GEOTRACK

368001

ASSESSMENT OF THERMAL HISTORY DATA FROM THE DURROON-1 WELL, BASS BASIN

A report prepared for
Bridge Oil
Sydney, Australia

Report prepared by: I. R. Duddy

February 1992

GEOTRACK REPORT #386

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368002

368003

CONTENTS

Attachments

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ASSESSMENT OF THERMAL HISTORY DATA FROM THE DURROON-1 WELL, BASS BASIN

EXECUTIVE SUMMARY

1. Apatite fission track analysis (AFTA) data collected as part of a Masters thesis are available from three samples in Durron-1, all drawn from the Early Cretaceous Otway Group section. Sparse vitrinite reflectance data from a variety of sources are available from some of the Tertiary, Late Cretaceous and Otway Group sections.

2. At face value the AFTA age and length data both suggest that the present geothermal gradient of ~30 to 32°C/km is either too high because of over-correction to measured BHT's, or has risen to the present-value within the last ~1 Ma. The maximum present temperature indicated by the AFTA data for sample L118 (present depth ~3023 m) is ~90°C, giving an estimated pre-Recent geothermal gradient of ~27°C/km. Correction of measured temperatures based on the procedures of Andrews-Speed et al 1984, gives a gradient of 27.2C/km in accordance with the AFTA data.

3. Given an effective geothermal gradient of 27°C/km for the recent past, the AFTA data is consistent with paleotemperatures up to ~30 to 40°C higher than the revised present temperatures.

4. There is some evidence from the AFTA data that cooling from maximum paleotemperatures occurred around ~95 to 100 Ma, in the interval between the top Otway Group and the outpouring of late Cretaceous basalt. This is consistent with the known period of major structuring throughout the Otway and Gippsland Basins to the north. It is also likely that the paleo-geothermal gradient at this time was in the range ~45 to 55°C/km, and that cooling was accomplished through a combination of decline in thermal gradient towards the present-level and uplift and erosion.

5. The VR data are scattered and provide equivocal paleotemperature information. They are consistent with either maximum paleotemperatures at the present-day or the possible AFTA thermal history indicating net cooling of up to 30 to 40°C in the mid Cretaceous.

6. It is recommend that a more extensive suite of VR data be collected from the entire section, but particularly at suitable horizons in the shallow Tertiary section, in the vicinity of the igneous rock at the top of the Otway Group and deep in the well, to provide better control on both absolute post-depositional paleotemperatures and the geothermal gradient at the time of maximum paleotemperatures.

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1. Introduction

1.1 Aims and objectives

This report was prepared in February, 1992 by Geotrack International Pty. Ltd., and gives brief assessment of AFTA and VR data from the **Durroon-1 well, Bass Basin,** supplied by **Bridge Oil Limited.** The assessment is made in good faith with the assumption that the data provided is of a suitable standard for interpretation.

2. Thermal history interpretation of Durroon-1

2.1 Data Quality

AFTA data:

AFTA data from three samples from the Otway Group section were provided (L4-116, -117 and 118), from depths of 1696 m, 2560 m and 2023 mbKB, respectively (note that the depths quoted on the AFTA sample sheets are with respect to sea bed not KB, resulting in some confusion as to which Formation the upper sample actually came from). These data had been collected as part of a Masters thesis at La Trobe University by Ms. Andrea O'Sullivan. Apatite yields were excellent in the three samples, and adequate age and length determinations are available for interpretation.

VR and TAI data:

VR and TAI data from a number of workers were supplied. The TAI data has not been considered quantitatively, but they appear to be lower that the measured VR data where comparison can be made (although it may be that the VR data is oxidized and too high as suggested in information supplied by Bridge). The available VR data are not really adequate to define the thermal history of Durroon-1 and should be supplemented by a more extensive collection from throughout the well.

Present temperature Data:

Present temperature data supplied by Bridge included a corrected present-day geothermal gradient of ~31°C/km, using an apparent sea bed intercept of ~60°F (15.6°C). This is a relatively high sea-bed temperature, and a value of ~10°C may be more appropriate. Using 10°C and the corrected BHT of ~109°C at 3012 m gives a slightly higher present-day geothermal gradient of ~33°C/km

However, the BHT correction used on the deepest measurement at 9913 ft is based on only two "time since circulation" measurements and appears to be fairly severe, and a somewhat lower temperature may be more appropriate. An empirical correction (based on Andrew-Speed et al 1984) that we have found to be fairly reliable gives a corrected BHT of ~96°C, resulting in a present-day geothermal gradient of ~27.2°C/km, significantly different to that estimated by Bridge. This discrepancy may explain some apparently anomalous AFTA data discussed below.

Taking the Bridge values allows the present-temperatures of the three AFTA samples (L4-116, -117 and -118) to be estimated as ~65, ~84 and ~109°C, respectively.

2.2 Summary interpretation

AFTA data:

Taken at face value, the AFTA age and length data are not compatible with the samples being heated to their present temperatures in a thermal history based on the preserved stratigraphy in the well and assuming that the present day geothermal gradient of ~31°C/km was constant throughout the history.

Both the track length distribution data and fission track age data from individual apatite crystals indicate that either the present temperatures, and hence geothermal gradient have been over-corrected, or that the geothermal gradient has risen to the present-value within the last ~1 Ma.

The single grain age data in sample L118 (present depth ~3023 m), in particular the lack of grains with zero fission track ages, indicate a maximum present temperature of ~90°C for this sample in the last 1 or so Ma.

Similarly, the track length distributions in all samples (particularly in samples 116 and 117) show a high proportion of track lengths >~13 μm, which are uncharacteristic of the samples having been heated to their present temperatures in response to the preserved stratigraphy, again suggesting a recent rise in geothermal gradient to the present level. While is is known that Cl-rich apatites are present in the Otway Group, and that such apatites retain long lengths to high temperatures, kinetic modelling of the length distributions in these samples using an appropriate compositional mixture still indicates that the present temperatures are anomalously high.

The single grain age data in sample 118 (present depth ~3023 m) suggests a maximum present temperature is ~90°C, giving a maximum estimated pre-Recent geothermal gradient of ~27°C/km.

Assuming that this value is close to the effective geothermal gradient prior to the Recent past, the AFTA age in the deepest sample (L118) data now suggests that this sample has experienced paleotemperatures after deposition that were sufficient to totally, or near totally, erase fission tracks in all apatites. A minimum temperature of ~130°C would be required to do this compared to a revised present temperature of ~90°C (or less). This suggests that the Otway group has undergone a net cooling of ~40°C from maximum post-depositional paleotemperatures.

The timing of cooling from maximum paleotemperatures is clearly an important aspect of the thermal history at Durroon-1. There is some tenuous evidence from the AFTA data, in particular the corrected apatite age of the deepest sample is ~100 Ma compared to a stratigraphic age of ~127 Ma (Bridge information), suggesting that cooling from maximum paleotemperatures occurred at around this time, in the interval between the top Otway Group and outpouring of the late Cretaceous basalt. This is consistent with the known period of major structuring at ~95 to 100 Ma throughout the Otway and Gippsland Basins to the north.

Vitrinite reflectance data:

The AFTA interpretation is naturally tentative, since it relies on data not collected by Geotrack International Pty. Ltd, and by a relatively inexperienced analyst. Ideally, in such situations we would look to the VR data for corroboration, but as discussed above the VR data is generally insufficient in both quality and quantity to allow firm independent estimates of paleotemperature or paleo-geothermal gradient to be made.

For a history based on the preserved stratigraphy and the present-day geothermal gradient of 31°C/km, the predicted VR profile (based on the kinetic description of Burnham and Sweeney (1989) as implemented in BasinMod (Platte River Assoc.) overestimates all but one of the sparse measured values throughout the Otway Group but underestimates the group of values measured by Cook in the Durroon Mudstone. Information supplied by Bridge suggests that the Durroon Mudstone values may be high due to oxidation, and certainly the VR values estimated from TAI correlation from similar levels are far lower. At face value the trend of the measured VR supports the AFTA data in indicating a paleo or present-day geothermal gradient that is lower than excepted value of ~31°C/km. The predicted VR trend based on the preserved stratigraphy and a geothermal gradient of ~27°C/km is consistent with the majority of the measured Otway group data and thus provides some corroboration for this aspect of the AFTA interpretation. However, other thermal history scenarios, some involving mid-Cretaceous cooling, would also be possible and more VR data are needed if a rigorous thermal history interpretation is to be established.

3. Discussion

3.1 Regional Considerations

Regional information suggests that the paleo-geothermal gradient prior to structuring in the mid-Cretaceous was in the range ~45 to 55°C/km (Geotrack International, unpublished data), and that cooling was accomplished through a combination of decline in thermal gradient towards the present-level and uplift and erosion. For example, using a value of 50°C/km, requires 900 m of uplift and erosion at ~95 Ma to give peak paleotemperature in the deepest sample of ~130°C. Modelling of the VR based on such a history predicts VR levels of ~0.75 for a present thermal gradient of 27C/km and a mid-Cretaceous thermal gradient of 50C/km at the present bottom hole, between the measured values at this depth. No uplift and erosion gives a predicted VR of ~0.62, lower than the lowest value near bottom hole. The area's possibilities are shown in Figure 1, while Figure 2 gives the possible AFTA derived thermal history.

In summary, the thermal history interpretation based on the currently available AFTA and VR are equivocal, being consistent with a range of burial histories involving between zero (putting most weight on the VR data) and ~900 m of mid-Cretaceous uplift and erosion (using the AFTA data and the highest VR values near TD).

3.2 Future work

The most cost effective way of potentially resolving the thermal history possibilities in Durroon-1 is through the collection of a more extensive and coherent VR data set from throughout the well. Corroboration of the AFTA data is desirable and we recommend either re-analysis of the three samples already processed, or complete recollection of a similar number of samples from the Otway group section.

References

Andrews-Speed, C.P., Oxburgh, E.R. & Cooper, B.A., "Temperature and Depth Dependent Heat Flow in Western North Sea *Bull AAPG*, 68, pp1764-1781

Burnham, A.K. and Sweeney, J.J., 1989, "A chemical kinetic model of vitrinite reflectance maturation." *Geochimica et Cosmochimica Acta*, 53, 2649-2657.

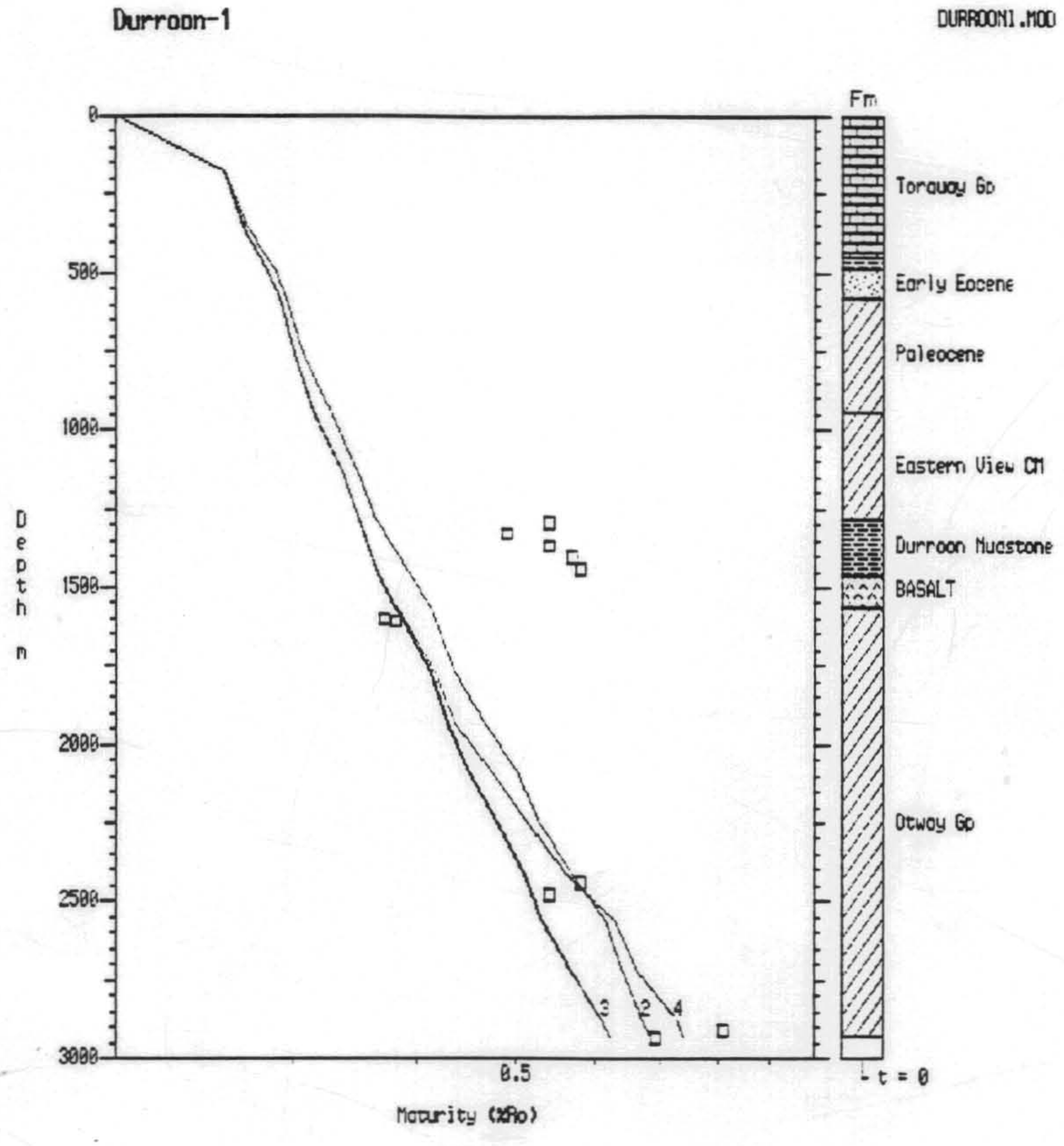

Figure 1 Measured VR and predicted VR profiles for various thermal histories, Durroon-1.

Profile 1&3 (overlaid): preserved stratigraphy; profile 1 has constant geothermal gradient of 27.2°C/km through time;Profile 3 has gradient of 50°C/km at 95 Ma declining to 27.2°C/km by 80Ma.

Profile 2: Preserved stratigraphy and constant geothermal gradient of 31°C/km through time.

Profile 4: Possible AFTA compatable history as for Profile 3, but with 900m of uplift and erosion at 95Ma.

The actual thermal history might be better resolved with more extensive VR measurements throughout the well.

5 cm

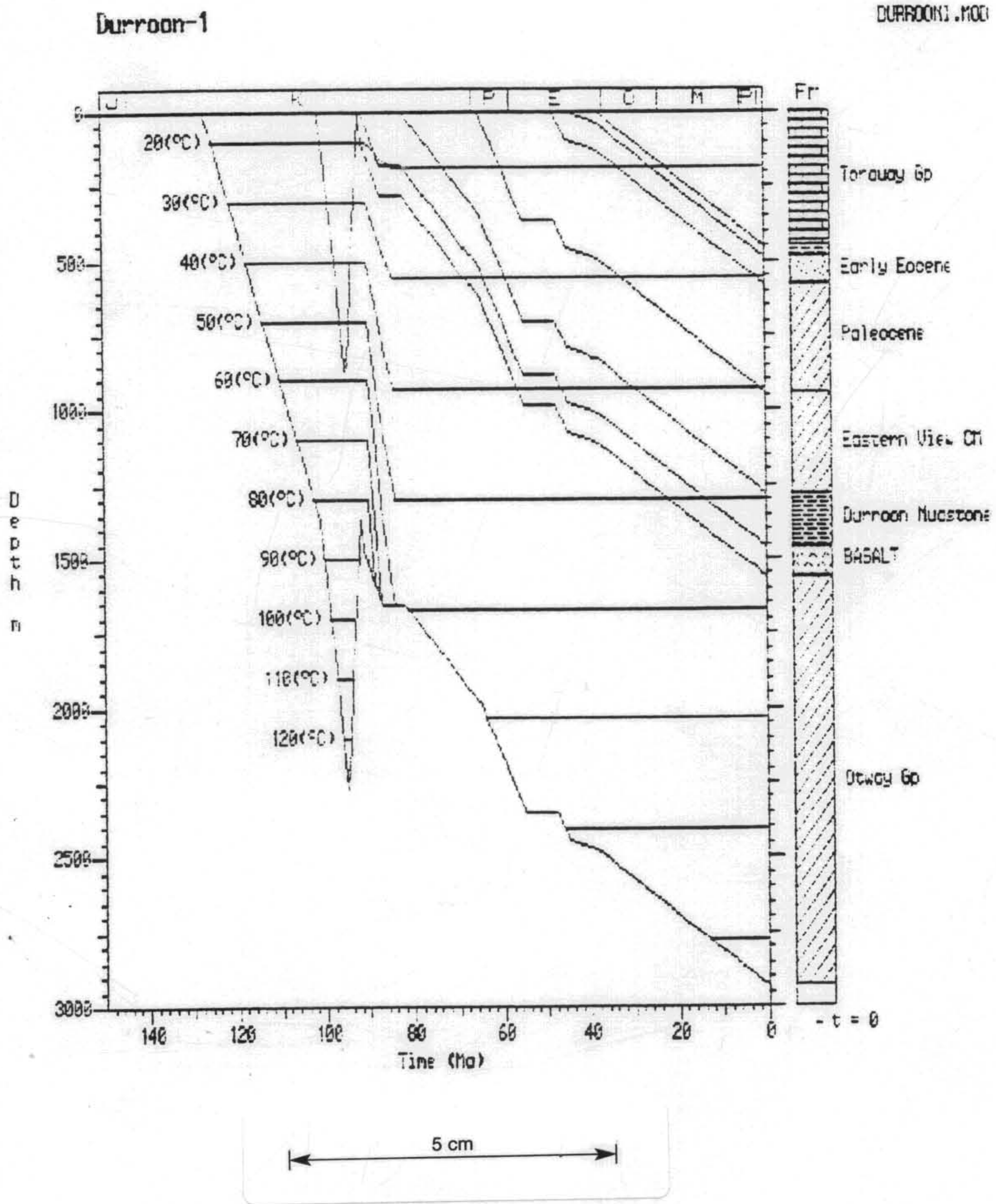

Figure 2: Possible AFTA history giving profile 3 in Figure 1 with gradient 50°C/km in mid-Cretaceos, declining to 27.2°C/km at 80 Ma, and 900m of uplift and erosion at 95 Ma.

DURROON #1

SUMMARY

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521/082/75

368012

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BAG

(1) KS

(2)

23/9/91

Dear Barry,

Here is the interpretation of Durroon-1. I've tried to incorporate as much as possible in the text without going overboard. I've also included 3 examples of the output of 'Basin Mod' from which the conclusions were derived. They should be fairly self-explanatory.

If you have any questions about anything I've written or any of the diagrams, please let me know.

Yours sincerely,

Andrea O'Sullivan

KS// No matter what Andrea did, AFTA results only conforms to Rv & BHT data if one applies a not-so-tenable heat flow history.

Variance in FT annealing paths related to variance in apatite composition could also be a "culprit".
In short AFTA directionally says relatively "cool" heat flow but **is** equivocal.

