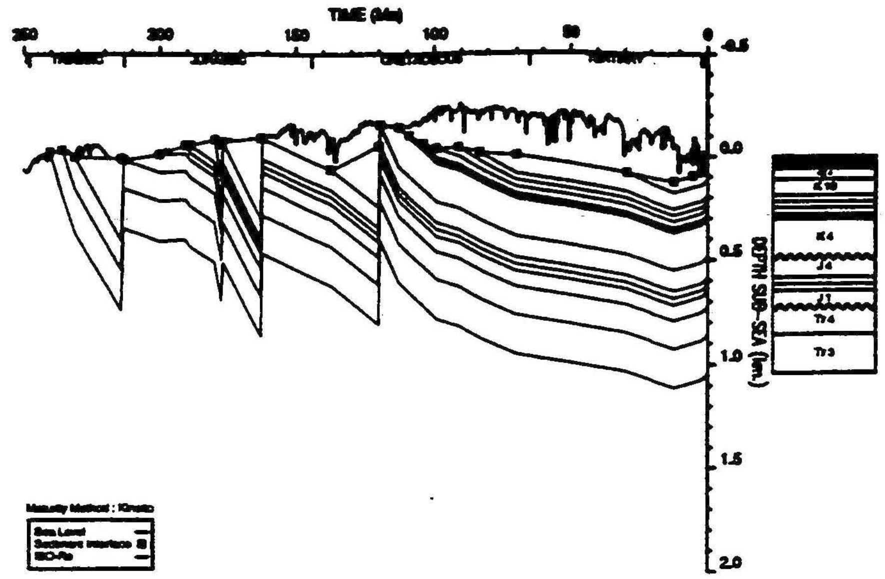
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : South Pepper 1



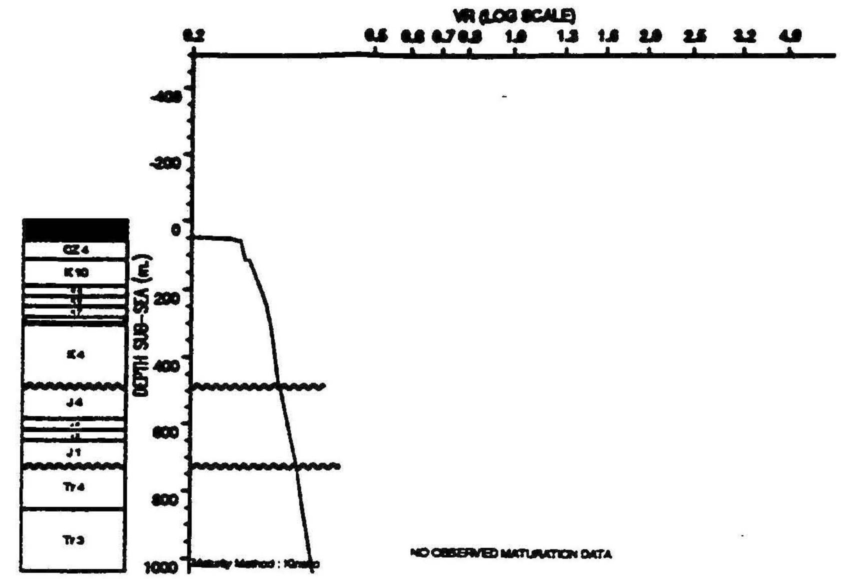
HYDROCARBON GENERATION PLOT : South Pepper 1



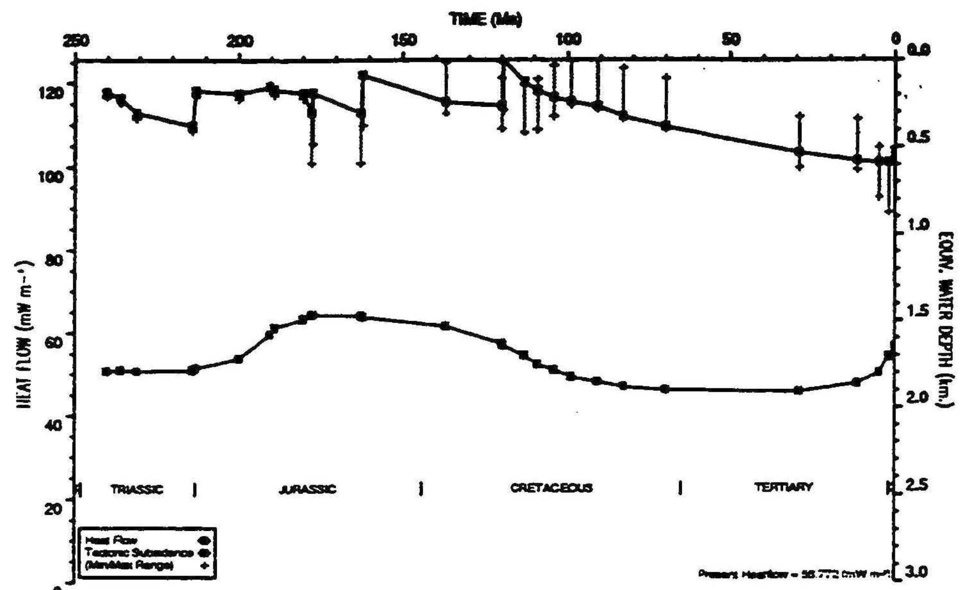
BED TEMPERATURE PLOT : South Pepper 1



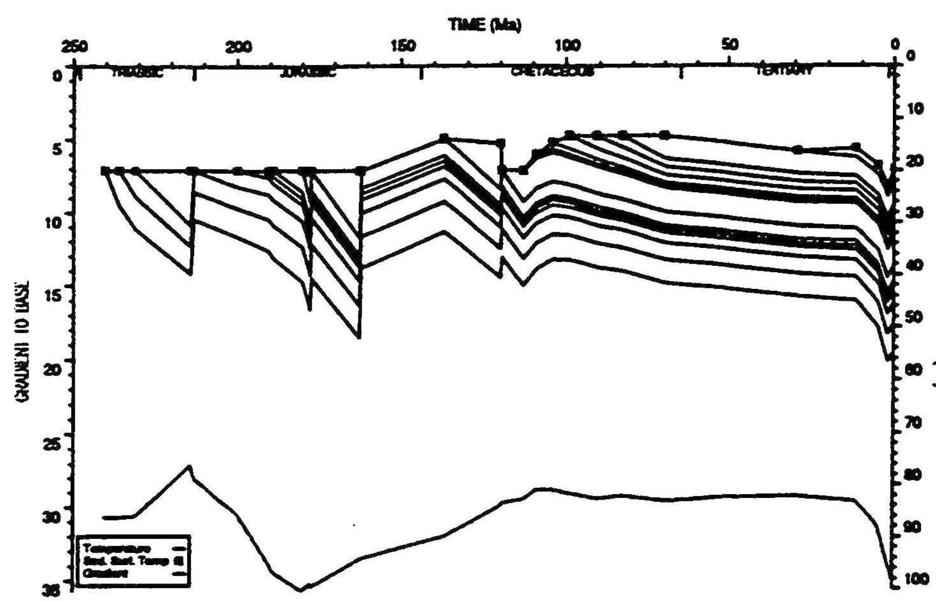
GEOHISTORY PLOT : Strickland 1



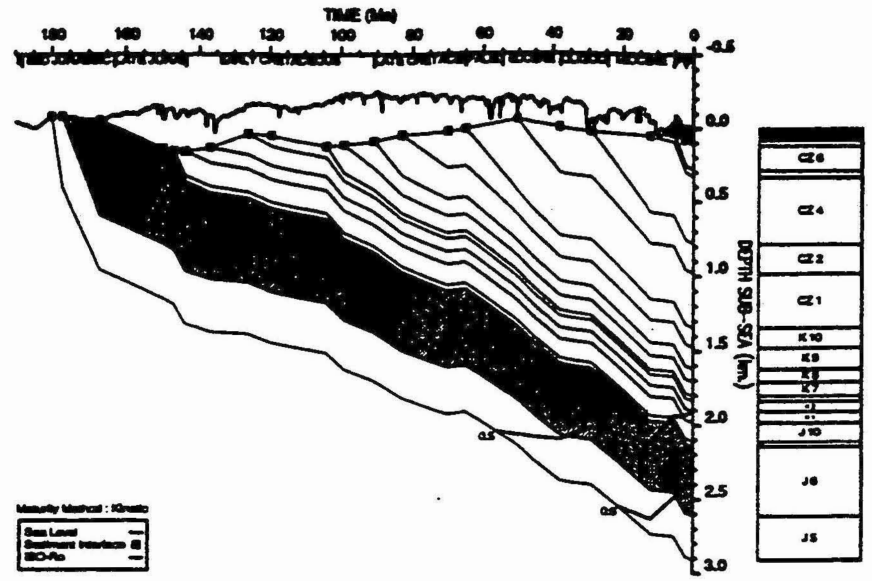
OBSERVED vs COMPUTED MATURITY PLOT : Strickland 1