Summary of Durroon-1 Well Data

Andrea J. O'Sullivan

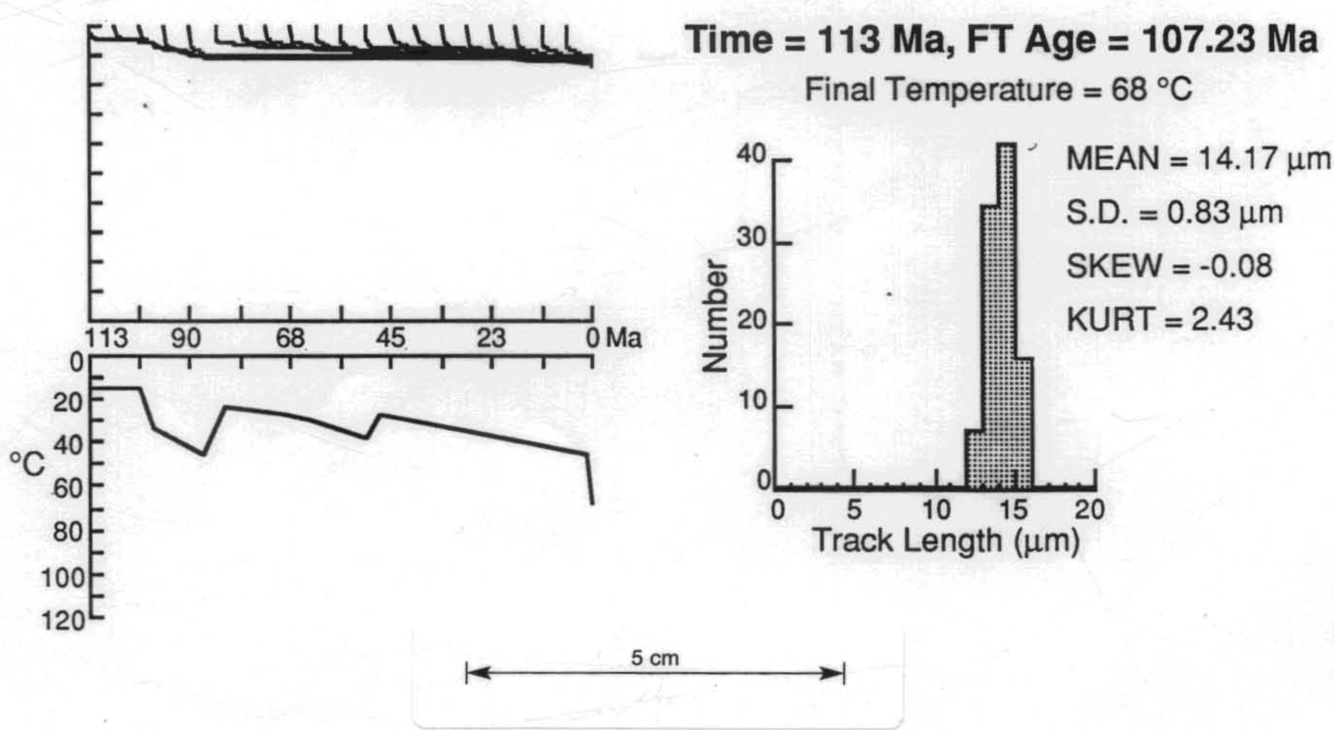
I have tried to model the AFTA results from Durroon-1 utilizing two different modelling programs. The first was a revised version of 'Supertrack', which we use here at La Trobe Uni. The second was 'BasinMod', which Geotrack uses. I will discuss the 'Supertrack' results first.

The following diagrams are my final versions for each of the three Durroon-1 samples, using 'Supertrack'. The top left insert shows the time-temperature paths of individual fission tracks formed sequentially (shown on the x-axis). The final fission track age and length distribution predicted by the model are a sum of these paths. The bottom left insert shows the modelled thermal histories for each sample, with a maximum of 12 fixed points. The resultant length distributions are narrower than those observed in the real data as the model assumes uniform apatite composition.

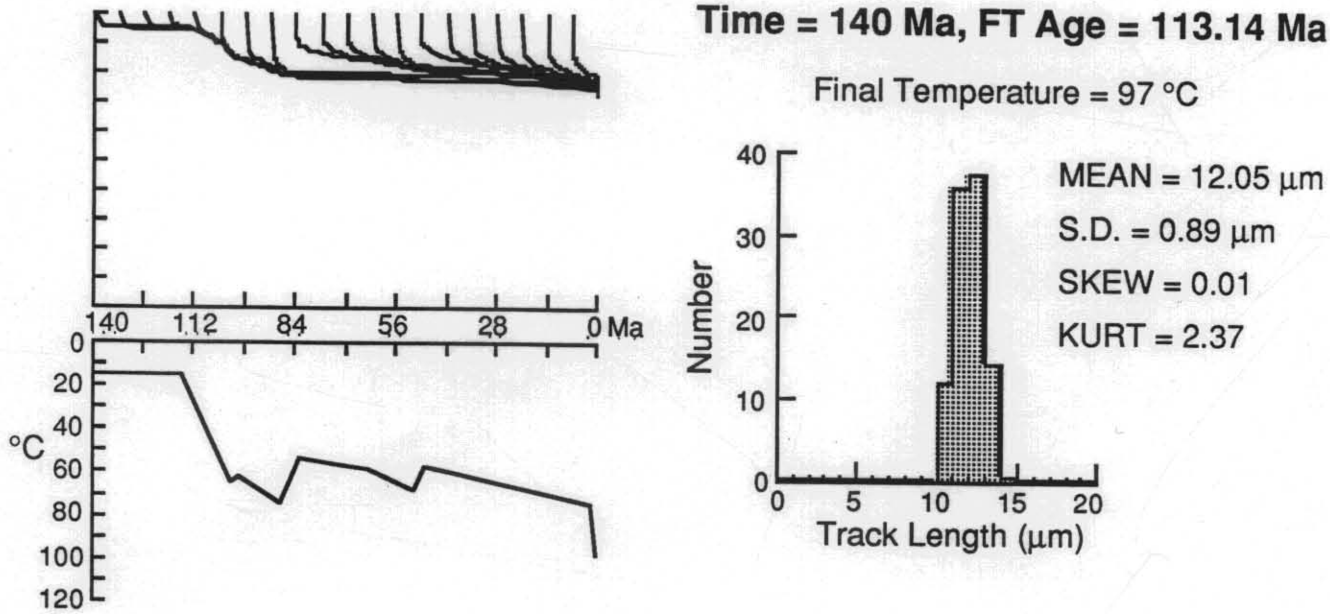
Supertrack modelling is a trial and error process, and the results below were the best fit obtained after a day of modelling. The model has a number of limitations, especially for sedimentary samples, as it assumes a constant apatite composition the same as Durango apatite, one of our standards. In reality, however, most sediment-derived apatites exibit a range of compositions, which alters their annealing characteristics.

When the Bridge burial history was converted to temperature, assuming a constant geothermal gradient with time (which is not strictly accurate), and put into the model, the bottom sample registered virtually a zero age and zero length. We realised that the samples appeared to contain a range of compositions, so we lowered the temperatures for each sample by first 10 °C, then 15 °C and then 20 °C. None of these fitted satisfactorily, so I adjusted the amounts of cooling for the different unconformity surfaces, trying to maintain geologic reality, resulting in the following 'interpretations'. The only way for the data to fit the 'Horner plot corrected' borehole temperatures is to invoke a very recent heating.

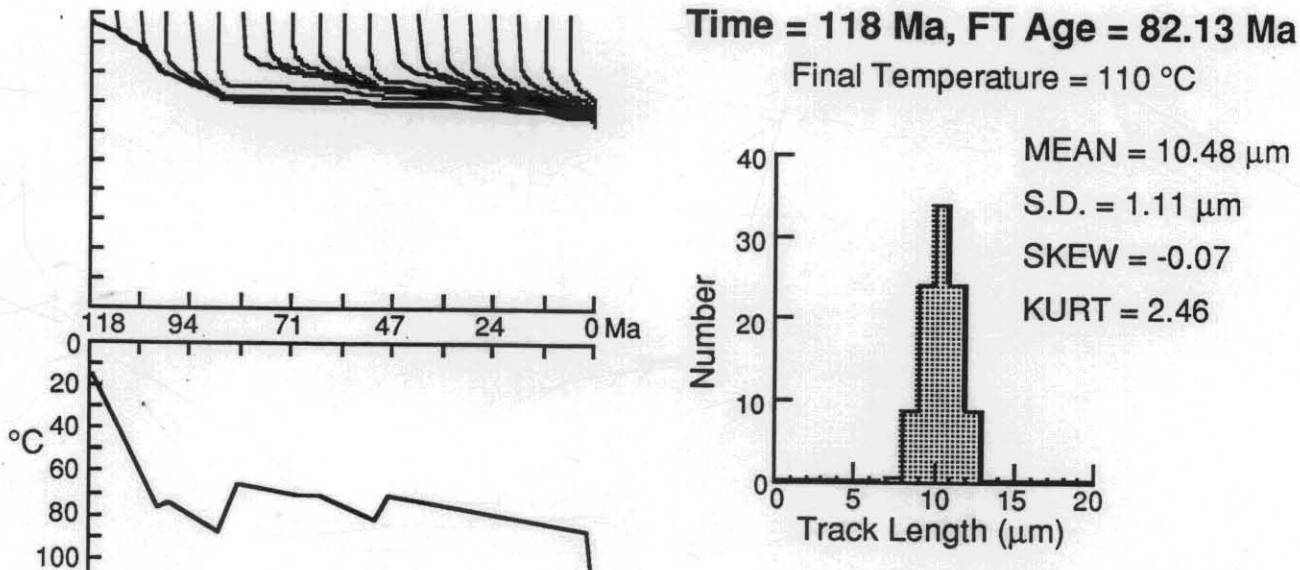
L4-116 1630m



L4-117 2500m



L4-118 2960m



5 cm

Later I worked with Paul Green at Geotrack using their modelling program 'BasinMod' which incorporates VR data, so we digitised the VR graph you sent. In order to explain these data, the model required either burial at greater temperatures than any of the fission track data would allow or a large heat pulse earlier in the geological history.

A short heat pulse of ~55 °C/km at 50 Ma was a reasonable fit for the VR data, but the predicted FT data was even further away from the observed, as the lowest sample *should* have been almost totally annealed. If the heat pulse is moved further back in time it fits the FT data better, but the heat pulse needs to be of greater magnitude in order to fit the VR (ie. a pulse of up to 80 °C/km at 85 Ma, which is unreasonable). To further complicate matters, the fission track single grain ages do not support the idea of a heat pulse. The radial plots shown below display FT single grain ages against precision of the individual ages (precision increases towards the right). If the idea of a heat pulse back at ~90 Ma were true, we would expect no FT ages older than ~110-120 Ma. However, as can be seen in the radial plots, both L4-116 and L4-117 exhibit FT ages as old as 190 Ma (±error). Even the lowest sample, L4-118, exhibits a single grain age of nearly 150 Ma.

Given that both the upper FT samples show some degree of inheritance from older apatite grains, the best and simplest fit for the FT data is a constant geothermal gradient with time of ~28 °C/km. However this underestimates the VR.

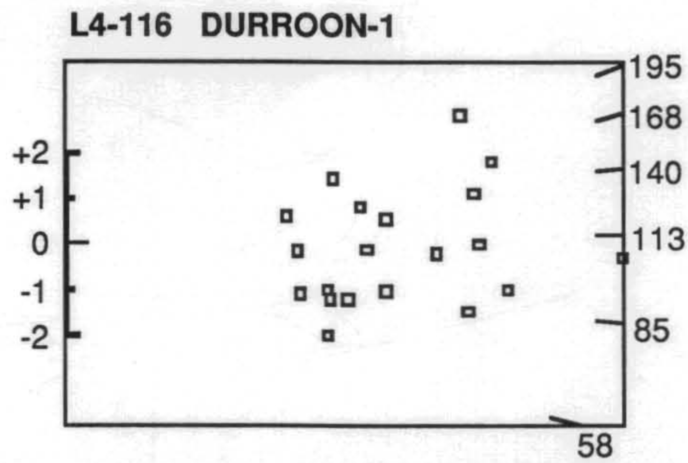
The conclusions which may be drawn from the modelling are:

1) There appears to be a large range in apatite composition in the samples, which makes it harder to compare observed data to modelled data

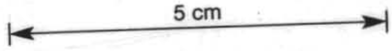
2) It seems likely from the fission track data that the VR values of ~0.8 from the bottom of the well may be a result of reworking, or may be incorrect

3) The present day temperature (and hence geothermal gradient) in Durroon-1 is probably slightly cooler than the recalculated temperature (ie. closer to the previous value of 28.4 °C/km than to the recalculated values of 29.4 to 31.6 °C/km)

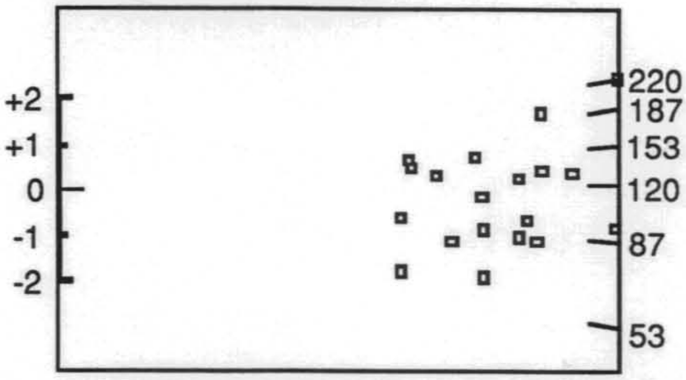
4) The present day temperature appears to be the maximum temperature the apatite samples have experienced.



Radial plot of single grain ages for sample L4-116. Ages (Ma) are shown along the right hand side of the diagram. Relative precision of single grain ages increases towards the right. The values on the left of the diagram indicate the ± 2 sigma error for each grain age, with the ages plotting radially from the zero value.

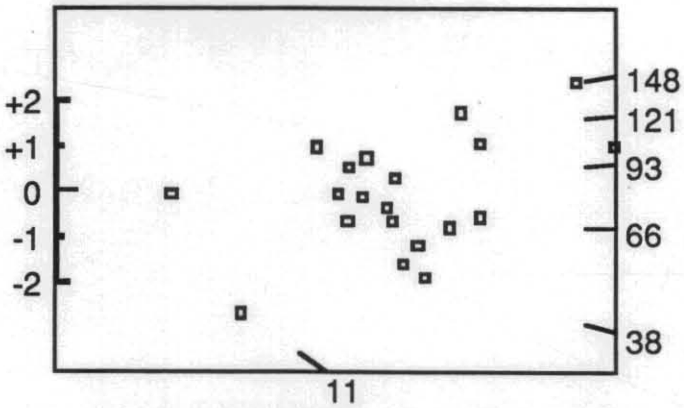


L4-117 DURROON-1

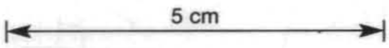


Radial plot of single grain ages for sample L4-117

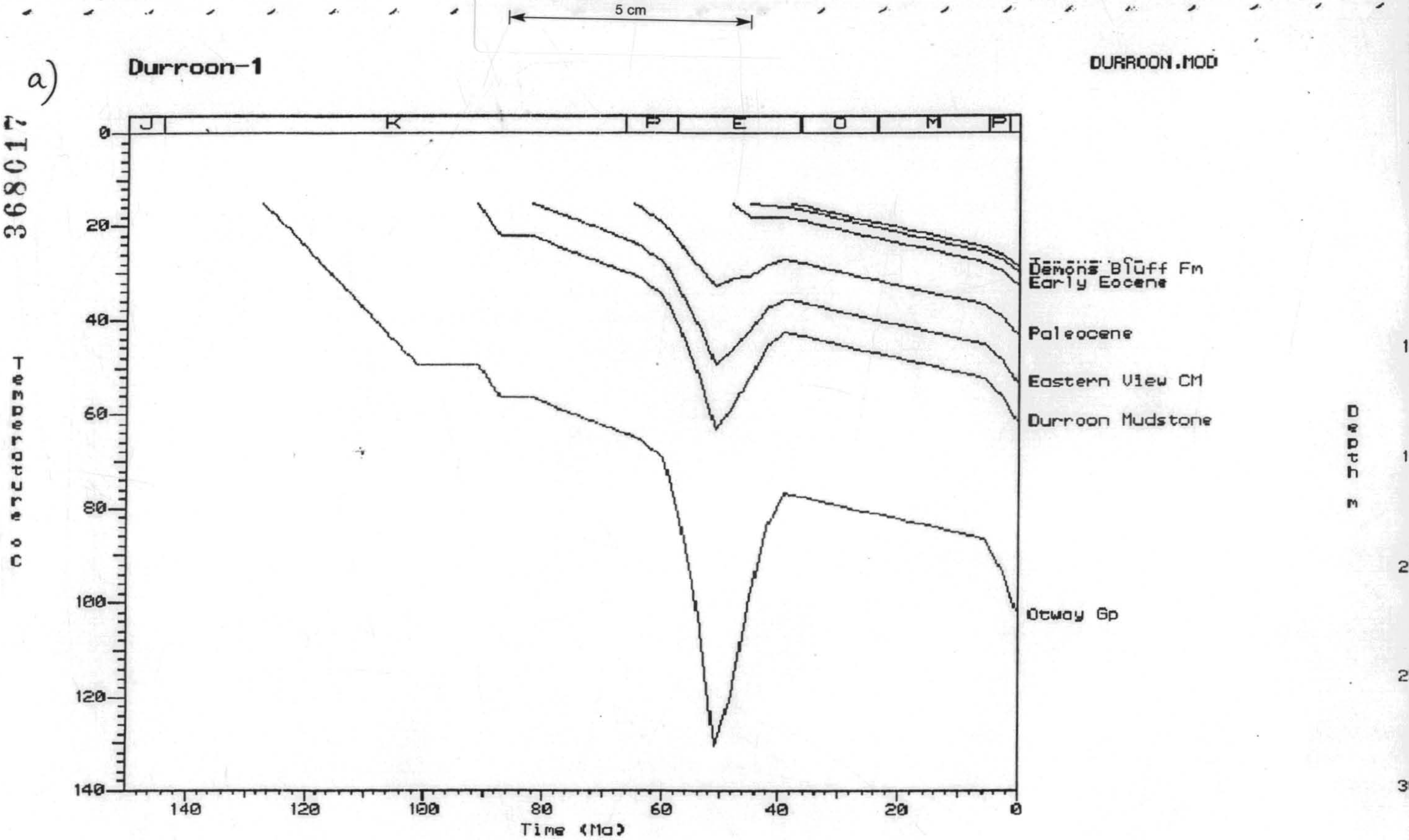
L4-118 DURROON-1



Radial plot of single grain ages for sample L4-118

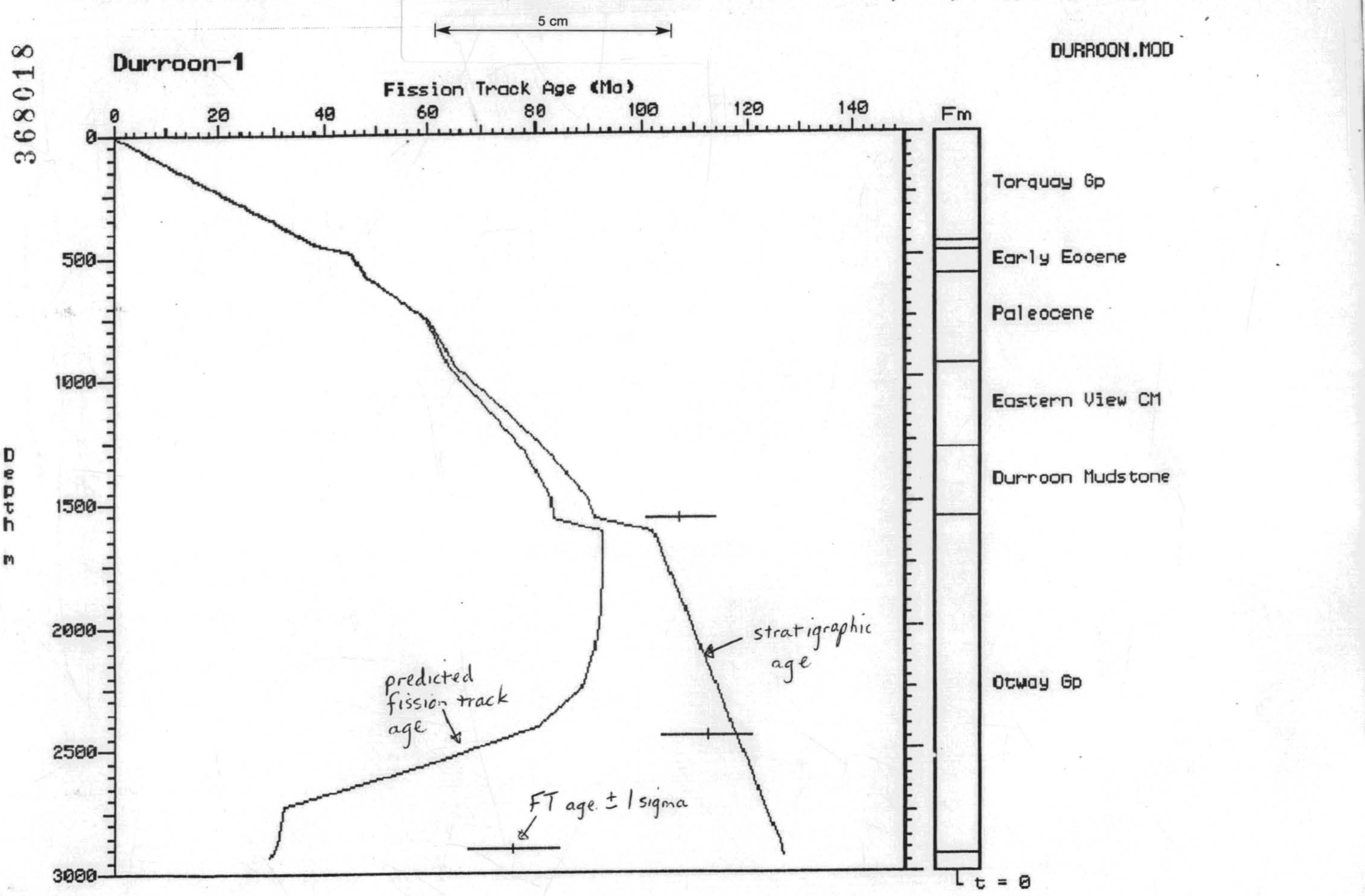


a)



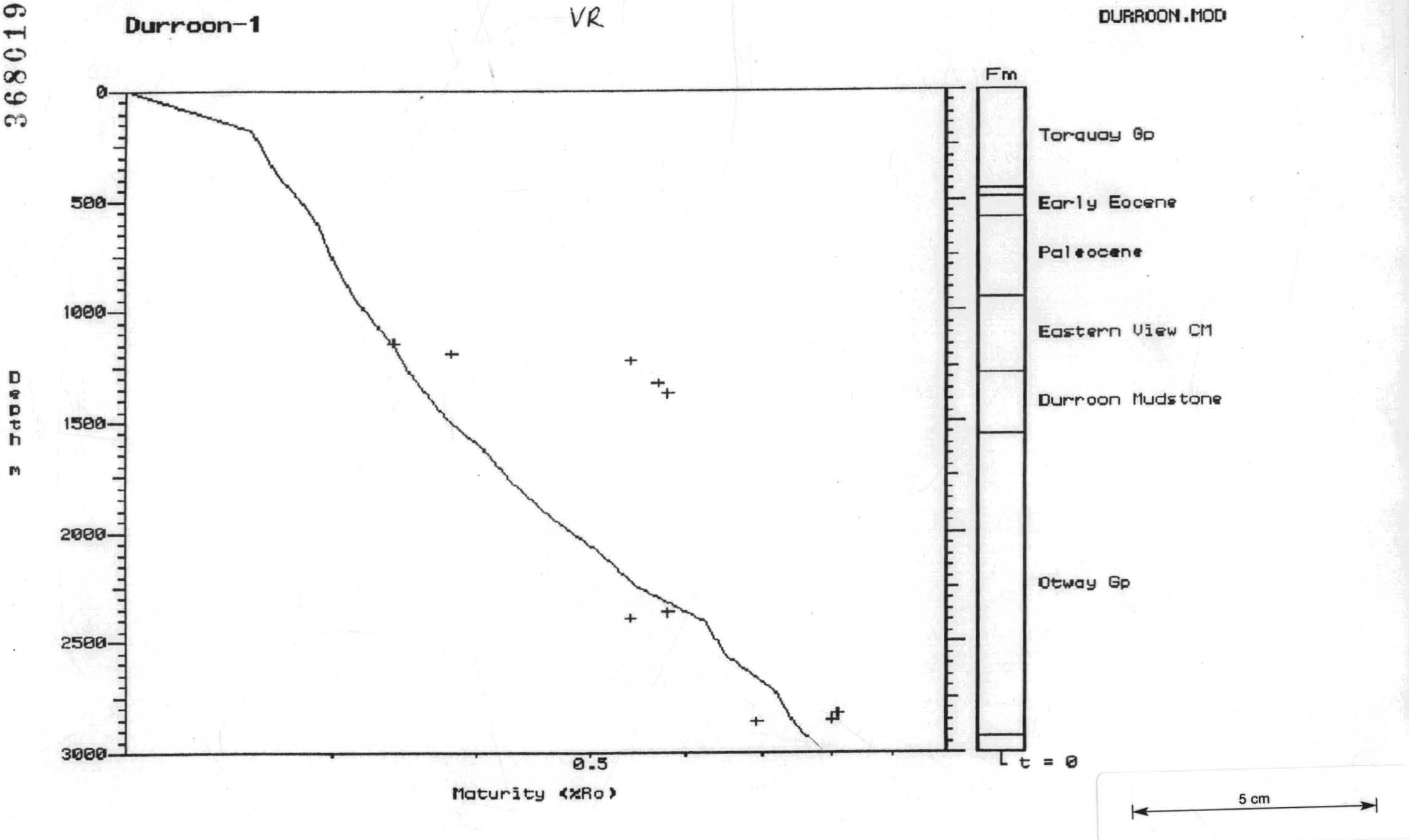
Heat pulse at 50Ma of 55 °C/km

368018



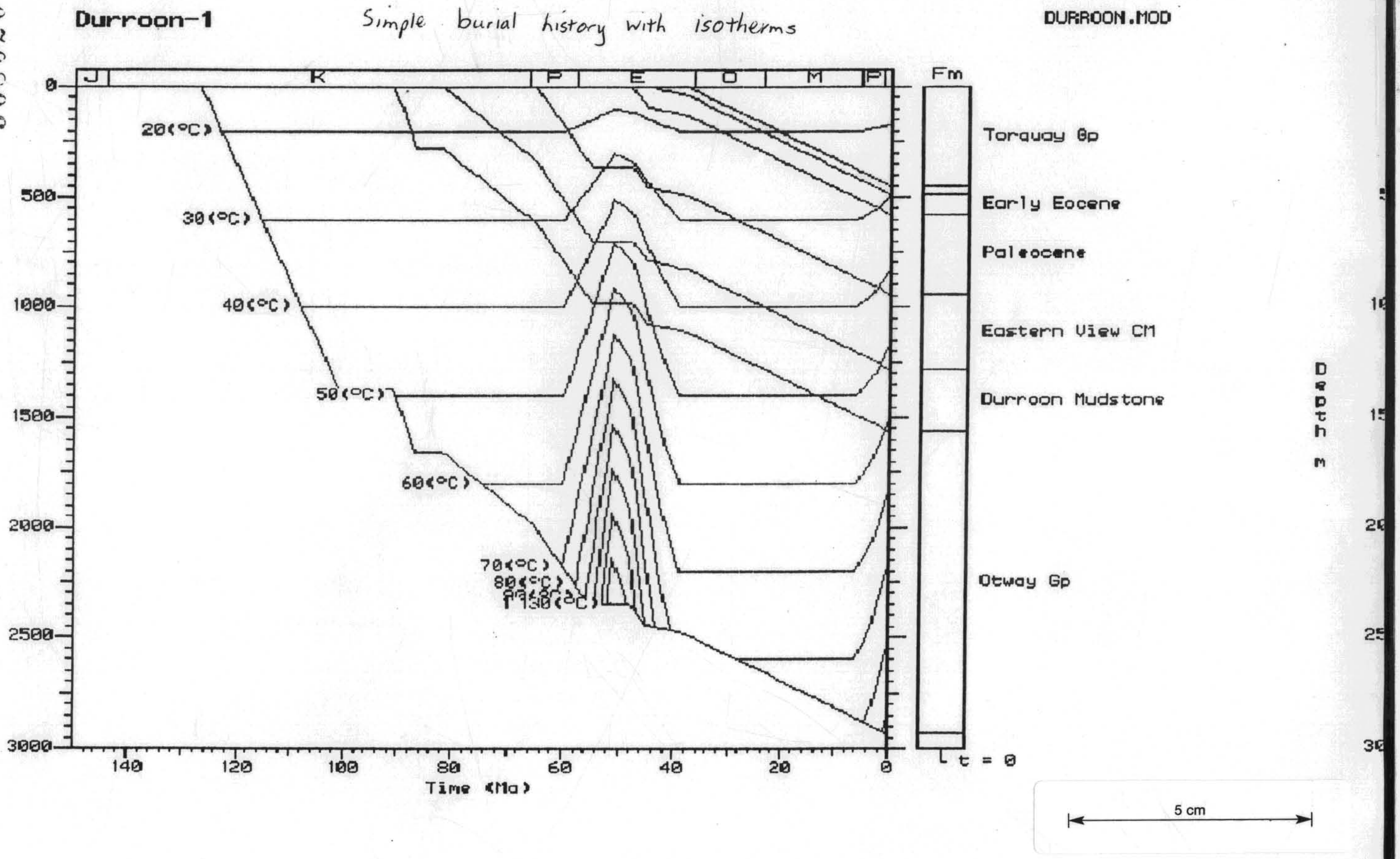
5 cm
Durroon-1
DURROON.MOD
Fission Track Age (Ma)
0
20
40
60
80
100
120
140
Fm
Depth m
0
500
1000
1500
2000
2500
3000
Torquay Gp
Early Eocene
Paleocene
Eastern View CM
Durroon Mudstone
Otway Gp
stratigraphic age
predicted fission track age
FT age ± 1 sigma
t = 0

368019



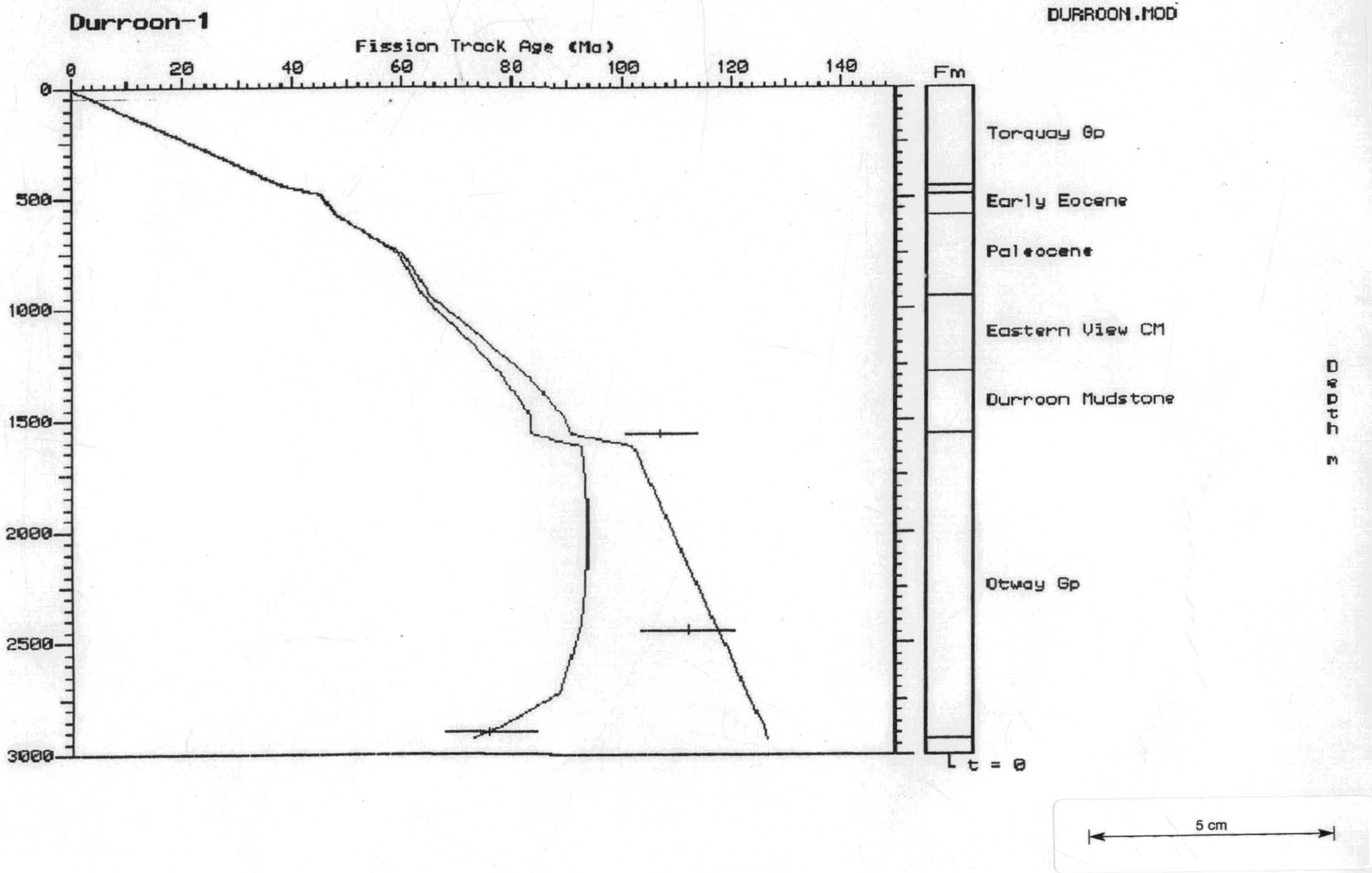
Durroon-1
VR
DURROON.MOD
Fm
Torquay Gp
Early Eocene
Paleocene
Eastern View CM
Durroon Mudstone
Otway Gp
t = 0
0
500
1000
1500
2000
2500
3000
Depth m
0.5
Maturity (%Ro)
5 cm

368020


Durroon-1
Simple burial history with isotherms
DURROON.MOD
J
K
P
E
O
M
P
Fm
0
500
1000
1500
2000
2500
3000
Depth m
20(°C)
30(°C)
40(°C)
50(°C)
60(°C)
70(°C)
80(°C)
130(°C)
Torquay Gp
Early Eocene
Paleocene
Eastern View CM
Durroon Mudstone
Otway Gp
t = 0
140
120
100
80
60
40
20
0
Time (Ma)
5 cm

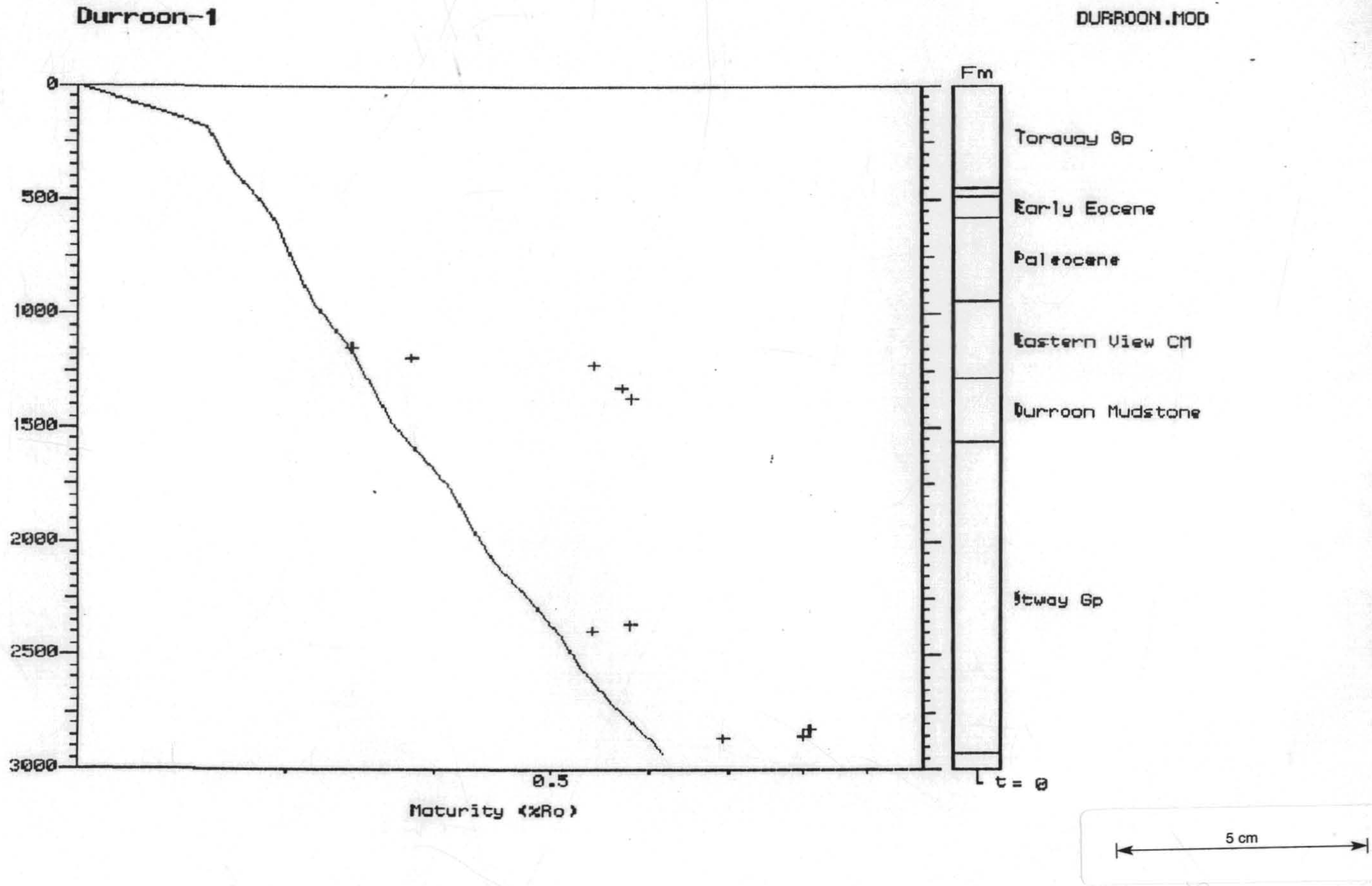
b)

368021



Constant gradient 27°C/km

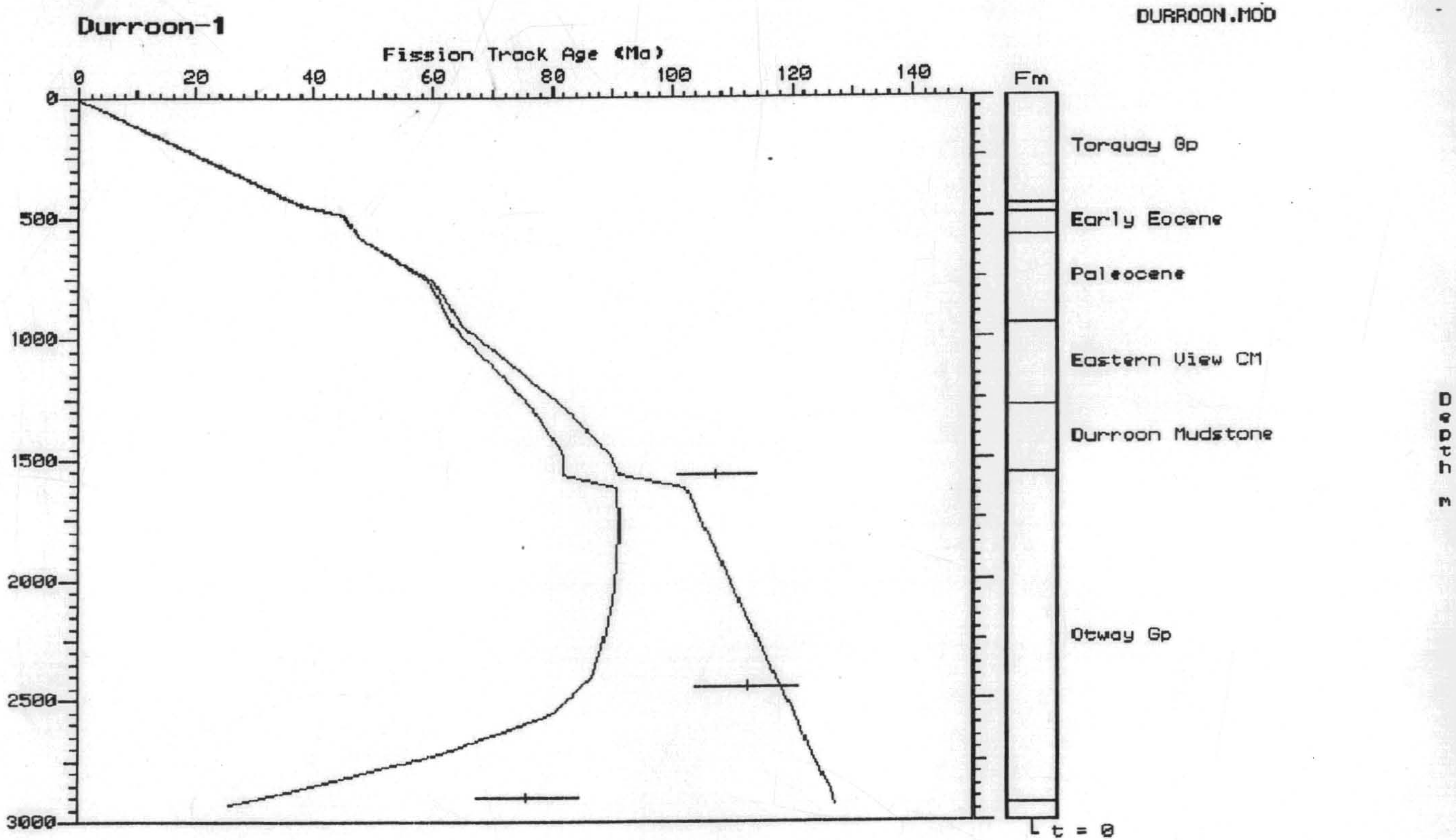
368022



Durroon-1
DURROON.MOD
Fm
0
500
1000
1500
2000
2500
3000
Depth m
0.5
Maturity (%Ro)
Torquay Gp
Early Eocene
Paleocene
Eastern View CM
Durroon Mudstone
Otway Gp
t = 0
5 cm

c)