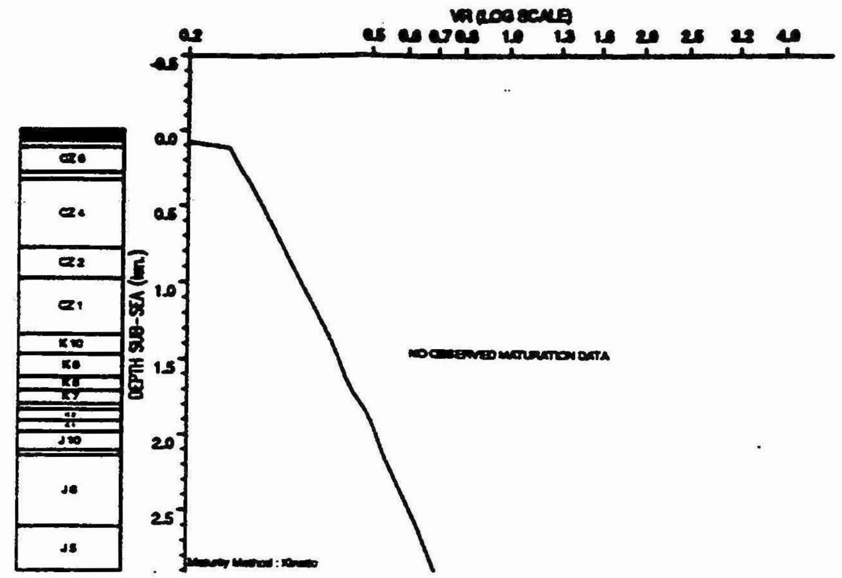
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Strickland 1



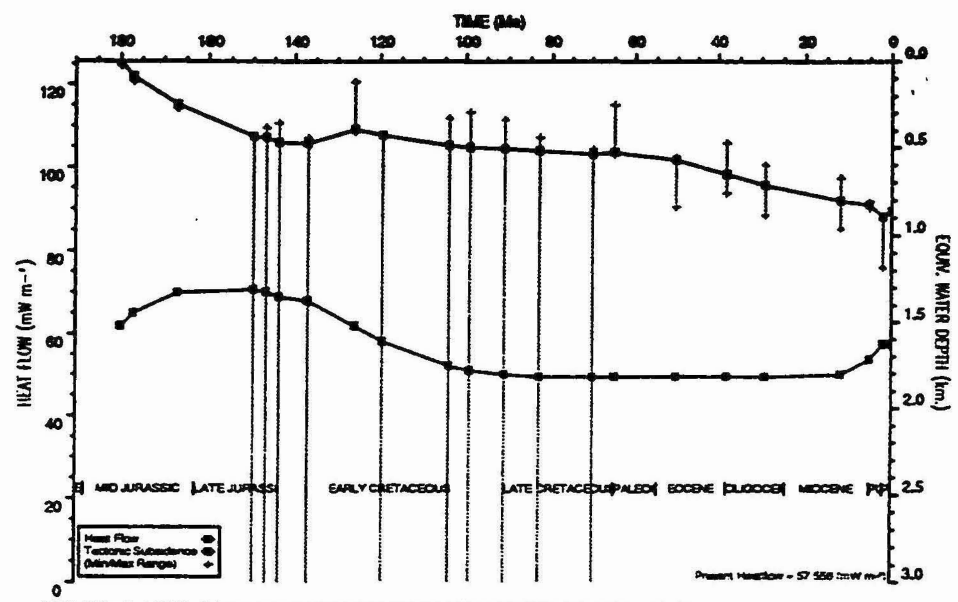
BED TEMPERATURE PLOT : Strickland 1



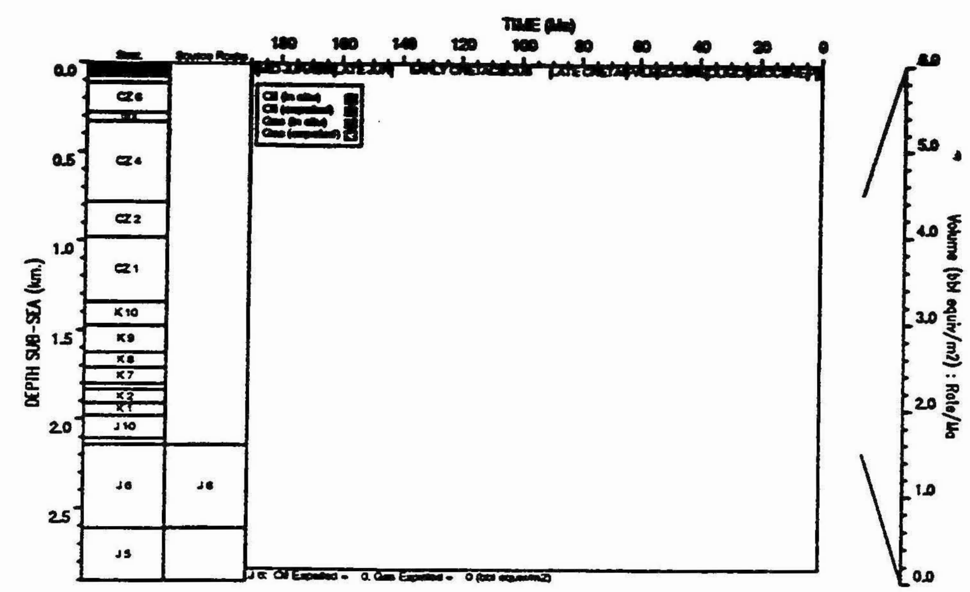
GEOHISTORY PLOT : Talisman 1



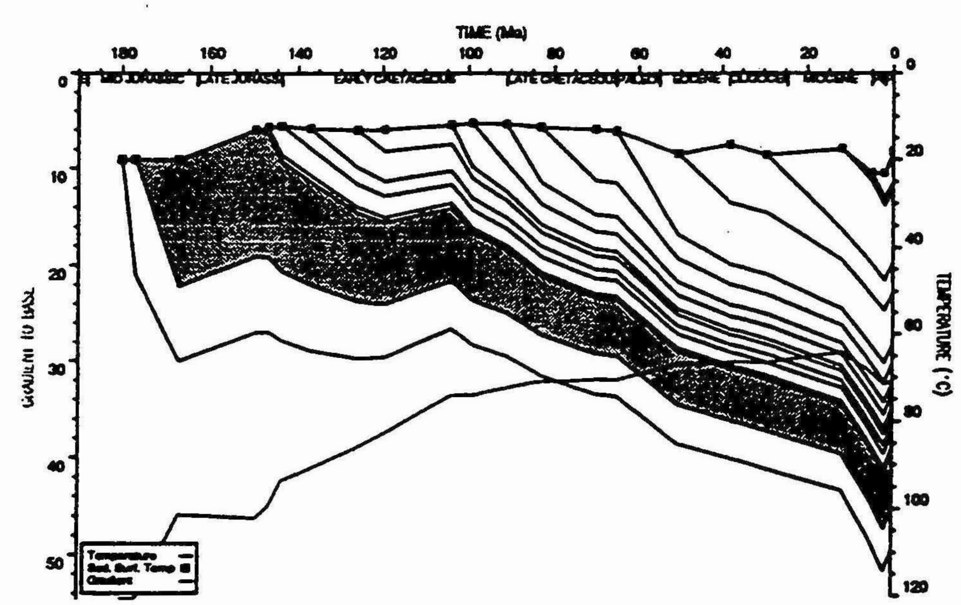
OBSERVED vs COMPUTED MATURITY PLOT : Talisman 1



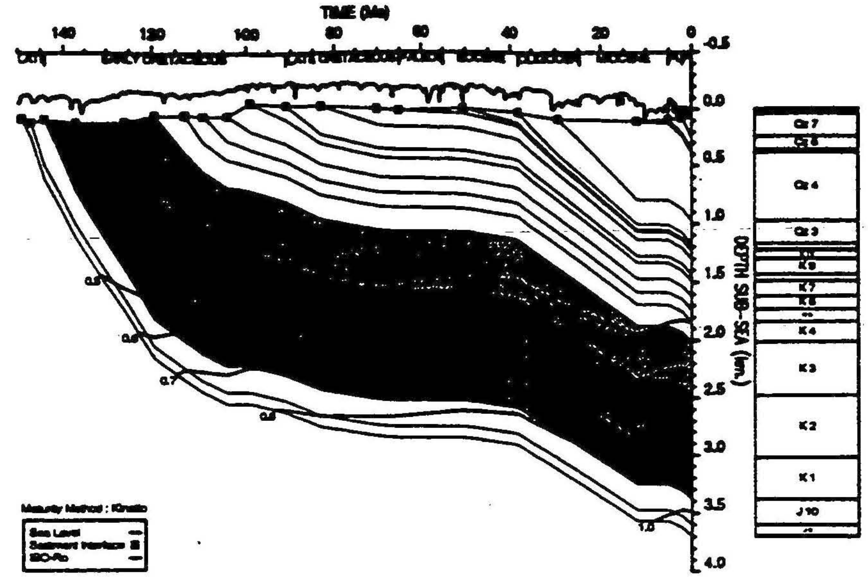
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Talisman 1