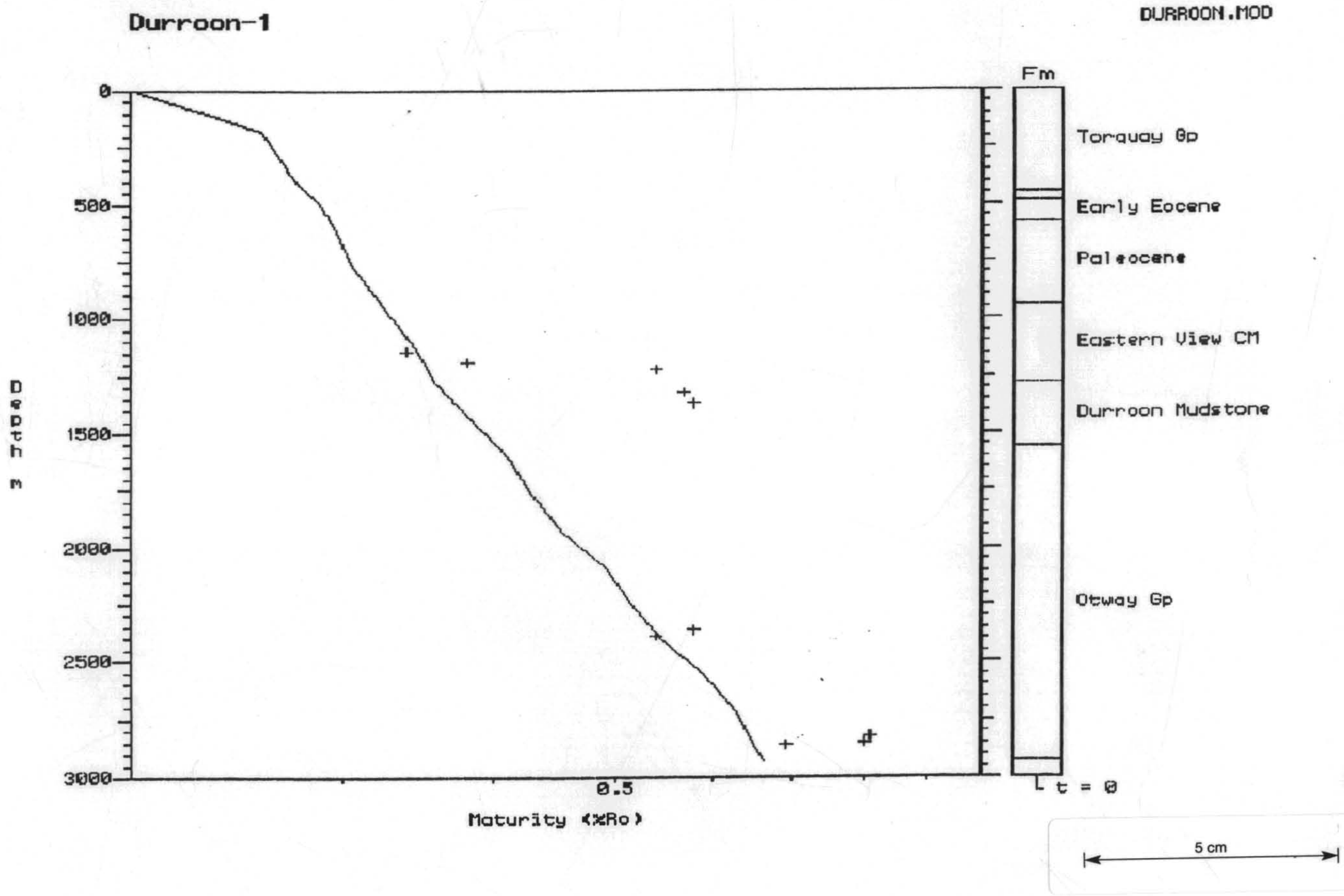
368023



5 cm

Constant gradient 30°C/km

368024


Durroon-1
DURROON.MOD
Fm
0
500
1000
1500
2000
2500
3000
Depth m
0.5
Maturity (%Ro)
Torquay Gp
Early Eocene
Paleocene
Eastern View CM
Durroon Mudstone
Otway Gp
t = 0
5 cm

368025

FACSIMILE TRANSMISSION RECORD

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Fax: (03) 479 1272

Transmission Details: **To: Barry Goldstein**
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Fax: (02) 283 4168

Dear Barry,

I called you earlier in the week and left a message for you to call me when you had time. As I have not heard from you yet, I'm sending the Durroon-1 data with this cover letter. I have not interpreted the data yet as at present I don't have bottom-hole temperature, etc. Kevin tells me that you have just had extra palynology and thermal history studies done on Durroon-1. Would it be possible for you to send me the relevant information so I can carry out an interpretation for the well. I would appreciate it if you could send me the data within the next few weeks. Thanks in advance!

Regards,

Andrea O'Sullivan

Andrea J. O'Sullivan

BAC

Document Details: **No. Pages: 5 (Including This Page)**
Date: ~~20/8/91~~ 9/8/91
From: Andrea J. O'Sullivan

L4-116 APATITE DURROON-1 ~1650m

IRRADIATION LU158
SLIDE NUMBER 8
COUNTED BY: AJOS

No.	Ns	Ni	Na	RATIO	U (ppm)	RHOs	RHOi	F.T. AGE (Ma)
1	40	63	48	0.635	15.3	9.482E+05	1.493E+06	136.1 ± 27.8
2	14	40	54	0.350	8.6	2.950E+05	8.428E+05	75.4 ± 23.5
3	68	139	40	0.489	40.4	1.934E+06	3.954E+06	105.1 ± 15.9
4	11	32	49	0.344	7.6	2.554E+05	7.430E+05	74.1 ± 26.0
5	38	75	32	0.507	27.2	1.351E+06	2.667E+06	108.9 ± 21.9
6	12	25	40	0.480	7.3	3.413E+05	7.111E+05	103.2 ± 36.4
7	30	62	60	0.484	12.0	5.689E+05	1.176E+06	104.0 ± 23.3
8	13	48	60	0.271	9.3	2.465E+05	9.102E+05	58.4 ± 18.3
9	19	24	50	0.792	5.6	4.324E+05	5.461E+05	169.3 ± 52.2
10	41	97	60	0.423	18.8	7.775E+05	1.839E+06	90.9 ± 17.2
11	44	48	100	0.917	5.6	5.006E+05	5.461E+05	195.6 ± 41.3
12	46	64	81	0.719	9.2	6.462E+05	8.990E+05	153.9 ± 30.1
13	21	54	48	0.389	13.1	4.978E+05	1.280E+06	83.7 ± 21.7
14	14	38	50	0.368	8.8	3.186E+05	8.647E+05	79.3 ± 24.9
15	20	41	70	0.488	6.8	3.251E+05	6.664E+05	104.8 ± 28.8
16	12	19	56	0.632	3.9	2.438E+05	3.860E+05	135.4 ± 50.1
17	21	33	70	0.636	5.5	3.413E+05	5.364E+05	136.4 ± 38.3
18	33	88	90	0.375	11.4	4.172E+05	1.112E+06	80.7 ± 16.7
19	24	41	90	0.585	5.3	3.034E+05	5.183E+05	125.6 ± 32.5
20	16	45	50	0.356	10.5	3.641E+05	1.024E+06	76.6 ± 22.4
	537	1076			10.4	5.100E+05	1.022E+06	

Area of basic unit = 8.789E-07 cm-2

Chi Squared = 30.144 with 19 degrees of freedom
P(chi squared) = 5.0 %
Correlation Coefficient = 0.855
Variance of SQR(Ns) = 1.94
Variance of SQR(Ni) = 3.30
Age Dispersion = 17.412 %

Ns/Ni = 0.499 ± 0.026
Mean Ratio = 0.512 ± 0.038

Ages calculated using a zeta of 338 ± 8 for SRM612 glass
Rho D = 1.282E+06cm-2; ND = 2817

POOLED AGE = 107.2 ± 6.5 Ma*
MEAN AGE = 110.0 ± 8.7 Ma
CENTRAL AGE = 107.0 ± 7.9 Ma

L4-117 APATITE DURROON-1 ~2530m

IRRADIATION LU158
SLIDE NUMBER 9
COUNTED BY: AJOS

No.	Ns	Ni	Na	RATIO	U (ppm)	RHOs	RHOi	F.T. AGE (Ma)
1	11	18	70	0.611	3.0	1.788E+05	2.926E+05	131.1 ± 50.3
2	10	14	40	0.714	4.1	2.844E+05	3.982E+05	152.9 ± 63.5
3	30	29	80	1.034	4.2	4.267E+05	4.124E+05	220.3 ± 57.8
4	8	19	60	0.421	3.7	1.517E+05	3.603E+05	90.6 ± 38.3
5	13	25	80	0.520	3.6	1.849E+05	3.556E+05	111.7 ± 38.3
6	15	34	100	0.441	4.0	1.707E+05	3.868E+05	94.9 ± 29.6
7	15	39	100	0.385	4.5	1.707E+05	4.437E+05	82.8 ± 25.3
8	18	29	80	0.621	4.2	2.560E+05	4.124E+05	133.1 ± 40.1
9	18	29	80	0.621	4.2	2.560E+05	4.124E+05	133.1 ± 40.1
10	7	28	100	0.250	3.3	7.964E+04	3.186E+05	53.9 ± 22.9
11	12	30	64	0.400	5.4	2.133E+05	5.333E+05	86.1 ± 29.5
12	14	20	56	0.700	4.2	2.844E+05	4.064E+05	149.9 ± 52.4
13	20	33	100	0.606	3.8	2.276E+05	3.755E+05	130.0 ± 37.0
14	21	48	100	0.438	5.6	2.389E+05	5.461E+05	94.1 ± 24.8
15	14	36	100	0.389	4.2	1.593E+05	4.096E+05	83.7 ± 26.5
16	21	23	100	0.913	2.7	2.389E+05	2.617E+05	194.9 ± 59.1
17	10	15	56	0.667	3.1	2.032E+05	3.048E+05	142.8 ± 58.5
18	16	27	100	0.593	3.1	1.820E+05	3.072E+05	127.1 ± 40.3
19	11	39	100	0.282	4.5	1.252E+05	4.437E+05	60.8 ± 20.8
20	10	28	100	0.357	3.3	1.138E+05	3.186E+05	76.9 ± 28.4
	294	563			3.9	2.008E+05	3.845E+05	

Area of basic unit = 8.789E-07 cm-2

Chi Squared = 24.748 with 19 degrees of freedom
P(chi squared) = 16.9 %
Correlation Coefficient = 0.366
Variance of SQR(Ns) = 0.48
Variance of SQR(Ni) = 0.68
Age Dispersion = 17.929 %

Ns/Ni = 0.522 ± 0.038
Mean Ratio = 0.548 ± 0.045

Ages calculated using a zeta of 338 ± 8 for SRM612 glass
Rho D = 1.282E+06cm-2; ND = 2817

POOLED AGE = 112.2 ± 8.8 Ma*
MEAN AGE = 117.7 ± 10.3 Ma
CENTRAL AGE = 112.2 ± 9.9 Ma

L4-118 APATITE DURROON-1 ~2990m

IRRADIATION LU158
SLIDE NUMBER 10
COUNTED BY: AJOS

No.	Ns	Ni	Na	RATIO	U (ppm)	RHOs	RHOi	F.T. AGE (Ma)
1	6	22	28	0.273	9.1	2.438E+05	8.940E+05	58.8 ± 27.1
2	15	23	50	0.652	5.3	3.413E+05	5.234E+05	139.8 ± 46.6
3	8	16	80	0.500	2.3	1.138E+05	2.276E+05	107.4 ± 46.6
4	13	42	56	0.310	8.7	2.641E+05	8.533E+05	66.7 ± 21.3
5	8	25	70	0.320	4.2	1.300E+05	4.064E+05	69.0 ± 28.1
6	1	3	40	0.333	0.9	2.844E+04	8.533E+04	71.8 ± 83.0
7	15	29	100	0.517	3.4	1.707E+05	3.300E+05	111.1 ± 35.5
8	7	15	50	0.467	3.5	1.593E+05	3.413E+05	100.3 ± 46.0
9	25	36	56	0.694	7.5	5.079E+05	7.314E+05	148.7 ± 39.0
10	6	17	100	0.353	2.0	6.827E+04	1.934E+05	76.0 ± 36.2
11	8	40	100	0.200	4.6	9.102E+04	4.551E+05	43.2 ± 16.8
12	9	38	80	0.237	5.5	1.280E+05	5.404E+05	51.1 ± 19.0
13	2	38	100	0.053	4.4	2.276E+04	4.324E+05	11.4 ± 8.3
14	9	22	54	0.409	4.7	1.896E+05	4.635E+05	88.0 ± 34.9
15	8	28	70	0.286	4.6	1.300E+05	4.551E+05	61.6 ± 24.8
16	11	39	90	0.282	5.0	1.391E+05	4.930E+05	60.8 ± 20.8
17	9	48	80	0.188	7.0	1.280E+05	6.827E+05	40.5 ± 14.8
18	25	53	90	0.472	6.8	3.161E+05	6.700E+05	101.4 ± 24.8
19	7	20	60	0.350	3.9	1.327E+05	3.793E+05	75.4 ± 33.2
20	6	10	28	0.600	4.2	2.438E+05	4.064E+05	128.7 ± 66.6
	198	564			4.7	1.630E+05	4.643E+05	

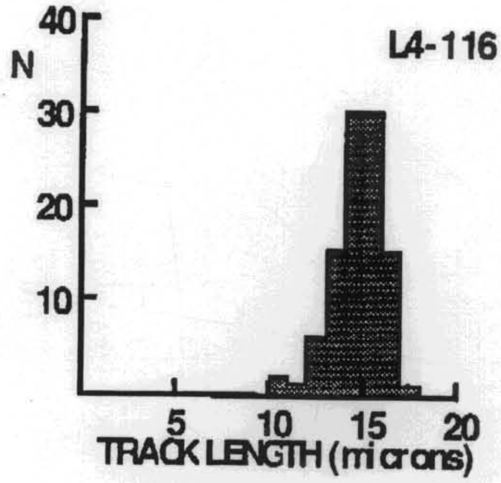
Area of basic unit = 8.789E-07 cm-2

Chi Squared = 32.782 with 19 degrees of freedom
P(chi squared) = 2.5 %
Correlation Coefficient = 0.549
Variance of SQR(Ns) = 0.94
Variance of SQR(Ni) = 1.87
Age Dispersion = 31.753 %

Ns/Ni = 0.351 ± 0.029
Mean Ratio = 0.375 ± 0.037

Ages calculated using a zeta of 338 ± 8 for SRM612 glass
Rho D = 1.282E+06cm-2; ND = 2817

POOLED AGE = 75.6 ± 6.7 Ma
MEAN AGE = 80.7 ± 8.3 Ma*
CENTRAL AGE = 75.6 ± 8.7 Ma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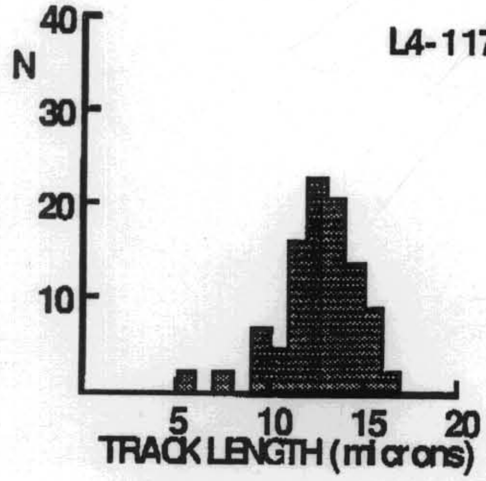
N
40
30
20
10
5
10
15
20
TRACK LENGTH (microns)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N
40
30
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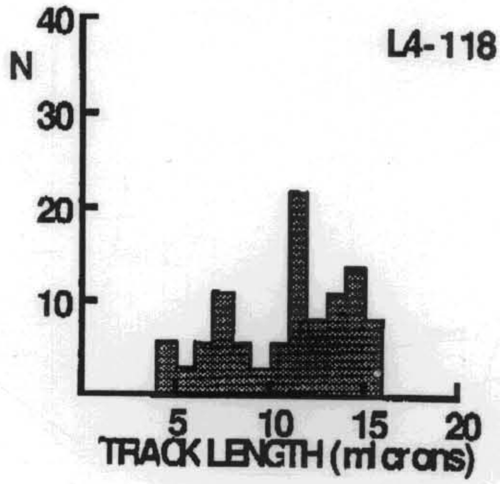
15
20
TRACK LENGTH (microns)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N
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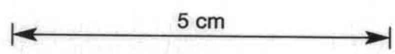
TRACK LENGTH (microns)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Attachment 2

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Revised MATOIL Modelling of Durroon-1

and the Boobyalla Sub-Basin, T/15P incorporating

GEOTRACK INTERNATIONAL'S AFTA Results

1. GEOTRACK's preferred analysis of the AFTA study (Appendix 1) is that Durroon-1 experienced high geothermal gradients of up to 55°C/km around 95-100 Ma ago, followed by erosion of about 900 metres of Otway Group, and a subsequent cold geothermal gradient of about 27°C/km to present day (equivalent to 90°C at T.D.).

2. If Bridge Oil's corrected BHT's in Durroon-1 (Table 1) are correct, the higher apparent present-day geothermal gradient of about 33°C/km (using a sea-floor temperature of 12°C) could be explained by a recent heating pulse (within the last 1 Ma or so).

3. AFTA data indicates that Durroon-1 has experienced paleotemperatures at least as high as 130°C near T.D., inferring much higher paleo-geothermal gradients than above. Unpublished Geotrack data indicates paleo-geothermal gradients of 45-55°C/km in the Otway and Gippsland Basins around 95-100 Ma ago - during breakup of Australia and Antartica. Even if the maximum 55°C/km gradient is used at Durroon-1, temperatures exceeding 130°C cannot be attained unless substantial erosion of Otway Group is inferred. Seismic data indicates about 300m of erosion at Durroon-1 compared with the Anderson Sub-basin, but 800-1000m or more may have been eroded compared with inferred thicknesses of Otway Group in the Boobyalla Sub-basin. A paleo-temperature of 130°C can **just** be attained if 800m of erosion occurred, and 900-1000m of erosion is necessary to comfortably exceed 130°C and result in the observed total, or near-total,

reliable values of Nicholas 1981: Table 3) and corrected BHTs:

	MATOIL MODEL	DURROON-1 DATA
VITRINITE REFLECTANCE	0.67% @ 3075mkB	0.69% @ 3014mkB
PRESENT-DAY TEMPERATURE	108^oC @ 3024mkB	110^oC @ 3021mkB

Onset of maturation (vitrinite reflectance of 0.7%) occurs at 3150mSS, with onset of gas generation (vitrinite reflectance of 1.3% - modelled below TD) at 4010mSS.

5. Modelling of the Boobyalla Sub-basin depocentre (see Table 4 and Figure 2 for stratigraphic input) (at SP300 Line WB82-40) using a slightly colder Heat Flow history than that used for Durroon-1 (5 mW/m^2 less for 0-96 Ma) predicts onset of maturity (vitrinite reflectance of 0.7%) at about the same depth as in Durroon-1. Although this is possible if the basin has equilibrated thermally <u>after</u> all effects of subsidence, maturation generally occurs at slightly greater, or much greater, depths in depocentres than on adjacent highs (due to the more conductive nature of the older basin margins than the rapidly deposited, undercompacted/overpressured basin-fill). Accordingly, due to the very high depositional rates observed in the Cenomanian Boobyalla Basin-fill (in excess of 1150m/Ma uncompacted or 520m/Ma compacted) a slightly lower heat flow again has been opted for - and heat flows $10mW/m^2$ less than those used for Durroon-1 for 0-96 Ma were modelled. The MATOIL model (BOOBYGB8 - using OMT-4, vitrinite; and BOOBYGB9 - using Organic Matter Type I, Green River Shale, see attached colour figures) predicts:

BOOBYALLA SUB-BASIN

ONSET OF MATURITY (0.7% Rv)	3300mSS
START OF GAS WINDOW (1.3% Rv)	4730mSS

6. The results are consistent with previous maturation studies in the Bass Basin (top of oil window in wells at 2.4 - 3.7 km and top of gas window at 4.4 to 6.0 km; the oil window is about 1.0 km deeper in depocentres). A direct comparison with the two nearest Bass Basin wells confirms that the modelled results are reasonable:

VITRINITE REFLECTANCE	BOOBYALLA SUB-BASIN* MODEL	CHAT-1*	SQUID-1*
0.52	2450	2525	-
0.53	2550	-	-
0.54	2650	-	-
0.55	2700	-	2510-2760
0.56	2750	-	-
0.57	2810	2685	-

* Depths are in metres subsea

TABLE 1

DURROON-1

kbe(ft) 32 ft

wd(ft) 225 ft

log	depth(ft driller	depth(m) driller	bht (f)	T time since circ(hr)	t time(hr) circ'd	rig operating time(hr)	T/T+t
isf/sonic	-3063	-933.6	96	7	1		0.88
n-d	-3063	-933.6	99	12	1	4	0.92
rft	-6030	-1838.0	147	16	1		0.94
n-d	-6030	-1838.0	147	10.5	1	4.5	0.91
isf/sonic	-6030	-1838.0	145	5	1		0.83
isf/sonic	-9913	-3021.5	176	5	1		0.83
n-d	-9913	-3021.5	196	11	1	5	0.92
seabotto	-225	-68.6	-	-	-	-	-

depth(ft) driller	depth(m) driller	extrap bht (f)	extrap bht (c)	T(f)/Z(ft) gradient to next BHT	t(c)/z(km) gradient to next BHT	T(f)/Z(ft) gradient BHT to s.f.	t(c)/z(km) gradient BHT to s.f.
-3063	-933.6	113	45.00	0.0165	30.10	0.0161	29.37
-3063	-933.6	113	45.00	0.0165	30.10	0.0161	29.37
-6030	-1838.0	162	72.22	0.0175	31.92	0.0163	29.72
-6030	-1838.0	162	72.22	0.0175	31.92	0.0163	29.72
-6030	-1838.0	162	72.22	0.0175	31.92	0.0163	29.72
-9913	-3021.5	230	110.00	n.a	n.a	0.0168	30.56
-9913	-3021.5	230	110.00	n.a	n.a	0.0168	30.56
-225	-68.6	60	15.56	0.0187	34.04	n.a	n.a

nb. Time since circ not given with n-d logs.
Assumed time since circ for ISF plus operating time for n-d plus 1 hr ~ time since circ for n-d.

nb. BHT's at 6132 (n-d) and 6153 (isf-sonic) are posted at the depth of the rft survey (6030).
This leaves the crossplot "clean" without consequential manipulation of the data set.

TABLE 2

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MATOIL DETAILED RESULTS

WELL:DURRNGB3

OIL WINDOW AND SOURCE ROCKS

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DURROON-1

SEDIMENTATION HISTORY

FORMATIONS

Number	Name	Period m.y.	Depth m	Uncompacted Deposition rate m /m.y.	Solid Deposition rate m /m.y.
1	RECENT SED	.0 - .5	0. - 5.	10.03	4.60
2	T.BELLUS	1.8 - 18.0	5. - 297.	20.69	9.50
3	P.TUBERCUL.	18.0 - 35.0	297. - 377.	6.09	2.80
4	U.N.ASPERS.	35.0 - 36.5	377. - 461.	75.34	34.58
5	M.N.ASPERS.	37.0 - 39.5	461. - 501.	22.08	10.14
6	L.N.ASPERS.	45.0 - 48.0	501. - 591.	87.85	40.32
7	L.BALMEI	55.0 - 66.0	591. - 954.	56.25	25.82
8	T.LONGUS	67.0 - 73.5	954. - 1054.	36.46	16.73
9	T.LILLIEI	73.5 - 80.0	1054. - 1207.	38.18	17.53
10	SENECTUS	80.0 - 82.0	1207. - 1291.	69.37	31.84
11	TRIPLEX	87.5 - 90.0	1291. - 1467.	249.27	114.42
12	VOLCANICS	90.0 - 91.5	1467. - 1572.	119.55	54.88
13	PARADOXA	101.0 - 106.0	1572. - 2148.	237.20	108.88
14	C.STR/U.C.H	106.0 - 118.5	2148. - 3000.	125.75	57.72
15	L.C.HUGHESI	118.5 - 137.0	3000. - 4000.	103.44	47.48
16	C.AUSTRALI.	137.0 - 145.0	4000. - 4300.	73.04	33.53

EROSIONS

Number	Name	Period m.y.	Amount eroded m	Uncompacted Erosion rate m /m.y.	Solid Erosion rate m /m.y.
1	PLEIST UC	.5 - 1.8	0.	.00	.00
2	B.TORQUAY	36.5 - 37.0	0.	.00	.00
3	B.DEMONS B.	39.5 - 45.0	100.	24.79	11.38
4	M.DIVER. UC	48.0 - 53.5	250.	62.28	28.59
5	L.M.DIVERS	53.5 - 55.0	-200.	-180.92	-83.04
6	TOP CRET UC	66.0 - 67.0	50.	78.23	35.91
7	TUR/CON UC	82.0 - 87.5	200.	59.54	27.33
8	T.OTWAY UC	91.5 - 96.0	900.	322.35	147.96
9	PANNOSUS	96.0 - 101.0	-800.	-255.94	-117.48

TABLE 3: MATURITY DATA, DURROON NO. 1

DEPTH (M) RKB	TYPE	MEAN (RANGE)	RV% EQUIV. OF TAI (3)	SOURCE/COMMENTS
1320	TAI	2.0	.35	Morgan (1985)
1375	TAI	2.1	.38	Morgan (1985)
1384	RV	.54 (.38-.67)		Cook (1985) 1
1420	RV	.49 (.41-.61)		Cook (1985) 1
1448	TAI	2.0	.35	Morgan (1985)
1457	RV	.54 (.47-.63)		Cook (1985) 1
1494	RV	.57 (.46-.68)		Cook (1985) 1
1542	TAI	2.2	.40	Morgan (1985)
1530	RV	.58 (.44-.74)		Cook (1985) 1
1603	TAI	2.2	.40	Morgan (1985)
1676	TAI	2.25	.42	Morgan (1985
~1691	RV	.37		Kantsler (1978) 2
1695.9	RV	.38 (.30-.4)		Nicholas (1981)
1743	TAI	2.3	.44	Morgan (1985)
1832	TAI	2.6	.57	Morgan (1985)
1905	TAI	2.5	.50	Morgan (1985)
1978	TAI	2.4	.46	Morgan (1985)
2530	RV	.58		Kantsler (1978) 2
2567	RV	.54		Nicholas (1981)
3000	RV	.81		Kantsler (1978) 2
3024	RV	.69 (.45-.80)		Nicholas (1981)

1. Macerals may be oxidized and reflectance too high.
2. Kantsler (1978) reflectance values tend to be high compared to other workers.
3. TAI/Ro ratios per Heroux (1978) wherein TAI/Ro = 1 as follow: 2/.35, 2.5/.5, 3/1.3 & 4/2.5.

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MATOIL DETAILED RESULTS

WELL:BOOBYGB9

OIL WINDOW AND SOURCE ROCKS

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TABLE 4: BOOBYALLA-SUB-BASIN

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SEDIMENTATION HISTORY

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FORMATIONS

Number	Name	Period m.y.	Depth m	Uncompacted Deposition rate m /m.y.	Solid Deposition rate m /m.y.
1	RECENT SED	.0 - .5	0. - 5.	10.03	4.53
2	TORQU/T.BEL	1.8 - 18.5	5. - 40.	2.15	.97
3	P.TUBERCUL.	18.5 - 35.0	40. - 80.	2.59	1.17
4	UP.N.ASPER.	35.0 - 36.5	80. - 150.	52.51	23.72
5	DEMONSBLUFF	37.0 - 39.0	150. - 190.	35.03	15.82
6	L.N.ASPERS.	39.5 - 48.0	190. - 270.	11.55	5.22
7	L.BALMEI	53.5 - 66.0	270. - 510.	25.71	11.61
8	T.LONGUS	67.0 - 73.5	510. - 660.	44.17	19.95
9	T.LILLEI	73.5 - 80.0	660. - 830.	39.72	17.94
10	UP.N.SENECT	80.0 - 83.0	830. - 1150.	171.04	77.26
11	DURROON MUD	84.0 - 91.5	1150. - 1600.	128.27	57.94
12	A.DIST/GOLD	91.5 - 95.5	1600. - 4050.	1154.94	521.70
13	A.DIST/VOLC	95.5 - 96.0	4050. - 4150.	395.28	178.55
14	P.PARAD/OTW	98.0 - 101.0	4150. - 4550.	657.75	297.11
15	C.STRIATUS	101.0 - 108.0	4550. - 5200.	186.41	84.20

EROSIONS

Number	Name	Period m.y.	Amount eroded m	Uncompacted Erosion rate m /m.y.	Solid Erosion rate m /m.y.
1	PLEIST UNC	.5 - 1.8	0.	.00	.00
2	BASE TORQU.	36.5 - 37.0	20.	45.98	20.77
3	EAST VIEW G	39.0 - 39.5	0.	.00	.00
4	M.DIVER.UNC	48.0 - 50.5	200.	93.94	42.43
5	L.M.DIVER.	50.5 - 53.5	-200.	-78.29	-35.36
6	TOP CRET UC	66.0 - 67.0	50.	69.86	31.56
7	N.SEN/AP UN	83.0 - 84.0	120.	196.06	88.56
8	T.OTWAY UNC	96.0 - 98.0	600.	589.15	266.12

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SOURCE ROCKS MARKERS

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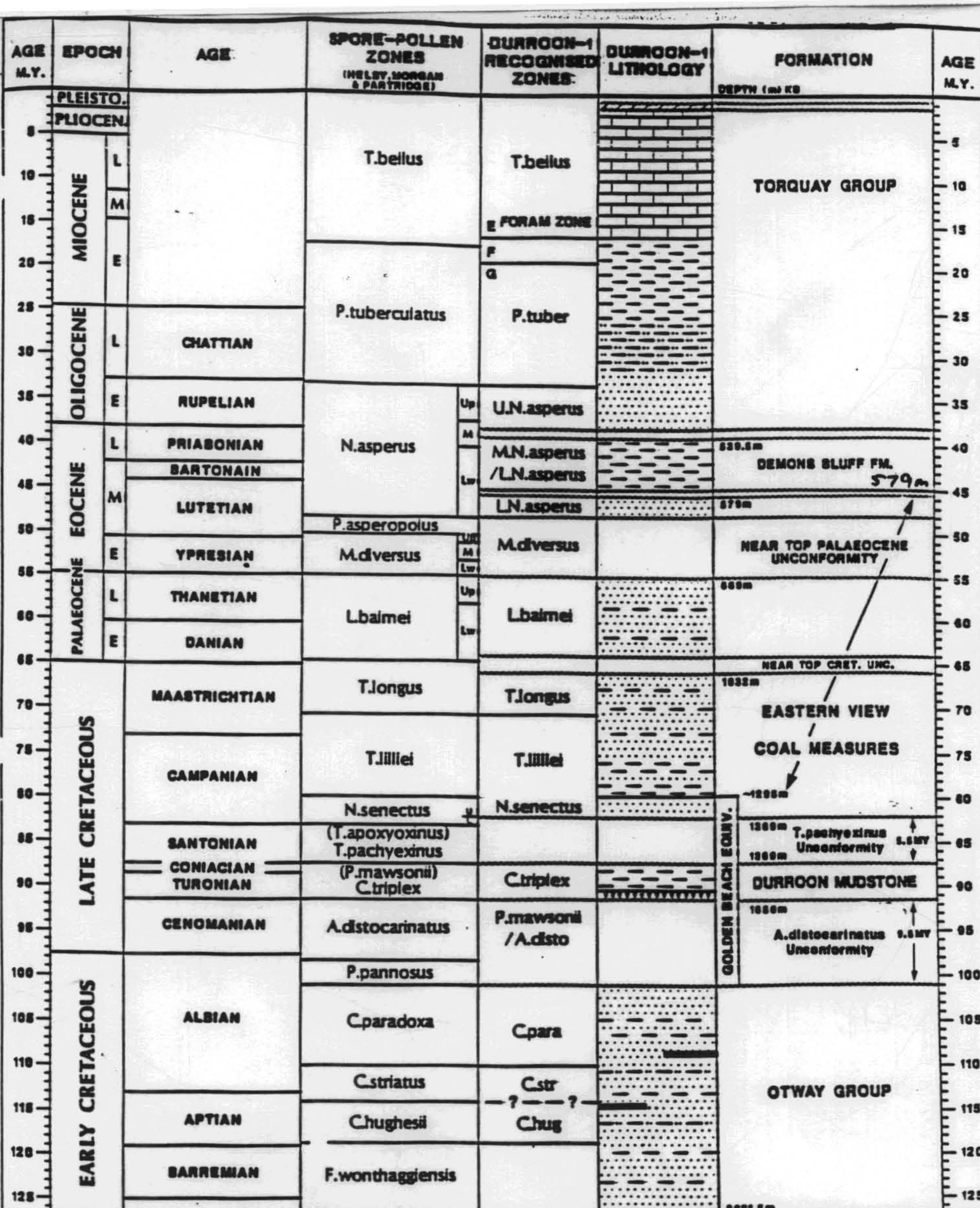
Number	Name	Depth m	Age m.y.
1	TOP EVCM	185.	38.8
2	TOP U CRET	560.	70.2
3	CAMPANIAN	749.	76.9
4	CENOMANIAN	3500.	94.6
5	CENOMANIAN	3501.	94.6
6	BSL CENOMA	3998.	95.4
7	BSL CENOMA	3999.	95.4
8	NR.T.OTWAY	4149.	96.0
9	NR.T.OTWAY	4150.	96.0
10	E.ALBIAN	4499.	100.8
11	E.ALBIAN	4500.	100.8



NOTE : PARTRIDGE (1973) RECOGNISED N.senectus ABOVE THE MID-UPPER CRETACEOUS UNCONFORMITY AT 1341.1m (SWC) AND UNDIFFERENTIATED C.triplex/A.distocarinatus BELOW AT 1374.7-1633.2m

MORGAN (1988) RECOGNISED T.lilliei ABOVE AT 1319m, AND TENTATIVELY L.lilliei BELOW IN A SPARSE ASSEMBLAGE AT 1374m, BUT DID NOT RECOGNISE EITHER N.senectus OR T.pachyexinus IN THE CUTTINGS SAMPLES.

THE WORK OF MORGAN (1991) IS MANIFESTED IN THIS CHART AND THEREFORE SUPERCEDES PREVIOUS INTERPRETATIONS.

5 cm

FIGURE 1

REFERENCES : HARLAND W.B. et al, 1982, A GEOLOGIC TIME SCALE, CAMBRIDGE UNIVERSITY PRESS.

JELL P.A. 1987, STUDIES IN AUSTRALIAN MESOZOIC PALYNOLOGY, ASSOC. OF AUSTRALIAN PALAEONTOLOGISTS.

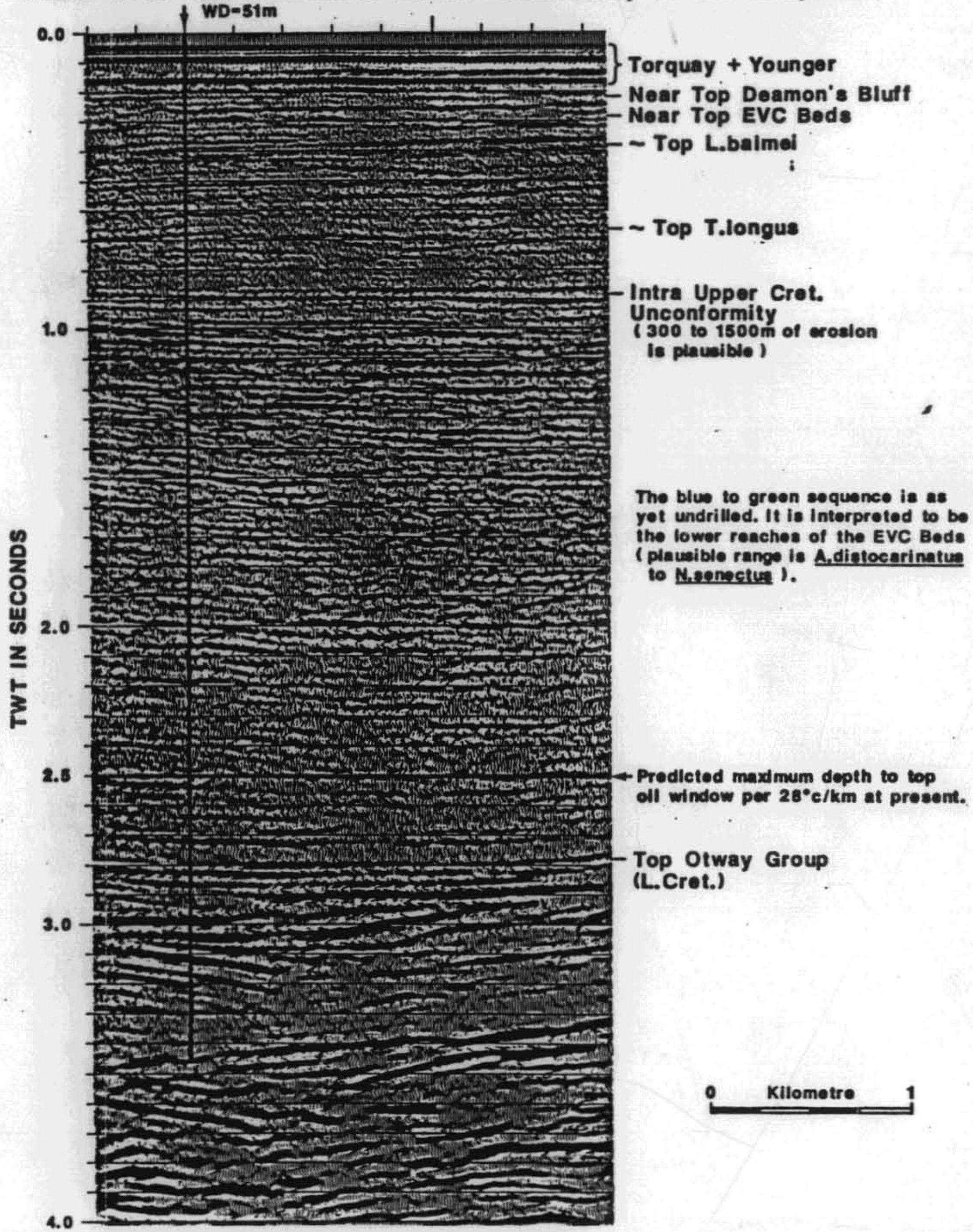
Bridge Oil Limited

DURROON-1 STRATIGRAPHIC CHART

AUTHOR : D.C.C.	DATE : AUG'88	REVISED :
DRAFTED BY : G.P.	FILING CODE :	FIGURE No. : 2

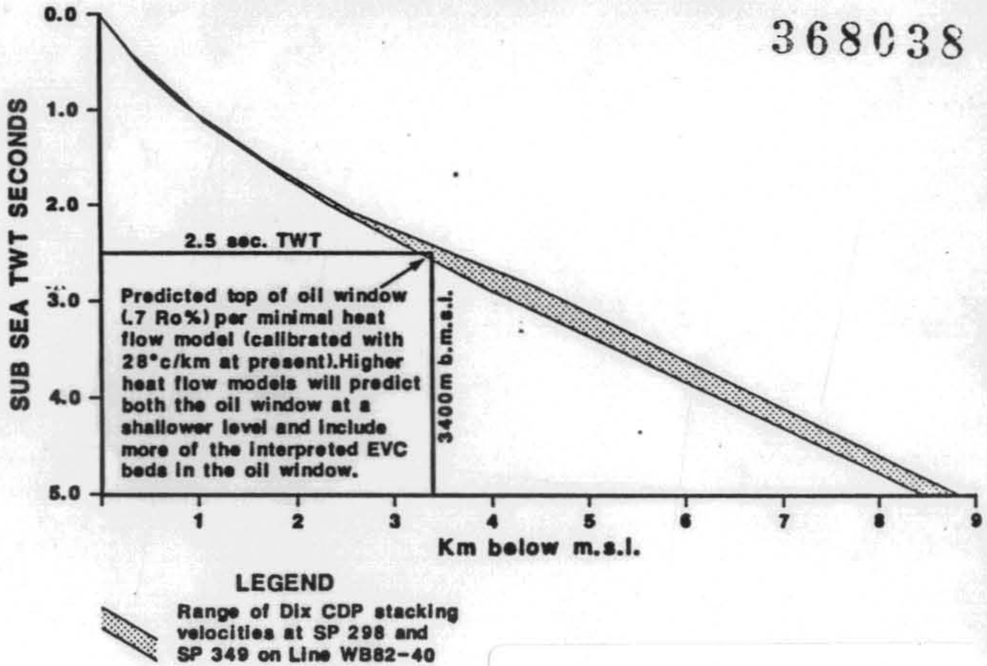
Postulated Source Rock Kitchen in Depocentre of Boobyalla Basin, T-15-P