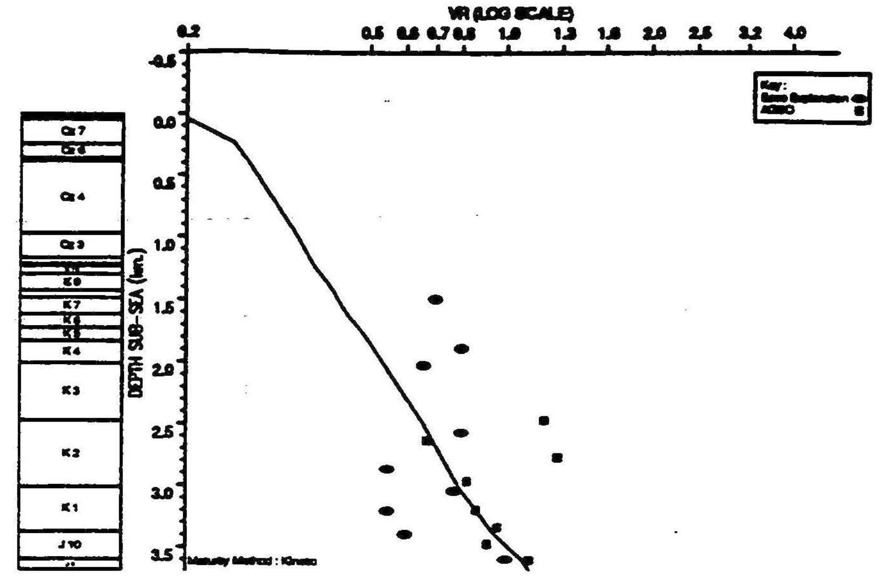
HYDROCARBON GENERATION PLOT : Talisman 1



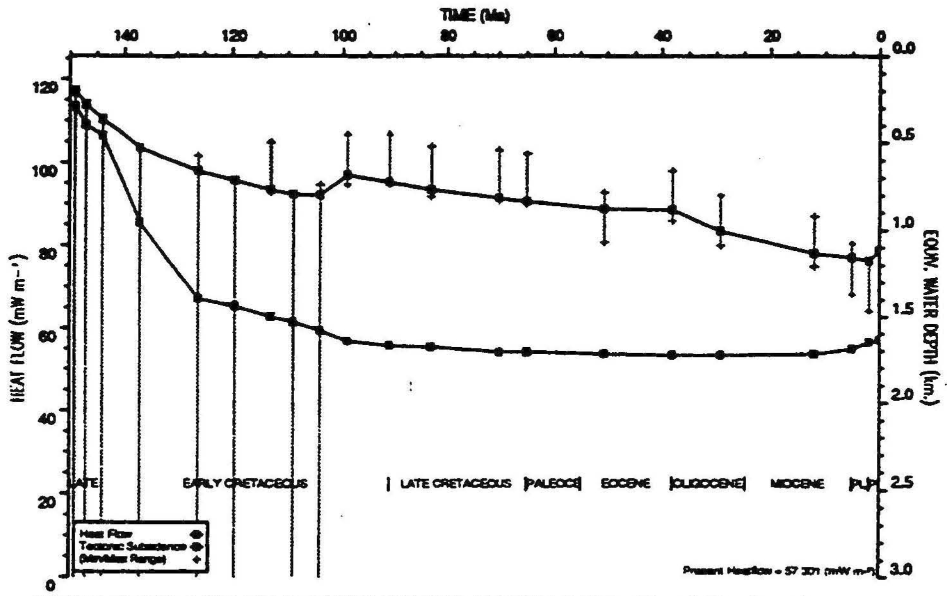
BED TEMPERATURE PLOT : Talisman 1



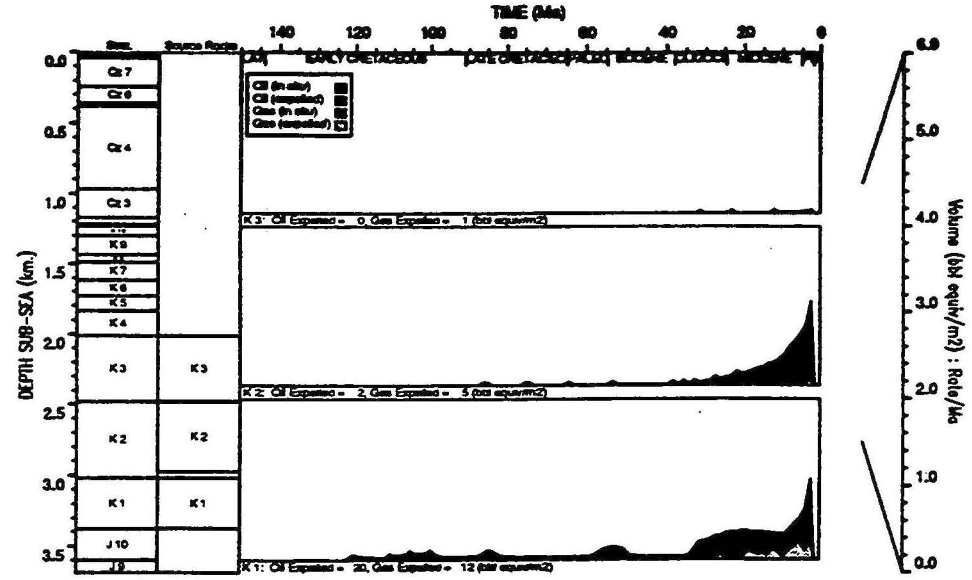
GEOHISTORY PLOT : Tryal Rocks 1



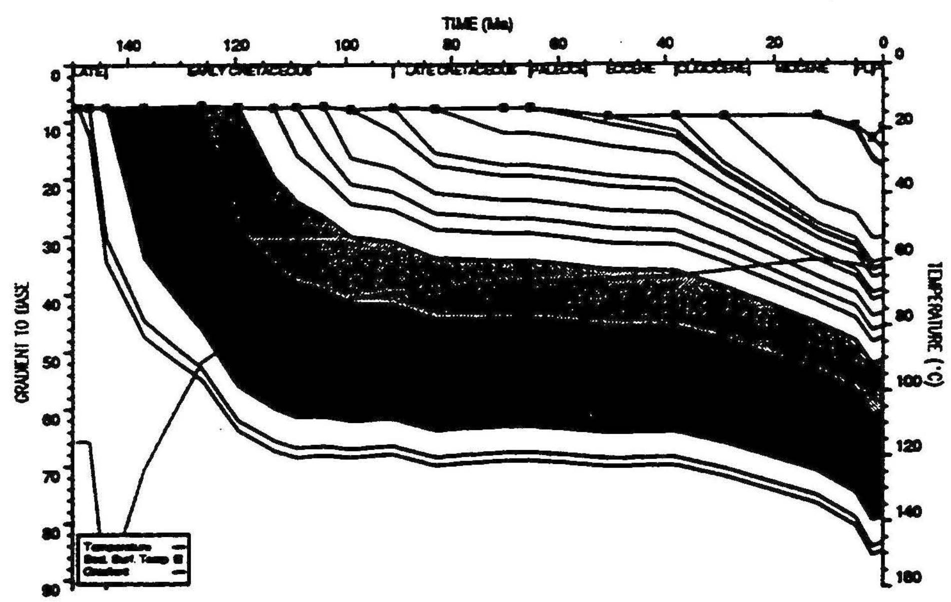
OBSERVED vs COMPUTED MATURITY PLOT : Tryal Rocks 1



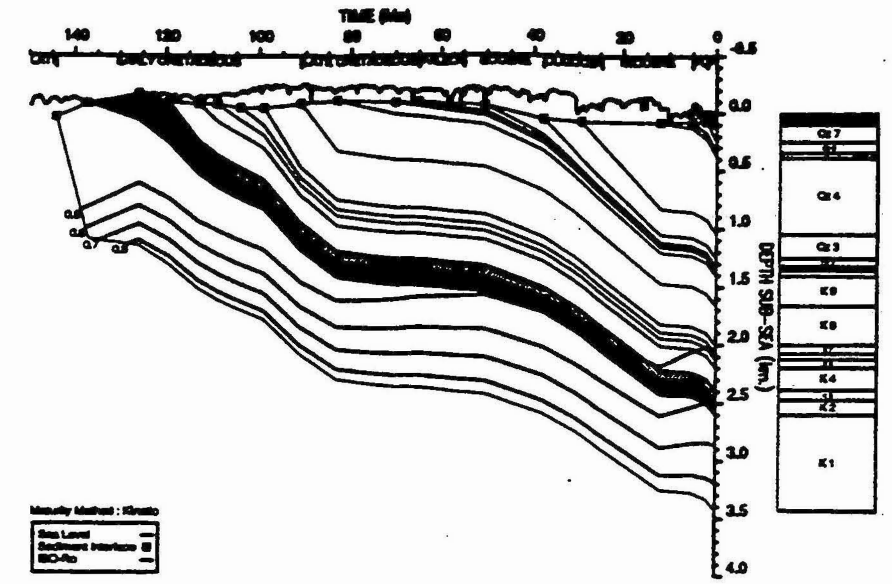
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Tryal Rocks 1