WB82-40 SP 300 (location of MATOIL Models Booby-## and Booby##X)



Basis for Depth Estimation at Selected Kitchen Point in Boobyalla Basin Depocentre, T-15-P.

368038



5 cm

Portion of Line WB82-40
Showing Depocentre of Boobyalla Basin.

Preliminary MATOIL Modelling using an extremely modest heat flow history (calibrated with a 28°c/km gradient at present day) indicates the interpreted EVC beds below 2.5 sec. TWT will be > .7 Ro% at present.

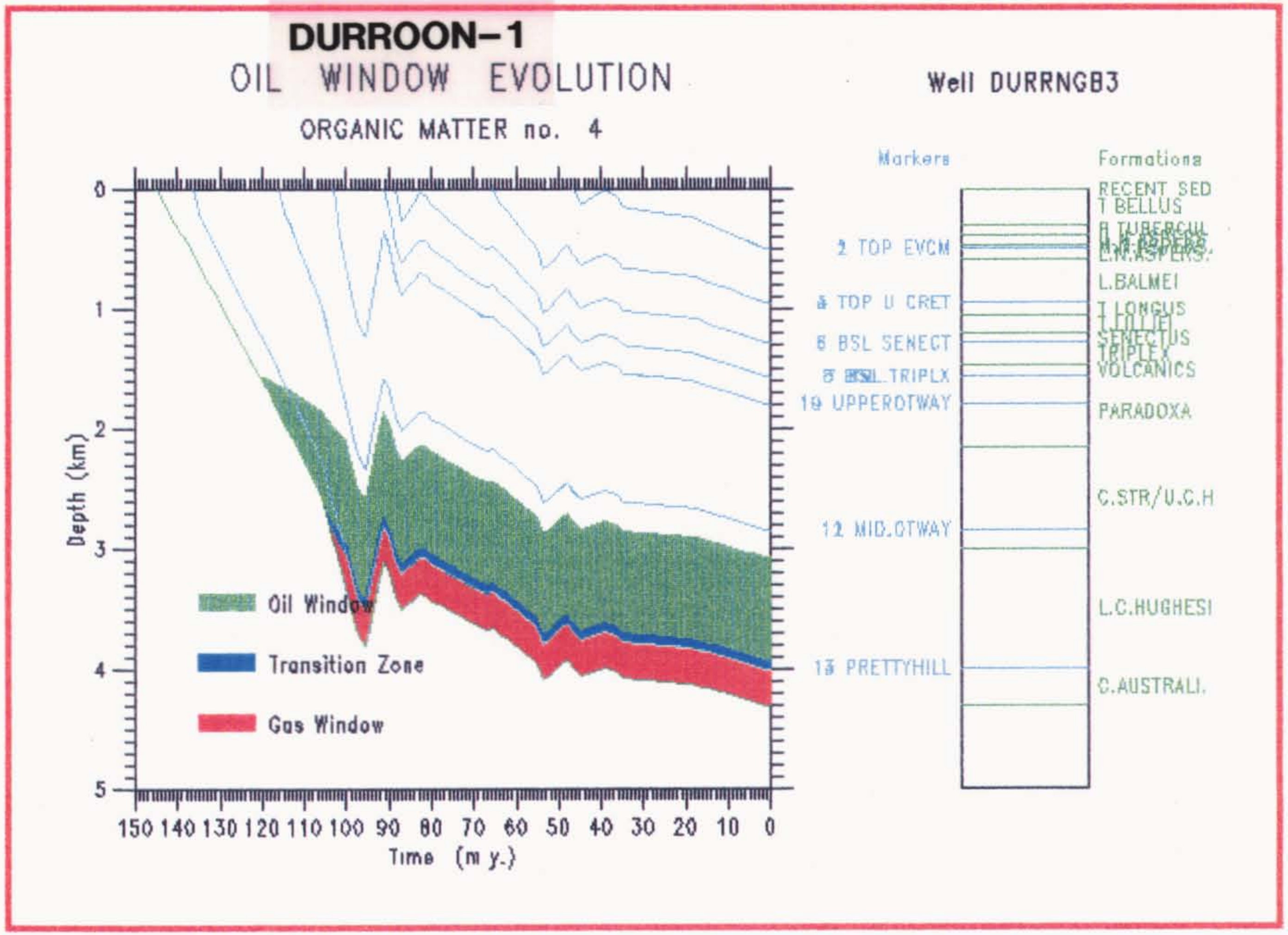
FIGURE 2

BRIDGE OIL LIMITED		
AUTHOR : B.A.G./ R.P.	DATE : AUG'88	REVISED :
DRAFTED BY : G.F.	FILING CODE :	FIGURE No. : 2

368039.

5 cm

DURROON-1

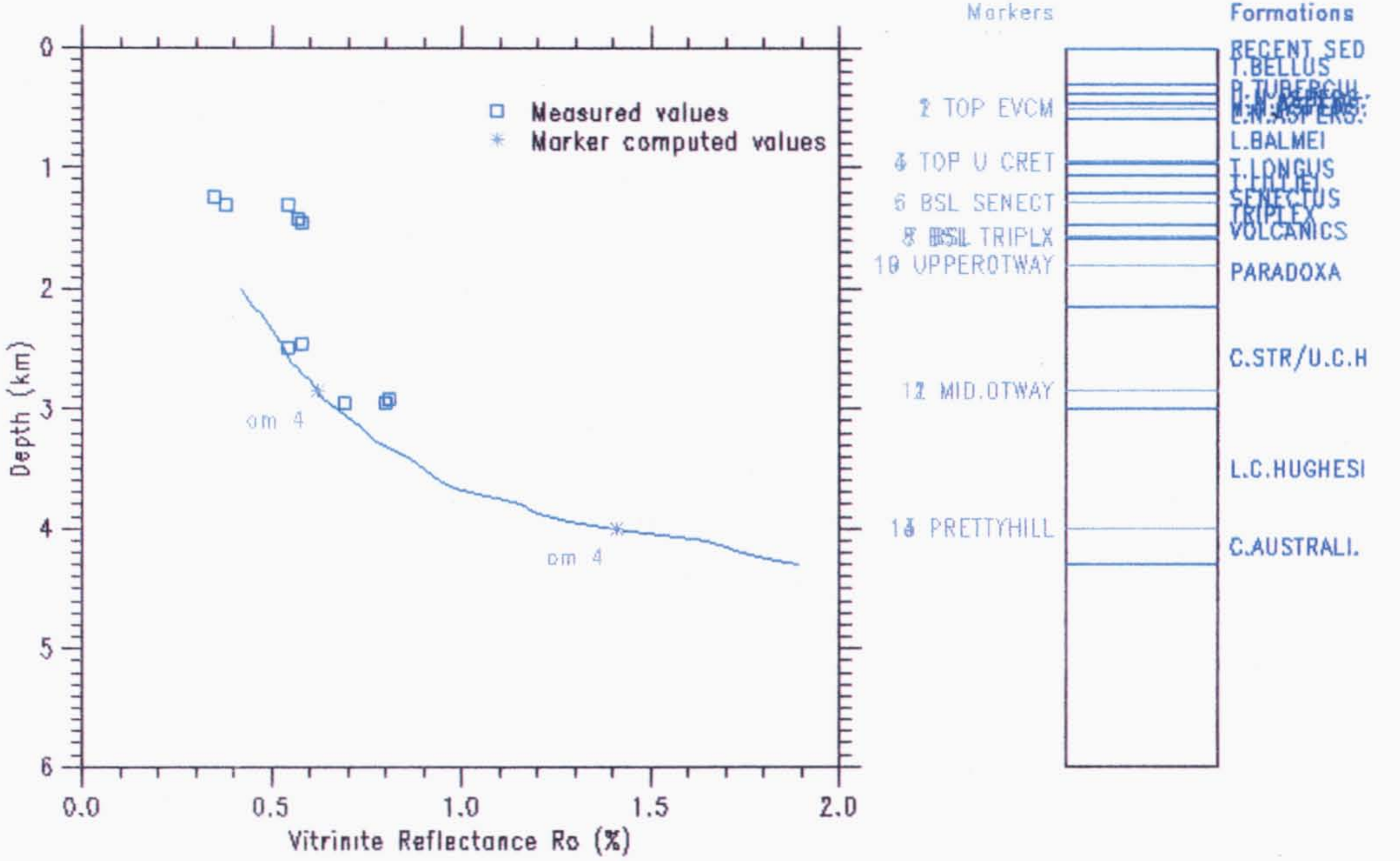


5 cm

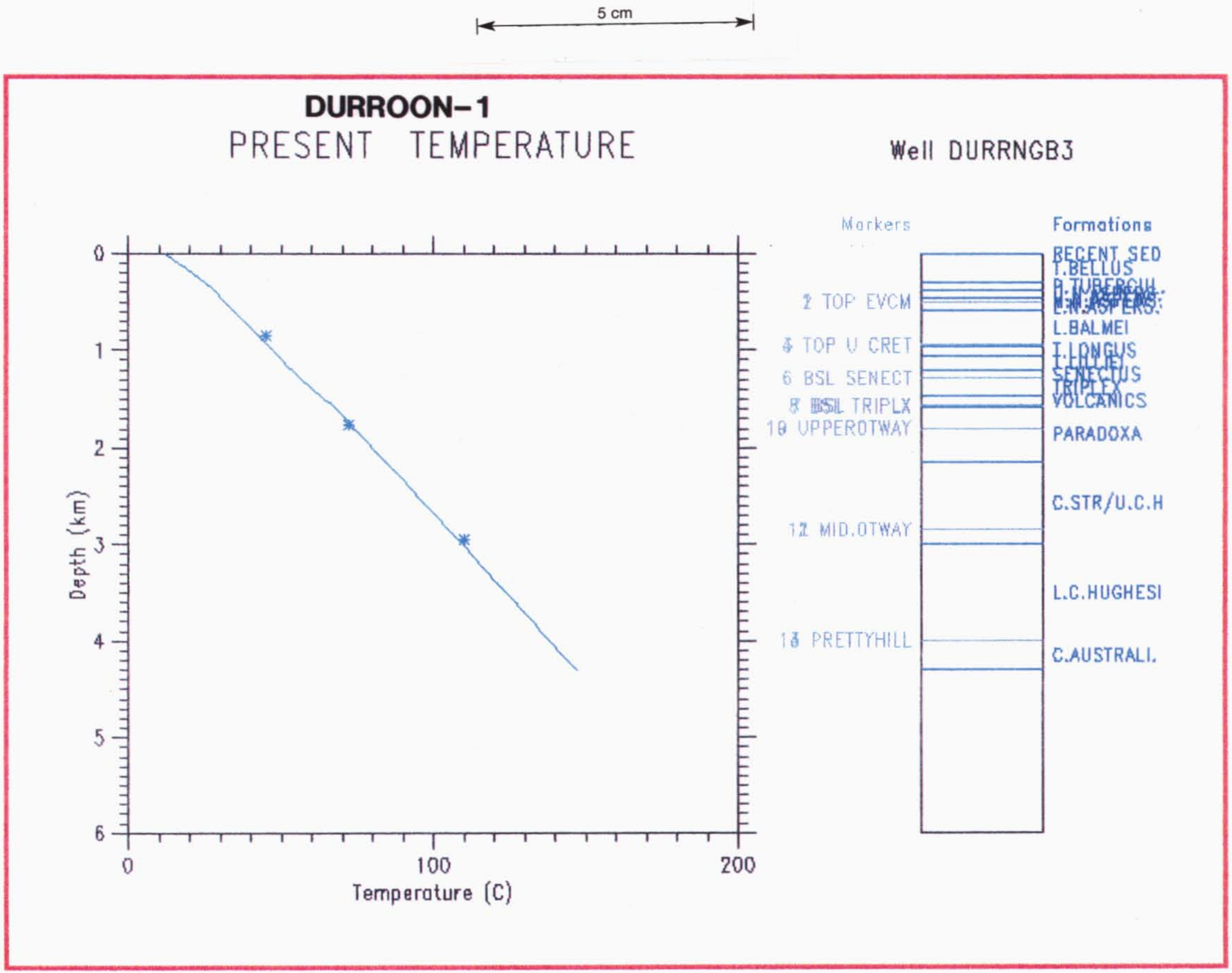
DURROON-1

PRESENT VITRINITE REFLECTANCE

ORGANIC MATTER no. 4



368040


5 cm
DURROON-1
PRESENT TEMPERATURE
Depth (km)
Temperature (C)
0
1
2
3
4
5
6
0
100
200
Well DURRNGB3
Markers
Formations
2 TOP EVCM
4 TOP U CRET
6 BSL SENECT
10 UPPEROTWAY
MID.OTWAY
PRETTYHILL
RECENT SED
T.BELLUS
L.BALMEI
T.LONGUS
SENECTUS
TRIPLEX
VOLCANICS
PARADOXA
C.STR/U.C.H
L.C.HUGHESI
C.AUSTRALI.