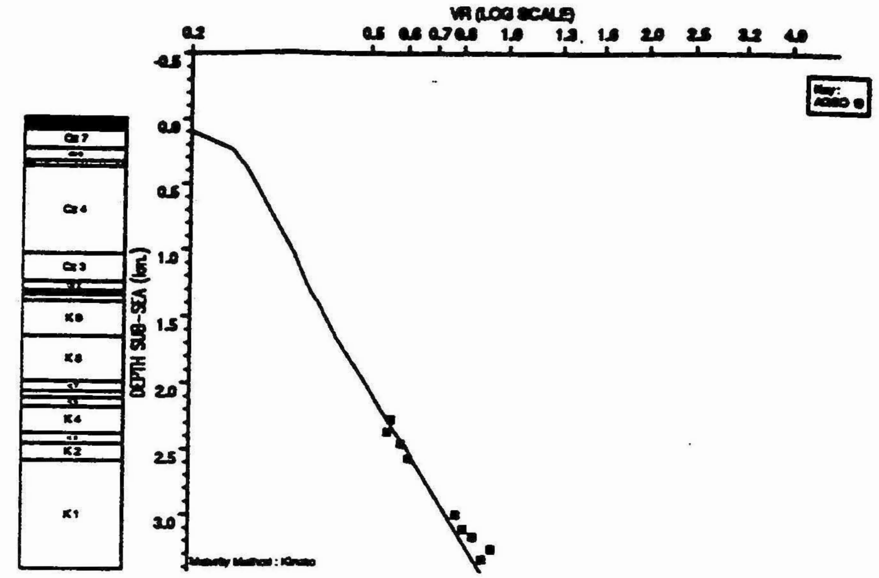
HYDROCARBON GENERATION PLOT : Tryal Rocks 1



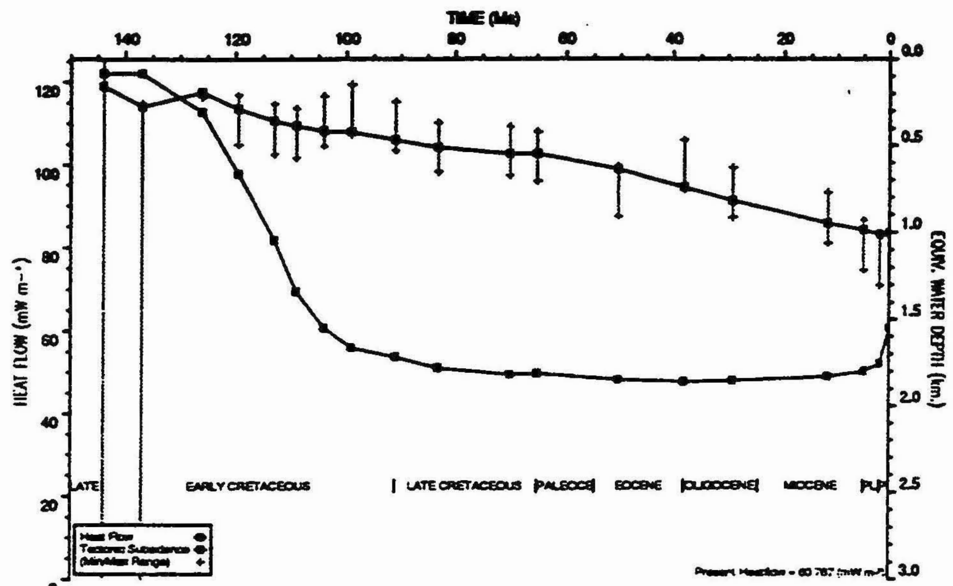
BED TEMPERATURE PLOT : Tryal Rocks 1



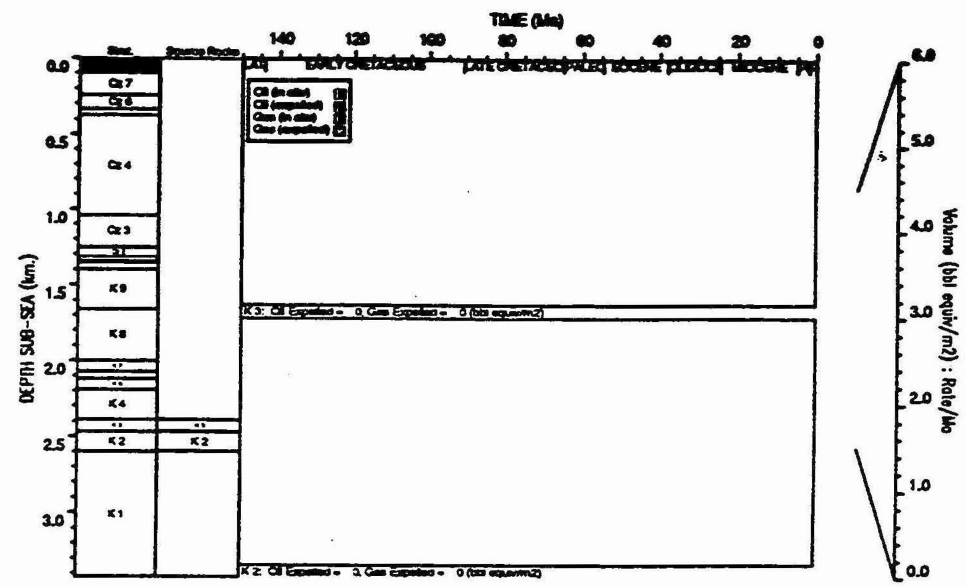
GEOHISTORY PLOT : West Barrow 2



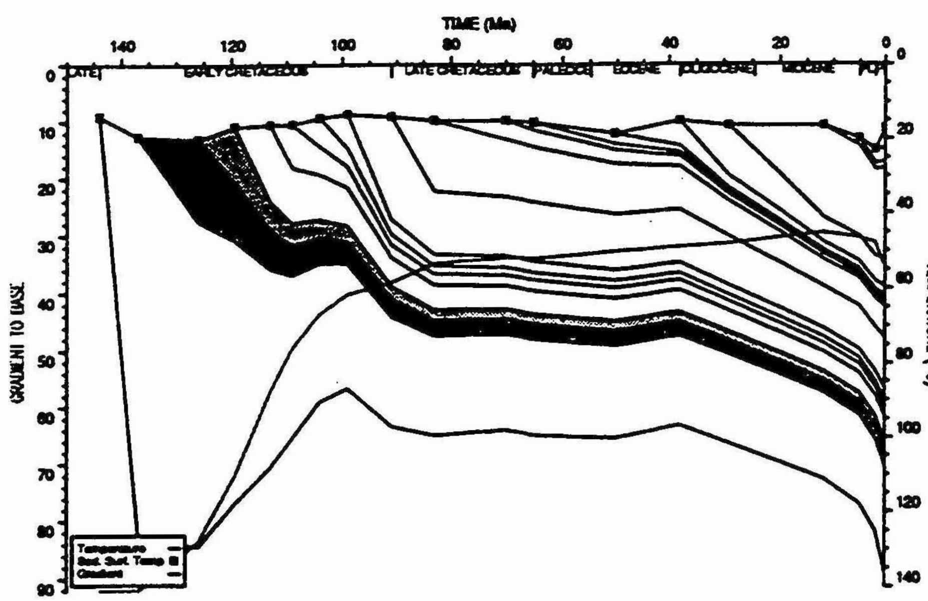
OBSERVED vs COMPUTED MATURITY PLOT : West Barrow 2



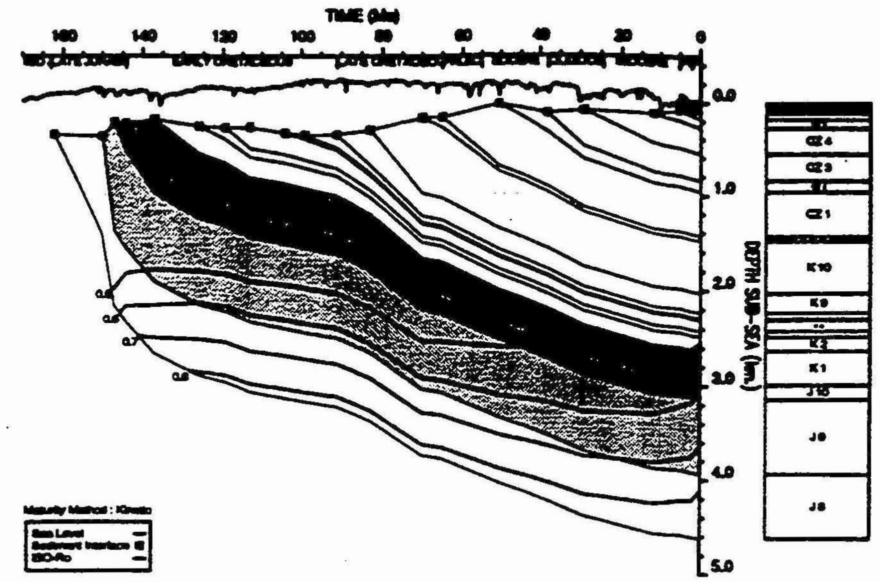
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : West Barrow 2