368042

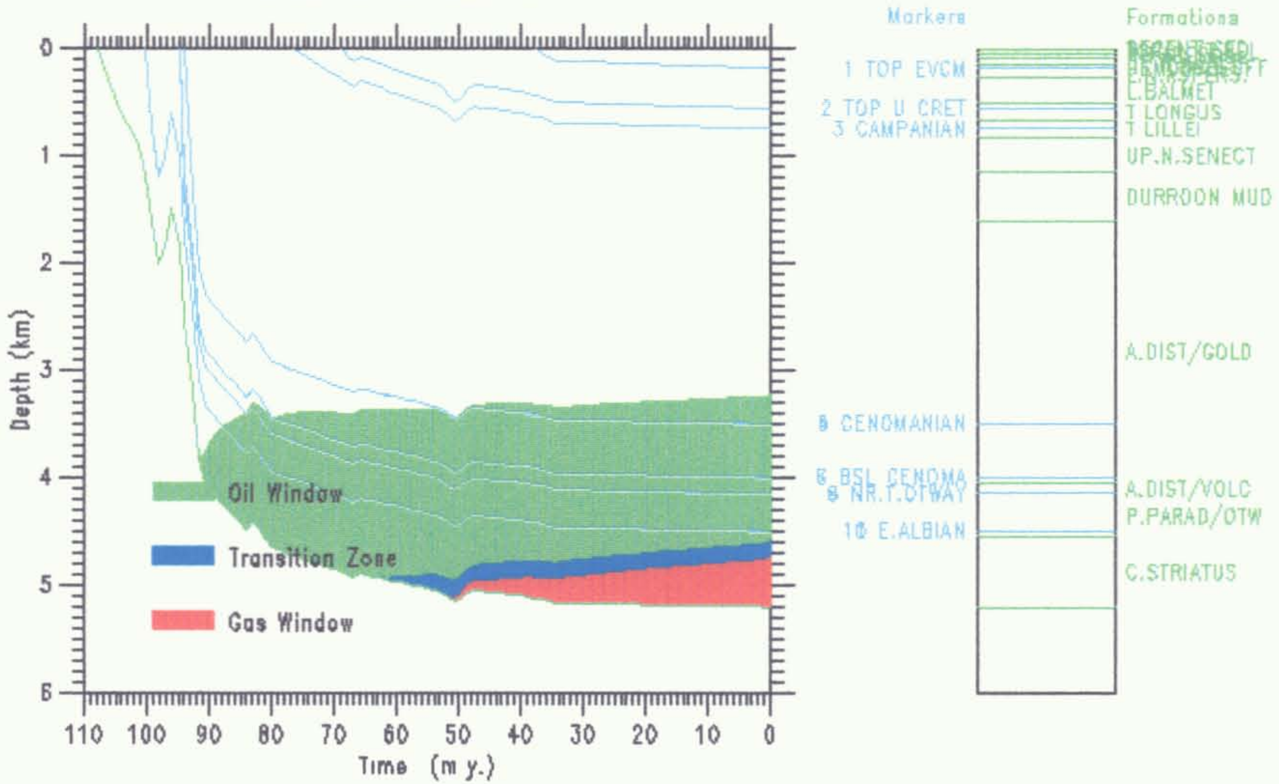
5 cm

BOOBYALLA SUB-BASIN DEPOCENTRE

OIL WINDOW EVOLUTION

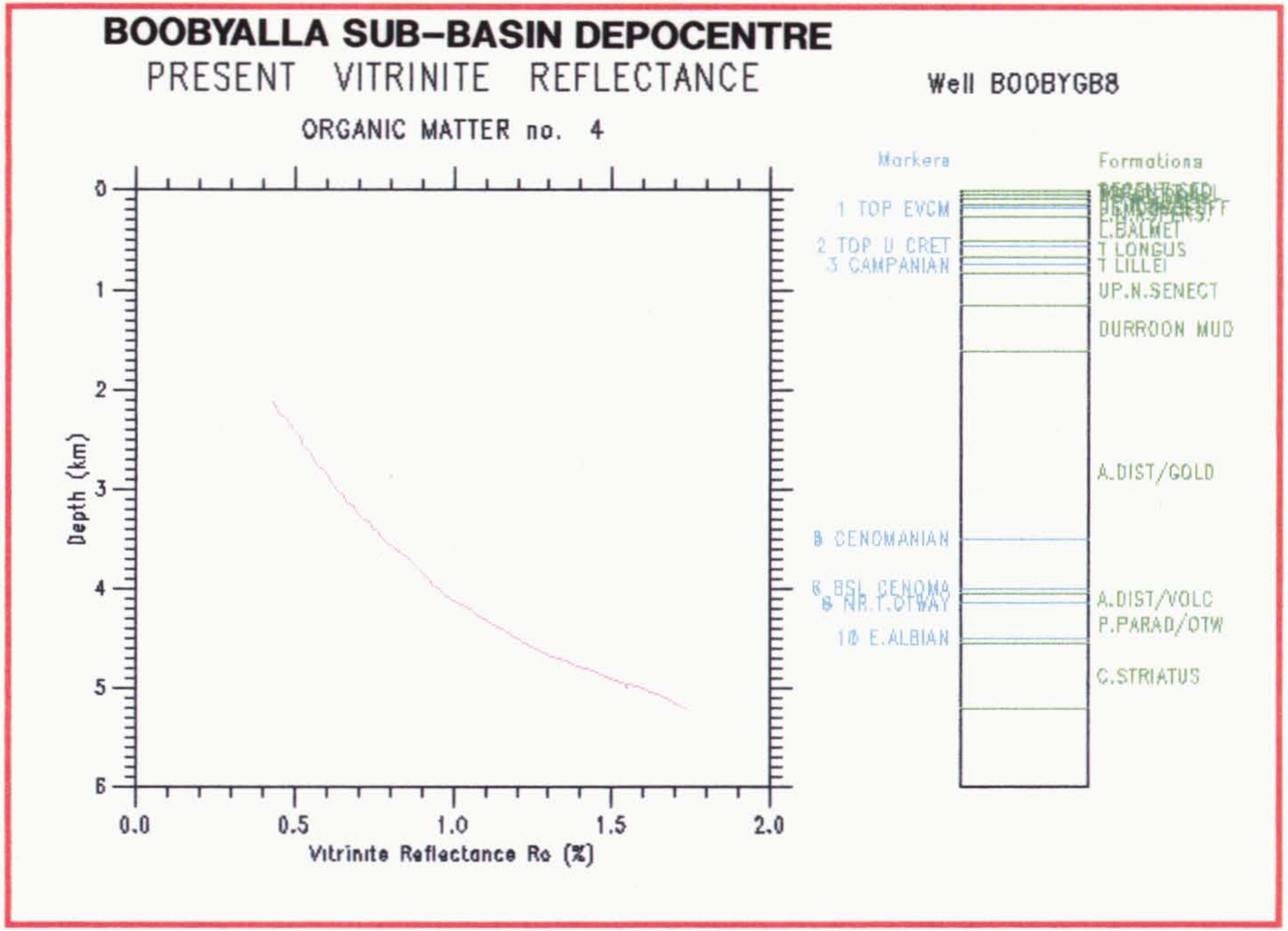
ORGANIC MATTER no. 4

Well BOOBYGB8



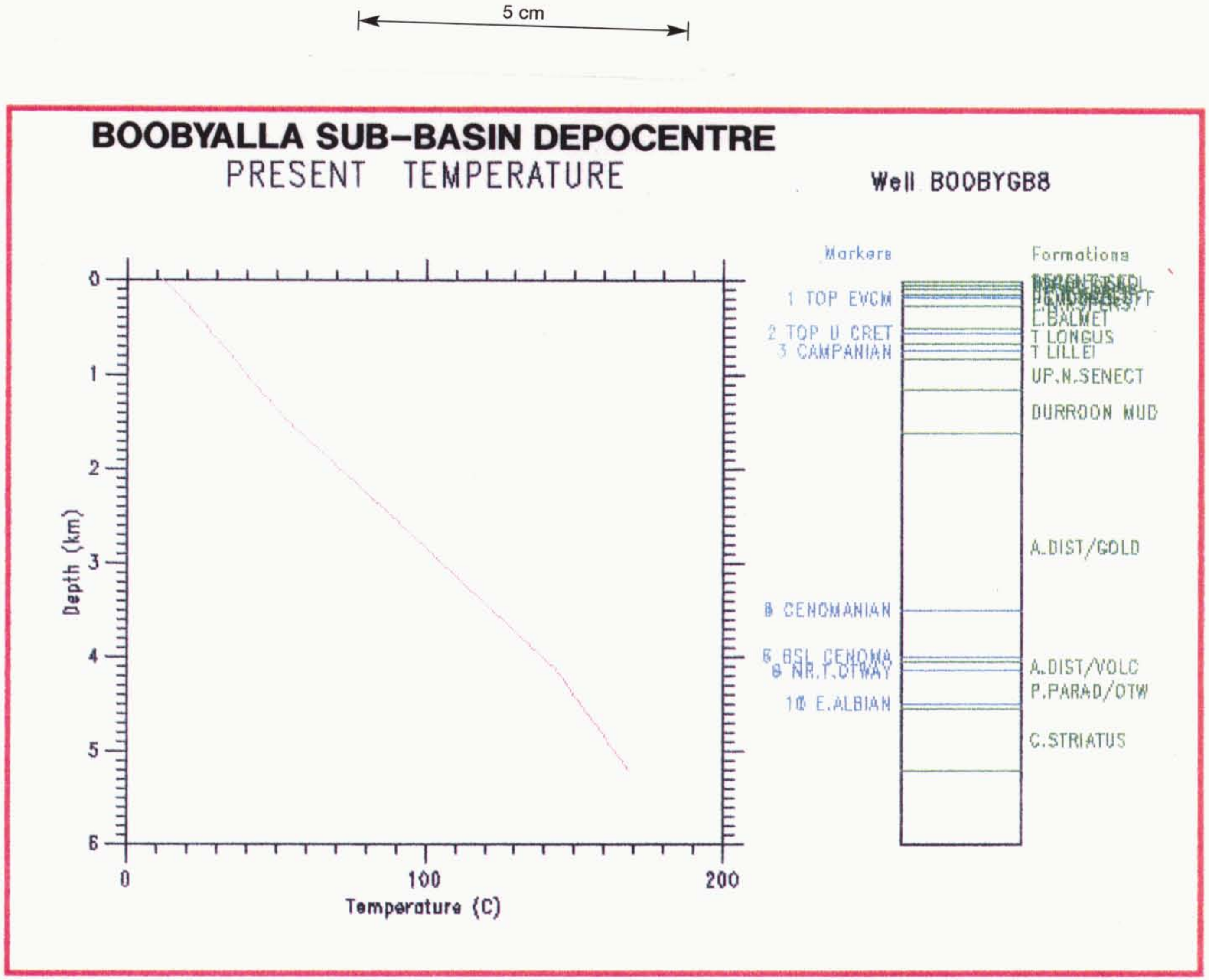
368043

5 cm



BOOBYALLA SUB-BASIN DEPOCENTRE
PRESENT VITRINITE REFLECTANCE
ORGANIC MATTER no. 4
Well BOOBYGB8
Markers
Formations
1 TOP EVCM
2 TOP U CRET
3 CAMPANIAN
L.BALMEI
T LONGUS
T LILLEI
UP.N.SENECT
DURROON MUD
A.DIST/GOLD
5 CENOMANIAN
6 BSL CENOMA
8 NR.T.OTWAY
10 E.ALBIAN
A.DIST/VOLC
P.PARAD/OTW
C.STRIATUS
Depth (km)
0
1
2
3
4
5
6
0.0
0.5
1.0
1.5
2.0
Vitrinite Reflectance Ro (%)

368044



5 cm
BOOBYALLA SUB-BASIN DEPOCENTRE
PRESENT TEMPERATURE
Well BOOBYGB8
Markers
Formations
1 TOP EVCM
2 TOP U CRET
3 CAMPANIAN
L.BALMEI
T LONGUS
T LILLEI
UP.N.SENECT
DURROON MUD
A.DIST/GOLD
CENOMANIAN
A.DIST/VOLC
P.PARAD/OTW
10 E.ALBIAN
C.STRIATUS
Depth (km)
Temperature (C)
0
1
2
3
4
5
6
100
200

Attachment 3

368045

TO: BAG **Ref:** 521/64/GB/caa

cc: GHR

FROM: GB 12 February, 1992

Re: Revised MATOIL Modelling of Durroon-1 and the Boobyalla Sub-Basin Incorporating AFTA Constraints

1. AFTA results indicate that high geothermal gradients affected the Otway Group section, and were followed by major erosion and rapid cooling after the 96 Ma breakup of Australia and Antarctica. The subsequent sedimentary section has experienced cold geothermal gradients (27°C/km) at least up to the last 1 Ma or so, when a recent heating pulse may have occurred (up to 33°C/km).

2. Several models were run to match the Durroon-1 downhole temperatures, and measured vitrinite maturity in the well. The preferred model assumes the following heat flow history:

Age (Ma)	**Heat Flow (mW/m^2)**
0	60 (calibrated to 59.4 using BHTs)
1.8	55
96	55
100	95
120	120
145	95

The model assumes high heat flow at 145 Ma (following onset of rifting at 160 Ma), increasing to a maximum at 120 Ma, but declining rapidly thereafter to breakup/onset of seafloor spreading at 96 Ma. Heat flow declines after about 120 Ma because this arm of the Otway Rift system fails, rifting commences southwest of Tasmania, and breakup/seafloor spreading finally occurs to the south of Tasmania (Veevers et al 1991 - Figures 4-7 inclusive). The recent heat pulse option has been incorporated to model corrected BHTs. The heat flow values for the Otway Group section (older than 100 Ma) were chosen after running a few models. The chosen values result in geothermal gradients up to 55°C/km in Otway Group section soon after deposition, but prior to the modelled 900m of erosion.

The MATOIL model closely matches Durroon-1 measured vitrinite (using the most reliable values of Nicholas 1981: Table 1) and corrected BHTs:

	MATOIL MODEL	DURROON-1 DATA
VITRINITE REFLECTANCE	0.67% @ 3075mkB	0.69% @ 3014mkB
PRESENT-DAY TEMPERATURE	108°C @ 3024mkB	110°C @ 3021mkB

Onset of maturation (vitrinite reflectance of 0.7%) occurs at 3150mSS, with onset of gas generation (vitrinite reflectance of 1.3% - modelled below TD) at 4010mSS.

3. Modelling of the Boobyalla Sub-basin depocentre (at SP300 Line WB82-40) using a slightly colder Heat Flow history than that used for Durroon-1 (5 mW/m^2 less for 0-96 Ma) predicts onset of maturity (vitrinite reflectance of 0.7%) at about the same depth as in Durroon-1. Although this is possible if the basin has equilibrated thermally after all effects of subsidence, maturation generally occurs at slightly greater, or much greater, depths in depocentres than on adjacent highs (due to the more conductive nature of the older basin margins than the rapidly deposited, undercompacted/overpressured basin-fill). Accordingly, due to the very high depositional rates observed in the Cenomanian Boobyalla Basin-fill (in excess of 1150m/Ma uncompacted or 520m/Ma compacted) a slightly lower heat flow again has been opted for - and

heat flows 10mW/m^2 less than those used for Durroon-1 for 0-96 Ma were modelled. The MATOIL model predicts:

BOOBYALLA SUB-BASIN

ONSET OF MATURITY (0.7% Rv)	3300mSS
START OF GAS WINDOW (1.3% Rv)	4730mSS

The results are consistent with previous maturation studies in the Bass Basin (top of oil window in wells at 2.4 - 3.7 km and top of gas window at 4.4 to 6.0 km; the oil window is about 1.0 km deeper in depocentres). A direct comparison with the two nearest Bass Basin wells confirms that the modelled results are reasonable:

VITRINITE REFLECTANCE	BOOBYALLA SUB-BASIN MODEL*	CHAT-1*	SQUID-1*
0.52	2450	2525	-
0.53	2550	-	-
0.54	2650	-	-
0.55	2700	-	2510-2760
0.56	2750	-	-
0.57	2810	2685	-

* Depths are in metres subsea

Attachment 4

368048

NEW PALYNOLOGY OF THE DURROON MUDSTONE,

DURROON-1, BASS BASIN

BY

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SOUTH AUSTRALIA

PHONE: (088) 322795
FAX: (088) 322798
REF:DW.BAS.DURROON1

for BRIDGE OIL

February, 1991

PALYNOLOGY OF THE DURROON MUDSTONE

DURROON-1, BASS BASIN

BY

ROGER MORGAN

CONTENTS

I SUMMARY

New study of 19 swc and cuttings and restudy/review of 13 previous cuttings in the Durroon Mudstone and encasing units is complete. The unexpected availability of swc material has expanded the project somewhat, but increased precision. The principal conslusions are

The Durroon Mudstone 1360m (4462ft) - 1660m (5446ft) appears to be entirely of C. triplex zone Coniacian (87.5my) - Turonian (91.5my) age, bounded above by 5my Tasman Sea breakup unconformity, and below by a 9.5my Southern Ocean breakup unconformity.

The upper Durroon Mudstone contains some striking algal assemblages expected to have encouraging oil source characteristics. These contain dominant (50-60% of palynomorphs) algal and dinoflagellate assemblages (4510ft swc, 4550ft swc, 4630-60ft cutts and 4900ft swc) and probably represent extensive lake systems developed during eustatic highstands. Many of these elements were recently described by Marshall (1989) from Kipper-1 and Sunfish-1 in the Gippsland Basin. There they occur only in the Golden Beach Formation equivalents and occur interbedded with the gas reservoir at Kipper-1. Notably, they are richer here than in the Gippland Basin.

Vail sea level charts show a total of around six cycles in the time span of the triplex zone. The best algal developments are likely to correspond to maximum lake development during highstands, and the logs suggest at least three cycles in the upper Durroon Mudstone, and perhaps three in the lower volcanic part.

Spore colour suggests marginal maturity on structure and full maturity below 2000m. However, the high algal content

may mature earlier.

The potential for new section offstructure as the unconformities diminish is intriguing. If sandy, it may provide reservior. If shaley, it may provide more source rocks. Offstructure, the upper Durroon Mudstone itself may be in deeper lake environments, and become more algal rich.

The present work has only enhanced the petroleum possibilities of the Durroon Mudstone. Instrumental geochemisty on the algal rich samples is the acid test.

368052

	AGE		SPORE - POLLEN ZONES	DINOFLAGELLATE ZONES
Early Tertiary	Early Oligocene		P. tuberculatus	
Early Tertiary	Late Eocene		upper N. asperus	P. comatum
Early Tertiary	Late Eocene		middle N. asperus	V. extensa
Early Tertiary	Middle Eocene		lower N. asperus	D. heterophlycta W. echinosuturata
Early Tertiary	Middle Eocene		P. asperopolus	W. edwardsii W. thompsonae
Early Tertiary	Early Eocene		upper M. diversus	W. ornata W. waipawaensis
Early Tertiary	Early Eocene		middle M. diversus	
Early Tertiary	Early Eocene		lower M. diversus	W. hyperacantha
Early Tertiary	Paleocene		upper L. balmei	A. homomorpha
Early Tertiary	Paleocene		lower L. balmei	E. crassitabulata T. evittii
Late Cretaceous	Maastrichtian		T. longus	M. druggii
Late Cretaceous	Campanian		T. lilliei	I. korojonense
Late Cretaceous	Campanian		N. senectus	X. australis
Late Cretaceous	Santonian		T. pachyexinus	N. aceras I. cretaceum O. porifera
Late Cretaceous	Coniacian Turonian		C. triplex	C. striatoconus P. infusorioides
Late Cretaceous	Cenomanian		A. distocarinatus	
Early Cretaceous	Albian	Late	P. pannosus	
Early Cretaceous	Albian	Middle	upper C. paradoxa	
Early Cretaceous	Albian	Early	lower C. paradoxa	
Early Cretaceous	Albian	Early	C. striatus	
Early Cretaceous	Aptian		upper C. hughesi	
Early Cretaceous	Aptian		lower C. hughesi	
Early Cretaceous	Barremian Hauterivian		F. wonthaggiensis	
Early Cretaceous	Valanginian		upper C. australiensis	
Early Cretaceous	Berriasian		lower C. australiensis	
Juras.	Tithonian		R. watherooensis	

FIGURE 1 ZONATION FRAMEWORK

5 cm

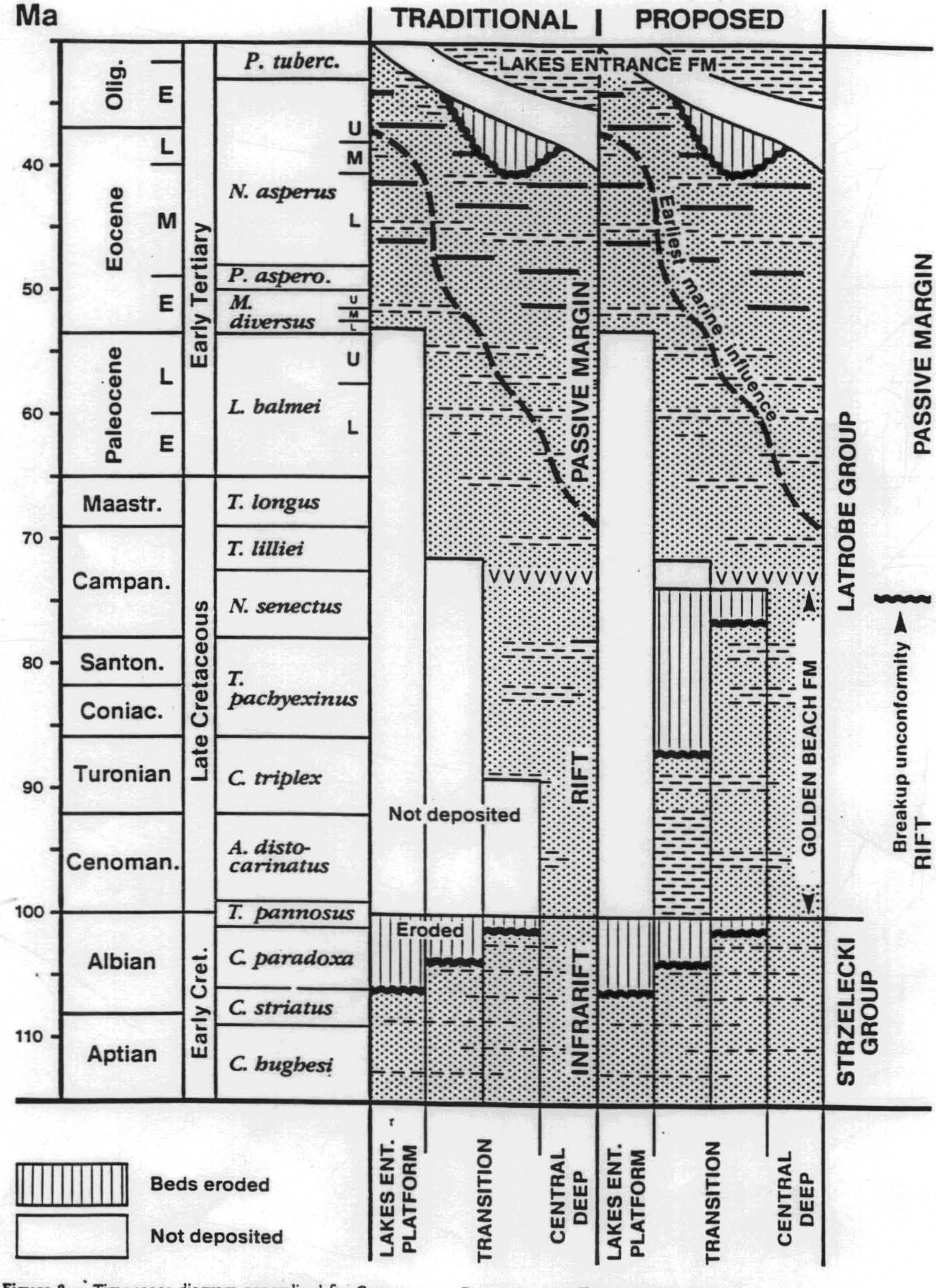

Figure 2 — Time-space diagram generalised for Cretaceous to Eocene in the offshore Gippsland Basin.

7

II INTRODUCTION

Barry Goldstein of Bridge Oil initiated a project to concisely define the age, environment and organic prospectivity of the Durroon Mudstone interval. Swc samples and selected cuttings were made available by Peter Baillie of the Tasmanian Geological Survey and studied herein. Raw data is presented in Appendix 1.