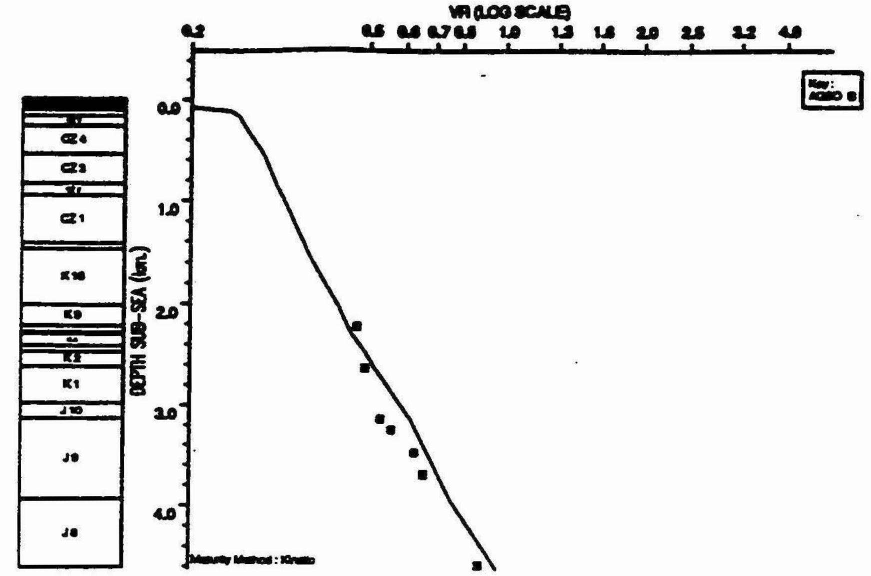
HYDROCARBON GENERATION PLOT : West Barrow 2



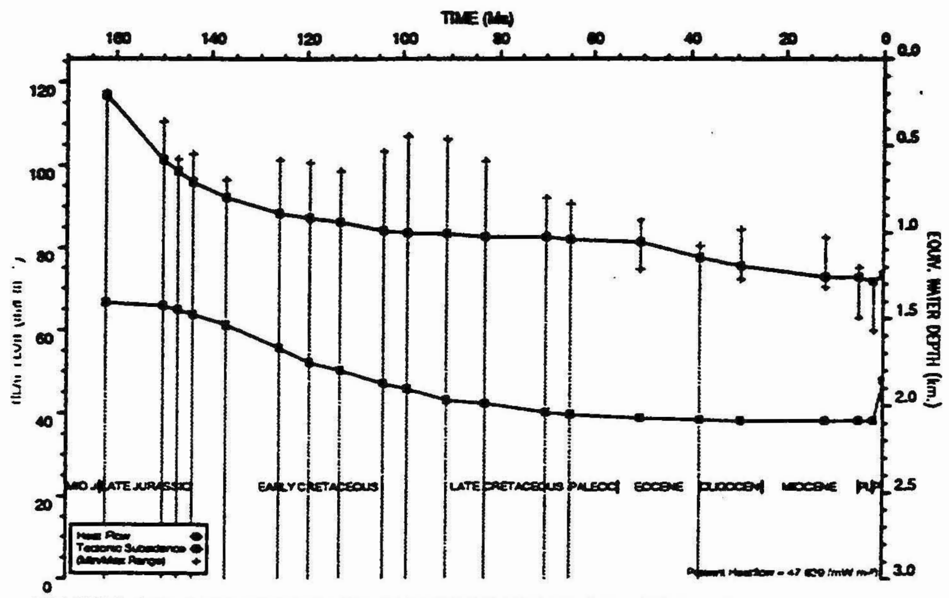
BED TEMPERATURE PLOT : West Barrow 2



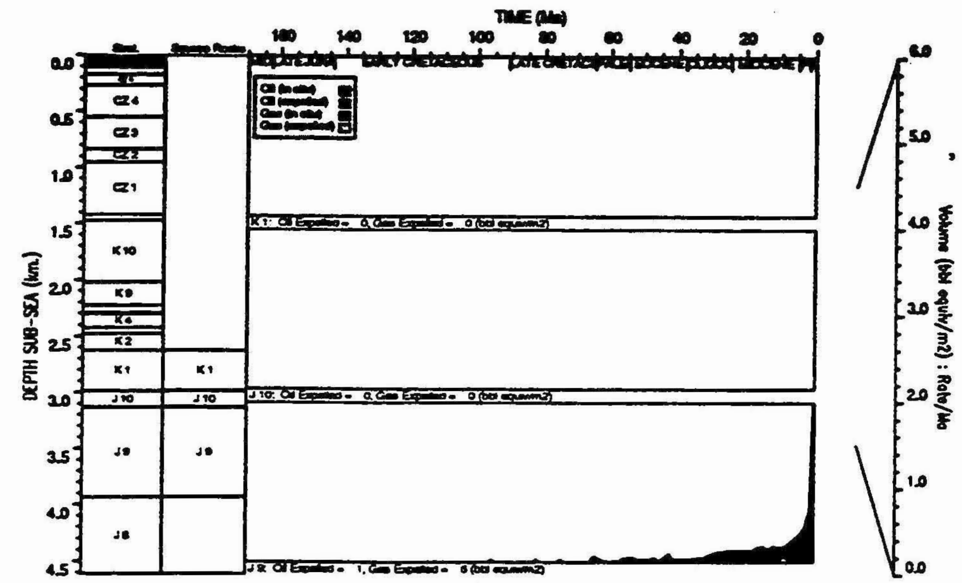
GEOHISTORY PLOT : Withnell 1



OBSERVED vs COMPUTED MATURITY PLOT : Withnell 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Withnell 1



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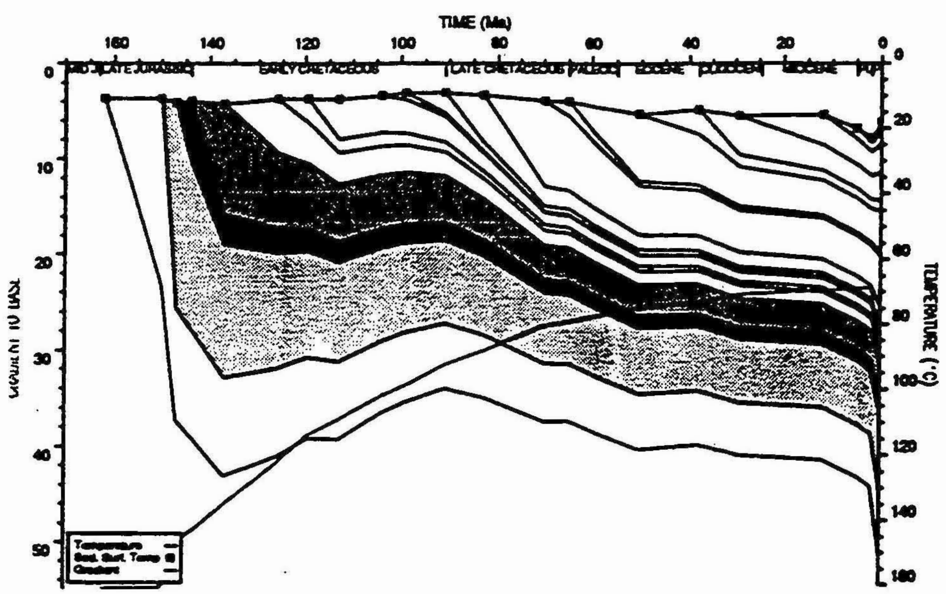

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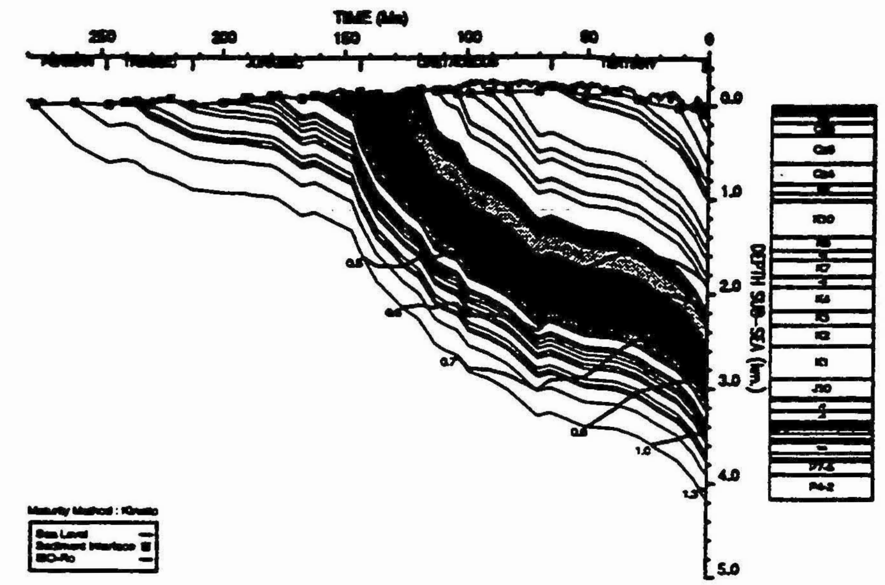
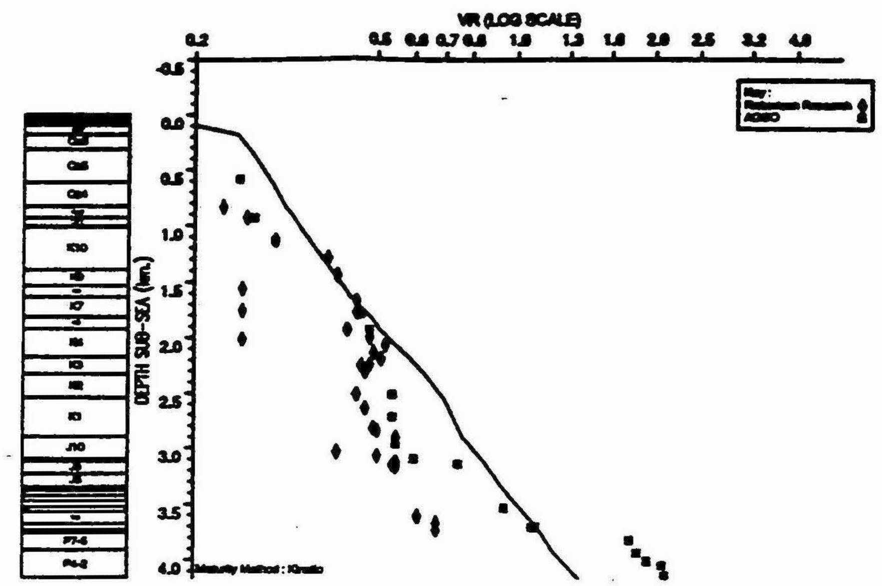
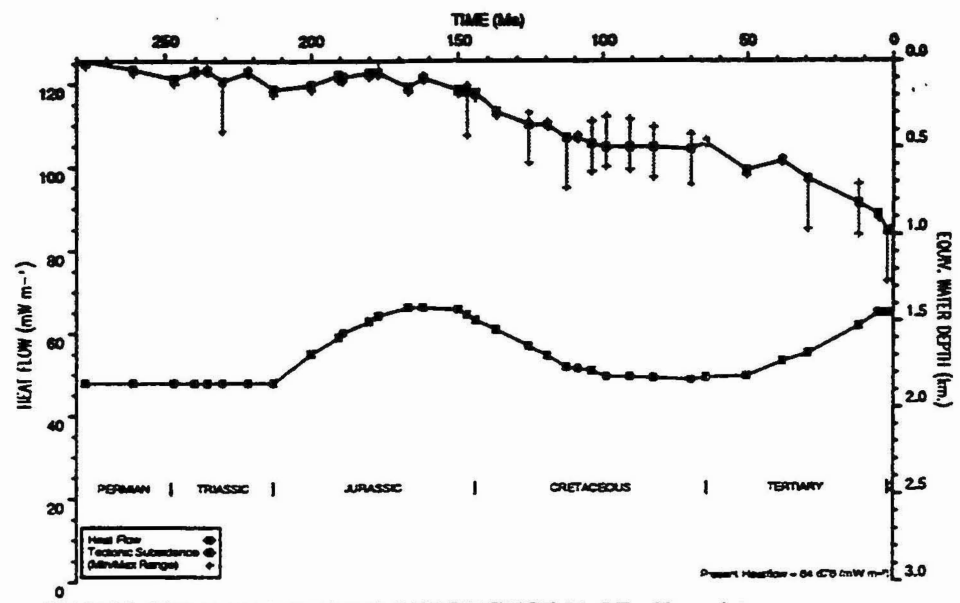


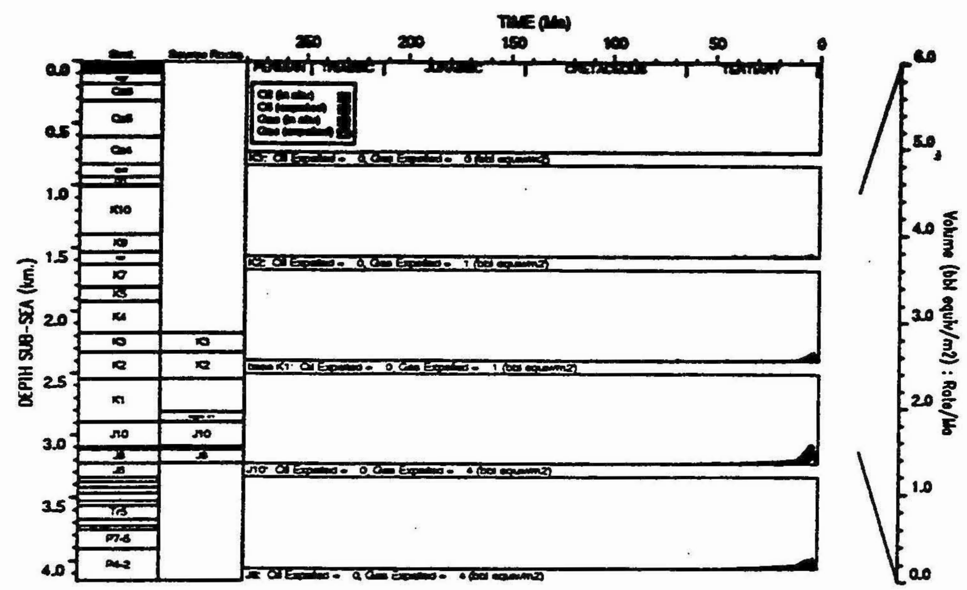
GEOHISTORY PLOT : Yampi 1



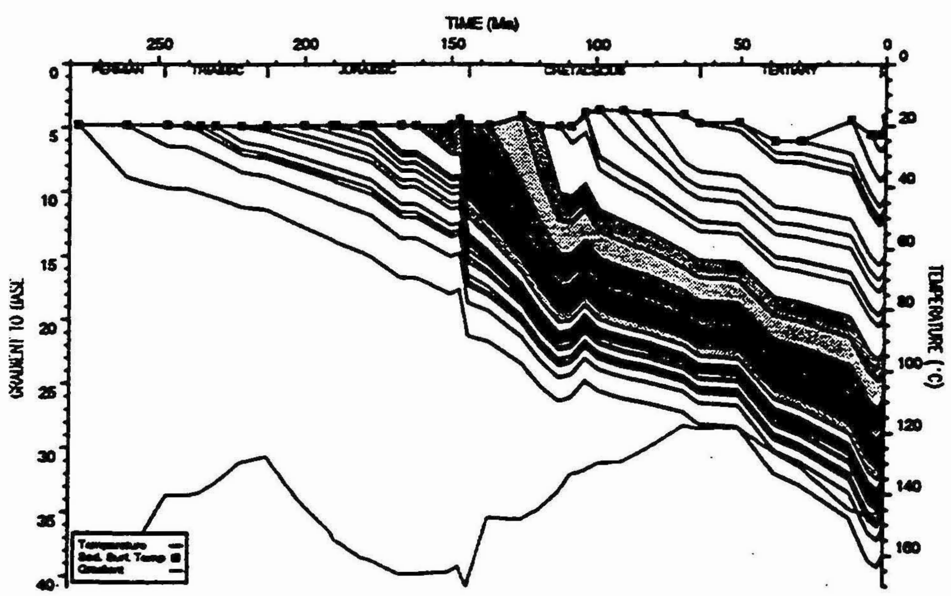
OBSERVED vs COMPUTED MATURITY PLOT : Yampi 1



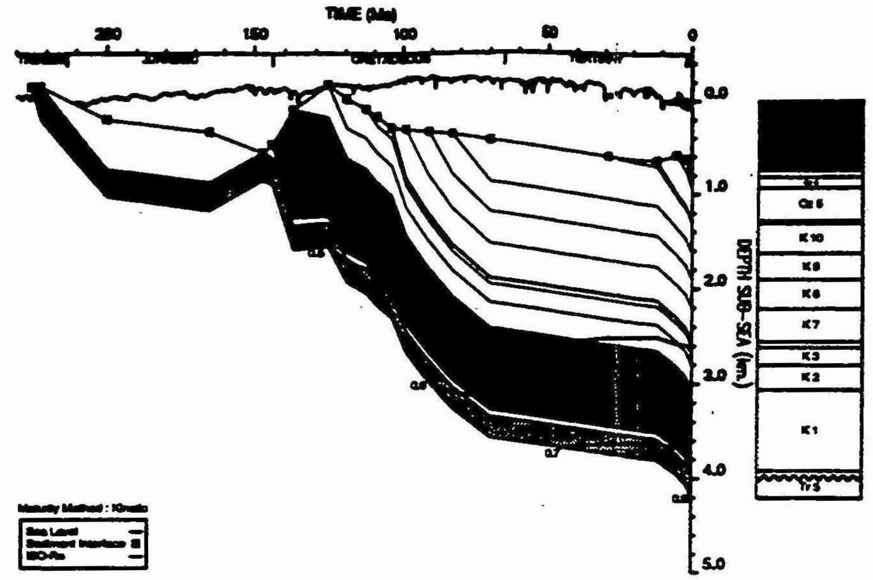
HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Yampi 1



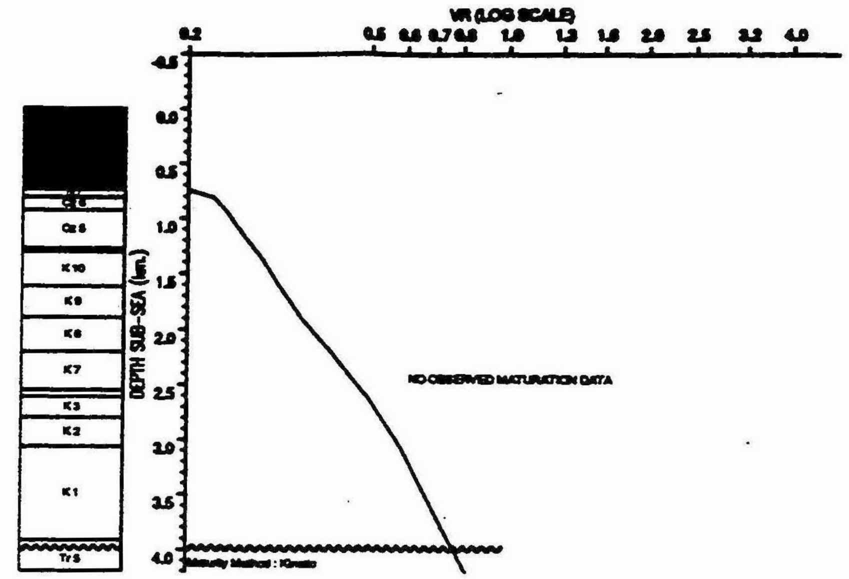
HYDROCARBON GENERATION PLOT : Yampi 1



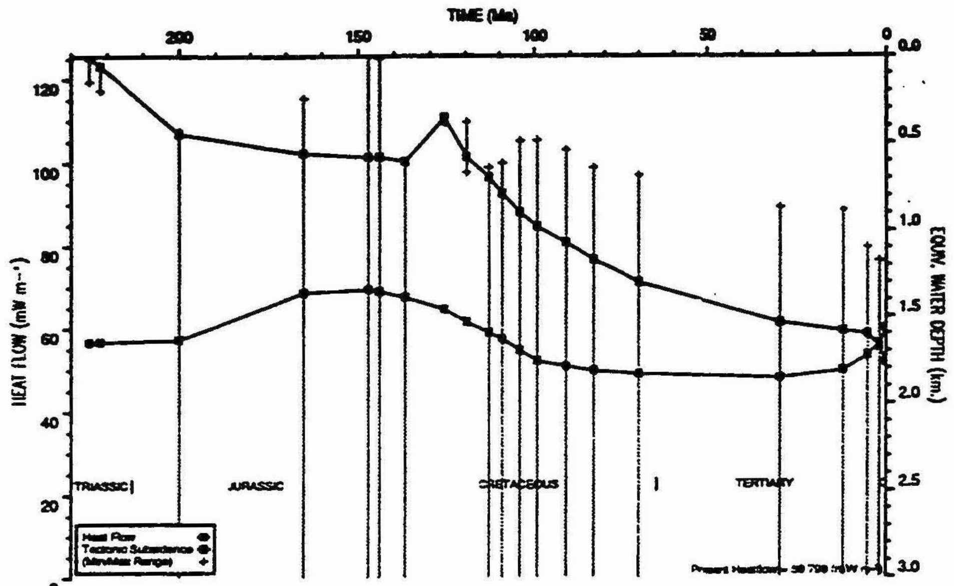
BED TEMPERATURE PLOT : Yampi 1



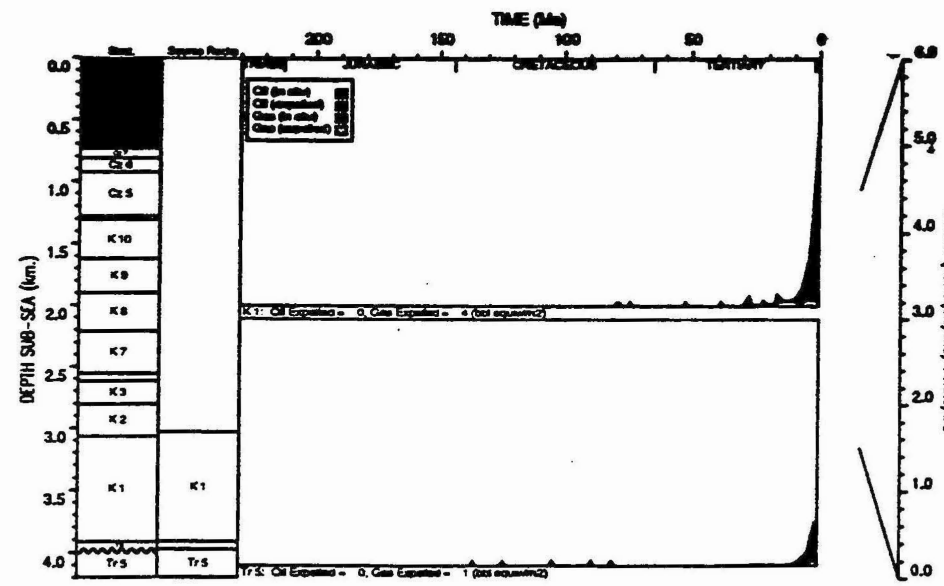
GEOHISTORY PLOT : Zeepaard 1



OBSERVED vs COMPUTED MATURITY PLOT : Zeepaard 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Zeepaard 1



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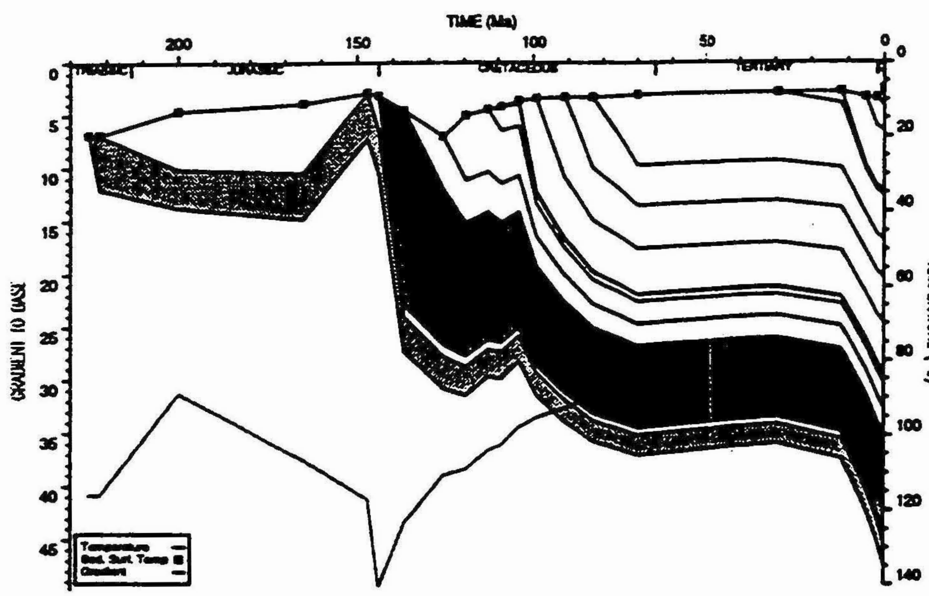
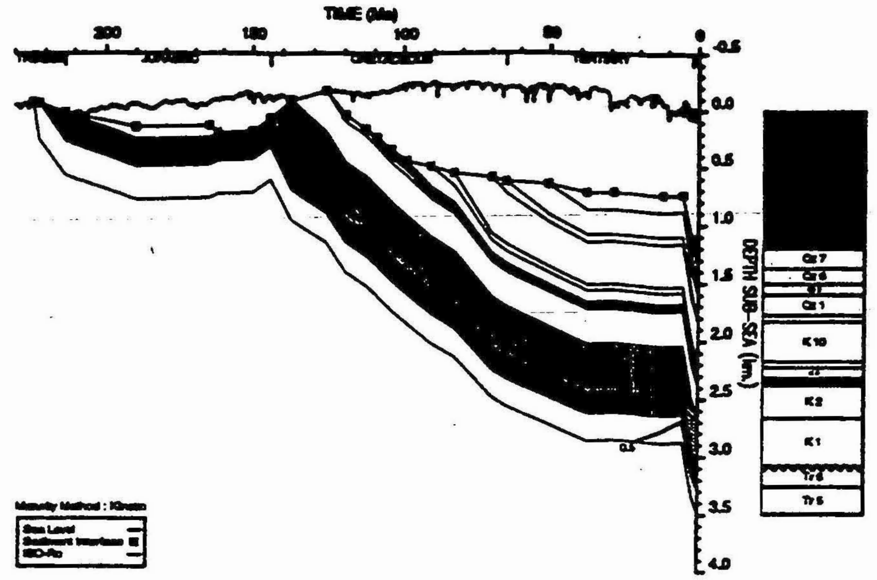
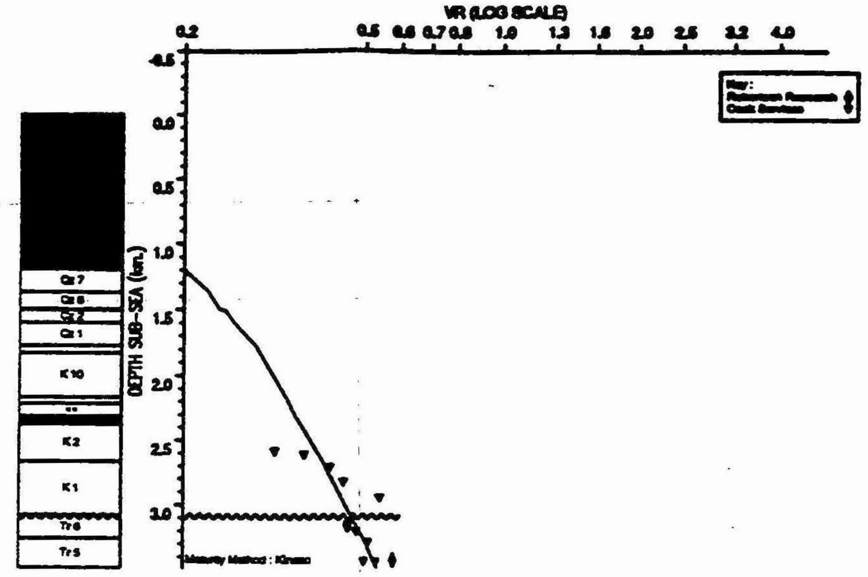


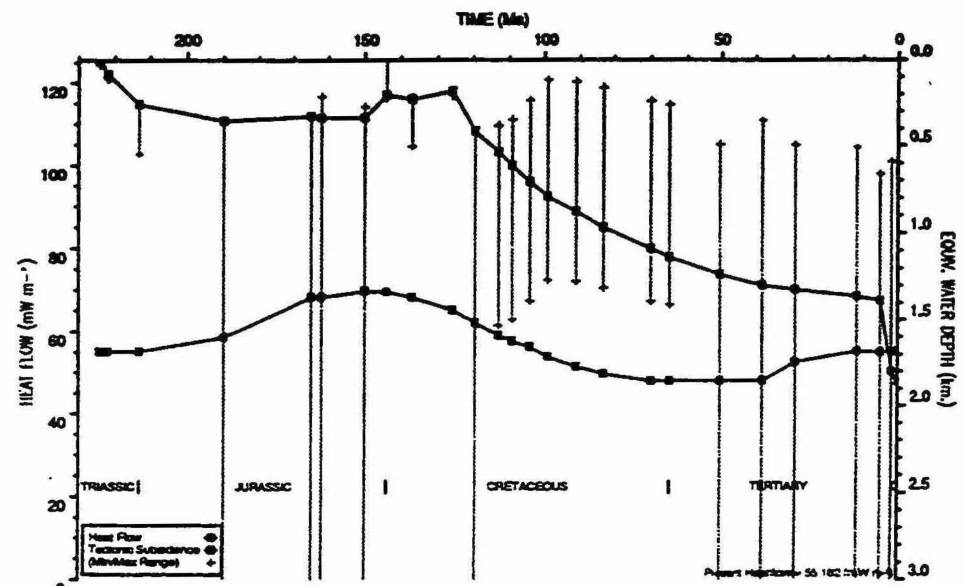
BED TEMPERATURE PLOT : Zeepaard 1



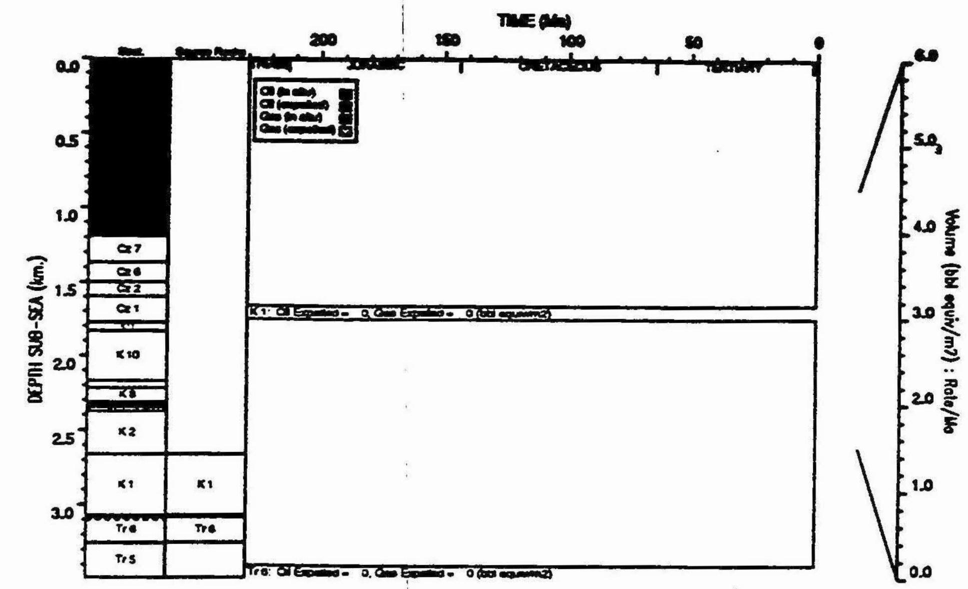
GEOHISTORY PLOT : Zeewulf 1



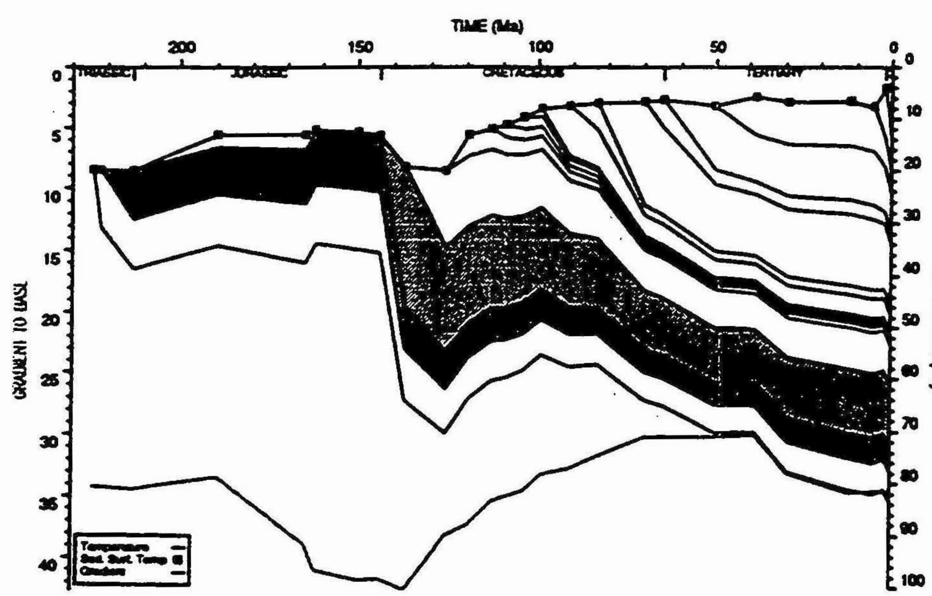
OBSERVED vs COMPUTED MATURITY PLOT : Zeewulf 1



HEATFLOW AND TECTONIC SUBSIDENCE PLOT : Zeewulf 1



HYDROCARBON GENERATION PLOT : Zeewulf 1



BED TEMPERATURE PLOT : Zeewulf 1