The published palynostratigraphic framework for the Cretaceous of Australia is most recently reviewed by Helby, Morgan and Partridge (1987). Until now, Cretaceous dinoflagellates had not been recorded from the Bass Basin and from the Gippsland Basin, although Marshall (1988) provided taxonomic study of some Santonian dinoflagellates. In unpublished work, Marshall (1987a) describes dinoflagellates from new cuttings samples in Pisces-1, Marshall (1987b) describes taxonomy and some stratigraphy of Campanian dinoflagellates and in (1987c) describes some Turonian - Campanian algal cysts. These latter algal forms are recorded here, but the younger dinoflagellates are still unrecorded from the Bass Basin. The Helby et al Zonal Scheme is shown in Figure 1.

In the Tertiary, the Gippsland zonal scheme was most recently published by Partridge (1976), but the scheme is essentially similar to that for New Zealand for which substantial new data is available in Wilson (1988). Significant new Gippsland data is available in unpublished and privately circulated material, Harris (1985), Morgan (1988) and Marshall and Partridge (1988). The zonal framework of Partridge (1976) is shown in Figure 1, and can be used in the Bass Basin. Figure 2 shows the geological framework recently published for the Gippsland Basin by Lowry (1987) and relevant here.

Organic maturity data was generated in the form of the Spore Colour Index and plotted on Figure 3. The oil and gas windows follow the general consensus of geochemical literature. The oil window corresponds to spore colours of light-mid brown (2.7) to dark brown (3.6). This would correspond to Vitrinite Reflectance values of 0.6% to 1.3%. However, factors such as detailed kerogen type, basin type, basin history and heating curves all affect precise interpretation, and analytical machine-based maturity parameters are probably more reliable.

III PALYNOSTRATIGRAPHY

A 4223ft swc (=1287m) : T. lillei zone

Assignment to the Tricolporites lillei zone is indicated at the top by the absence of younger indicators and at the base by oldest common Gambierina rudata and Nothofagidites senectus. Common species include N. senectus, N. endurus, Phyllocladidites mawsonii and G. rudata.

This is in accord with the zonal assignment in Partridge (1979).

Non-marine probably fluvial environments are suggested by the absence of algae or acritarchs and common cuticle with pollen and spores.

Yellow to light brown spore colours suggest early marginal maturity for oil.

B 4300ft swc (=1311m) - 4450ft swc (=1356m) : upper N. senectus zone.

Assignment to the upper part of the Nothofagidites senectus zone is indicated at the top by frequent N. endurus without G. rudata and at the base by oldest frequent N. endurus, N. senectus and Tricolpites sabulosus. Within the interval, common forms include P. mawsonii, N. endurus and Cyathidites minor.

This swc based data is in accord with the zonal assignments of Partridge (1979) and is superior to the slightly younger assignment of Morgan (1985a), which was cuttings based.

Non-marine probably fluvial environments are indicated by the absence of saline or lacustrine indicators, and the rich and diverse spores and pollen.

Light brown to yellow spores indicate early marginal maturity for oil.

C lower N. senectus to T. pachyexinus zones : not seen.

This usually distinctive interval was not seen and is presumed absent by hiatus. The zones are probably present offstructure in the basin, as they are clearly present in the deeper parts of both the Gippsland and Otway Basins. To my knowledge they have not yet been recognized in the Bass Basin.

D 4510ft swc (=1375m) - 5190ft swc (=1582m)(5400ft cutts =1646m) : C. triplex zone

Assignment to the old Clavifera triplex zone (now renamed the P. mawsonii zone) is indicated at the top by the absence of younger indicators and at the base by oldest P. mawsonii. The interval is further characterized along the northern margin of the Gippsland Basin and herein by a marked dominance of Dilwynites granulatus, and at the top by youngest Coptospora "pileosa". The algal associates are also distinctive. Amongst the pollen and spores, Dilwynites and Falcisporites dominate down to 5030ft (=1533m), with Cyathidites dominant below. Assignment is firm to the oldest P. mawsonii in swc at 5190ft, but rather more tentative below where it could be caved into the cuttings. Notably older indicators such as Appendicisporites distocarinatus, Hoegisporis spp and Trilobosporites trioreticulatus were not seen, and so the entire interval is assigned to the triplex zone, and the distocarinatus zone is interpreted as missing. Within the unit, an upper interval (4510ft =1375m to 4955ft =1510m) can be distinguished from a lower interval (5030ft =1533m to 5400ft =1646m) which contains first downhole Crybelosporites striatus, Foraminisporis asymmetricus and Cicatricosisporites cuneiformis.

This assignment is slightly different to that of Partridge (1979) but identical to that of Morgan (1985a).

The algal/microplankton content of the interval is very striking, and comprises from 1% to 60% of palynomorphs. Rimosicysta spp, and Morkallacysta spp occur in almost every sample, but their abundances and occurrences enable detailed subdivision of the unit. These subdivisions may be of only local significance, although their association with distinct log units suggestive of sequence stratigraphic sequences, suggests signigicant correlative potential.

At the top, (4510ft swc =1375m) microplankton comprise 60% of palynomorphs with Morkallacysta "verrucosa" dominant, Rimosicysta kipperi subordinate and Morkallacysta "psilata" rare. I call this the "verrucosa" acme zone. M. verrucosa only occurs rarely below this point and then only in cuttings where it may be caved. Next (4550ft swc =1387m and 4660ft cutts =1420m), microplankton comprise 50-60% of palynomorphs with M. "psilata" dominant and R. kipperi and M. "verrucosa" rare. The lower sample is in cuttings and could be caved from above the log break at 1395m. I call this the "psilata" acme zone. These zones together represent an algal maximum and are probably associated with maximum algal productivity during maximum lake development. This usually occurs during highstand when paleoslope is reduced and drainage systems back up. Next (4800ft =1463m), microplankton comprise only 1% of palynomorphs and Rimosicysta eversa first occurs downhole with rare R. kipperi and M. "verrucosum". I call this the R. eversa partial range zone. Next (4900ft swc =1494m), microplankton again comprise 60% of palynomorphs with abundant R. eversa and a varied assemblage including spiny acritarchs (Micrhystridium) and the distinctive Wuroia spp for the first time downhole. The spiny acritarchs suggest slight saline influence. I call this the eversa acme zone. The next interval (4930ft cutts =1503m to 5030ft swc =1533m) contains rare microplankton with R. kipperi prominent throughout and Micrhystridium present. At the top (4930ft swc =1503m) R. eversa is present, but may be caved in these cuttings. Micrhystridium suggests slight saline influence, and I call this the kipperi partial range zone. This group of zones may represent eustatic rise with saline influence at the base (kipperi zone) passing to maximum lake development still with saline influence (eversa acme zone) succeeded by shallowing (eversa partial range zone). The associated logs suggest an upward coarsening sequence stratigraphic unit over this interval 1540m - 1457m.

At the base (5190ft swc = 1582m to 5400ft cutts = 1646m), microplankton are again very rare (less than 1% of palynomorphs) and comprise Botryococcus, Rimosicysta spp and Morkallacysta spp with Micrhystridium at 5190ft only. The cuttings sample may be partly or wholly caved and so I have not attempted to subdivide this interval which may be essentially similar to the kipperi unit above.

Environments clearly alternate within this interval, but are essentially within the range of fluvial to lacustrine, with intermittent minor saline influence.

Light brown spore colours indicate marginal maturity for oil generation. The high algal content suggests excellent oil source characteristics and that maturity may be higher than first appears.

E 5410ft swc (=1649m) - 5460ft cutts (=1664m) : indeterminate.

These two samples are essentially barren, containing only trace quantities of long ranging Mesozoic taxa. They therefore cannot be assigned to any zone. Local heating from the volcanics may have destroyed in situ palynomorphs.

F A. distocarinatus to P. pannosus zones : not seen.

These zones have not yet been recognized in the Bass Basin, but their distinctive and common occurence in the Otway Basin suggests that they should be distinctive when penetrated here, on first downhole occurrences of taxa such as Hoegisporis uniforma, Appendicisporites distocarinatus, Trilobosporites trioreticulatus and perhaps rare Coptospora paradoxa. Their absence indicates an unconformity probably located at or near 1650m.

G 5500ft swc (1676m) - 7236ft swc (=2206m) this study : C. paradoxa zone.

Assignment to the Coptospora paradoxa zone is indicated at the top by top consistent C. paradoxa without younger indicators, coincident with a downhole influx of C. striatus and F. asymmetricus. At the base, oldest C. paradoxa is diagnostic. Previous work extends below the samples studied here and places the lower boundary at 7236ft swc (=2206m). Cyathidites, Falcisporites and Microcachryidites are common with spores such as Aequitriradites spinulosus, Foraminisporis dailyi and C. striatus frequent.

Non-marine fluvial environments are indicated by the absence of lacustrine or saline indicators, and the abundant and diverse spores and pollen.

Spore colours of light brown above about 2000m indicate marginal maturity, while colours of light to mid brown below 2000m indicate maturity for oil generation.

368062

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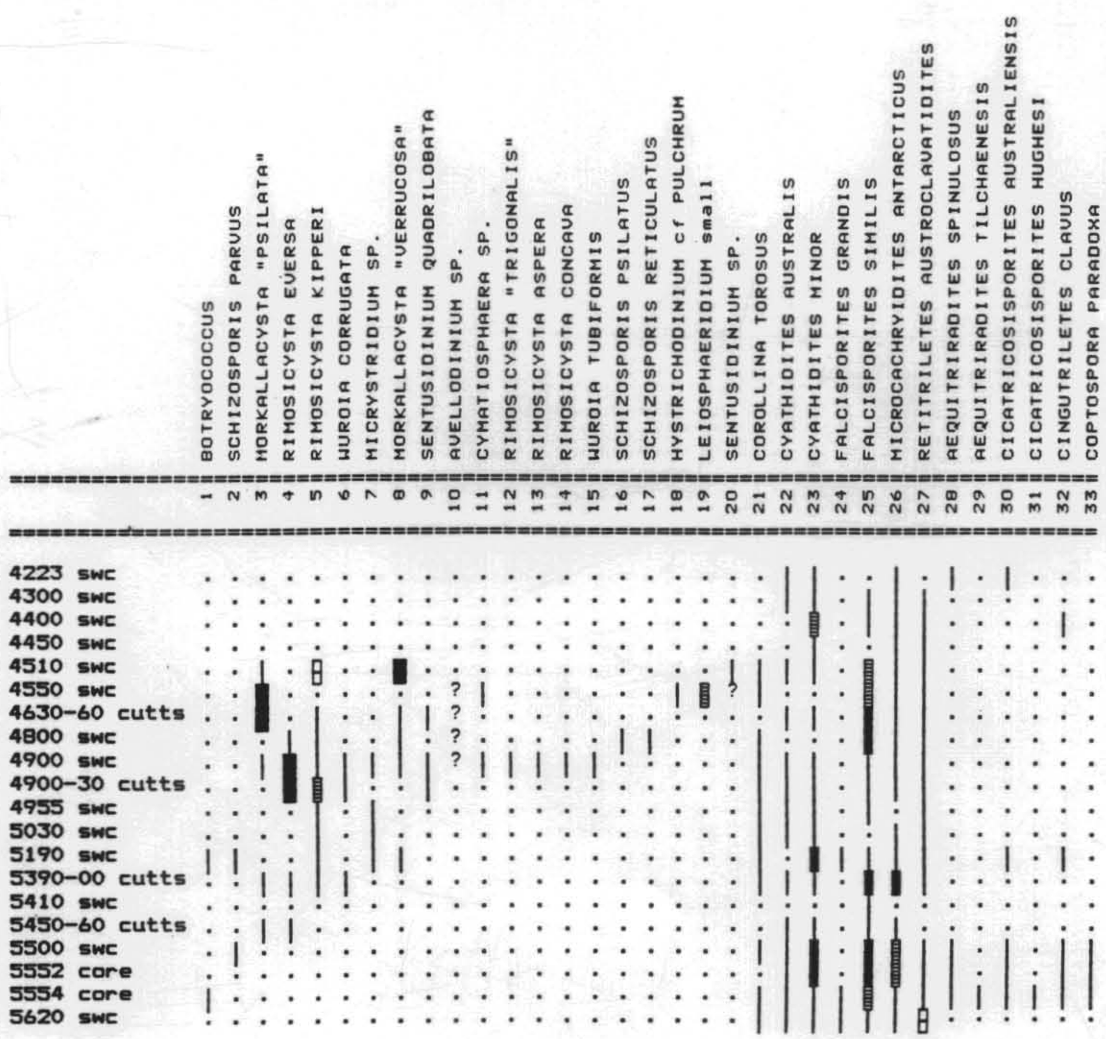
C L I E N T: Bridge Oil
W E L L: Durroon #1
F I E L D / A R E A: Bass Basin

A N A L Y S T: Roger Morgan D A T E : February '91
N O T E S: all sample depths are in feet

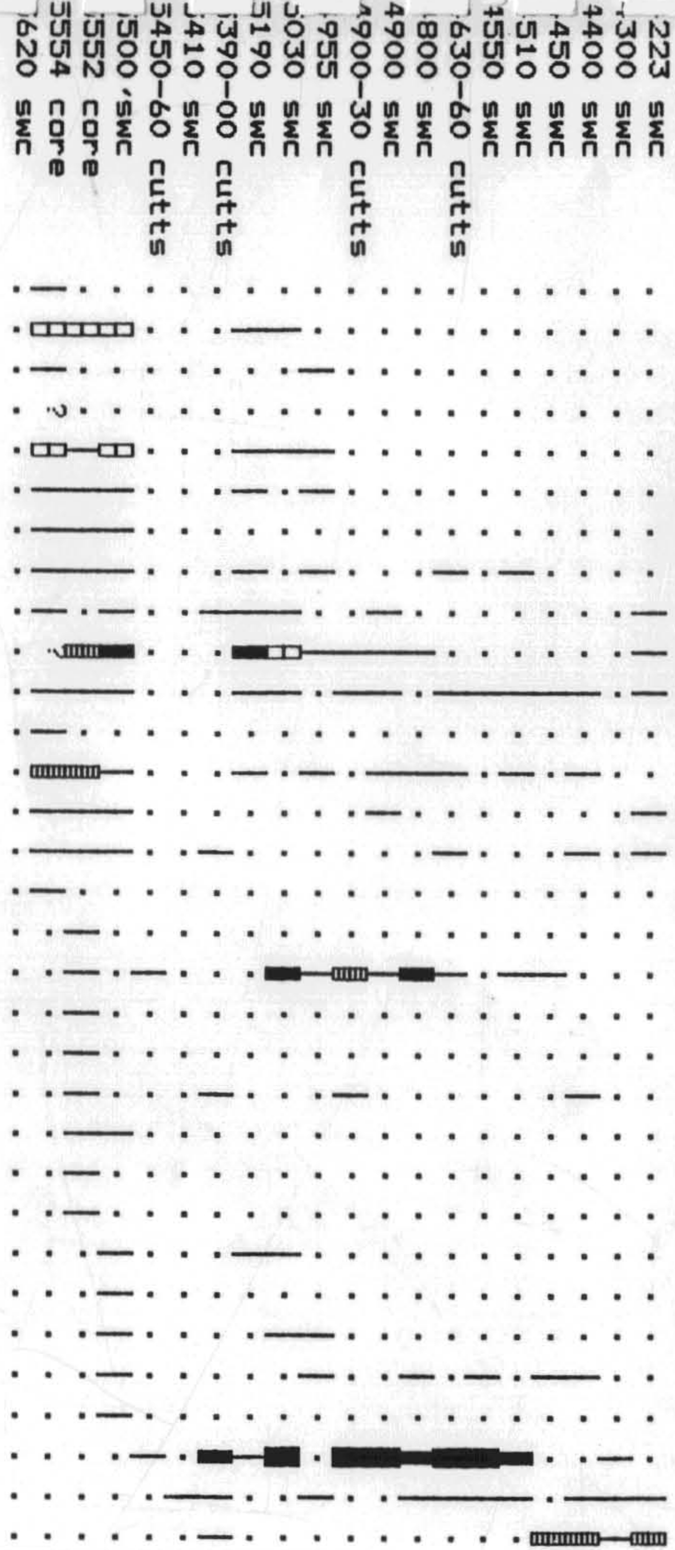
RANGE CHART OF GRAPHIC ABUNDANCES BY LOWEST APPEARANCE: dinos & s/p

Key to Symbols

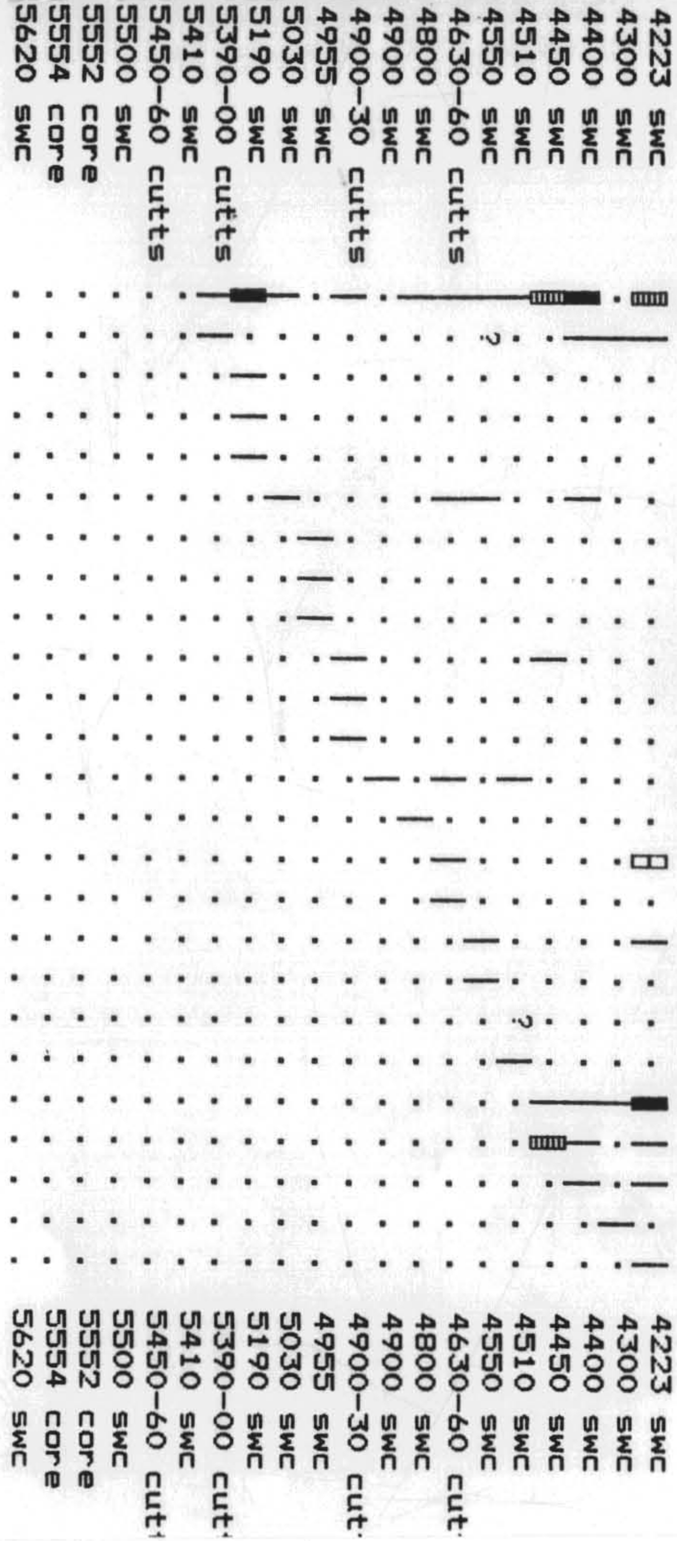
= Very Rare
= Rare
= Few
= Common
= Abundant
? = Questionably Present
. = Not Present



368063



34 COUPERISPORITES TABULATUS
35 CRYBELOSPORITES STRIATUS
36 DICTYOTOSPORITES COMPLEX
37 DICTYOTOSPORITES SPECIOSUS
38 FORAMINISPORIS ASYMMETRICUS
39 FORAMINISPORIS DAILYI
40 FOVEOTRILETES PARVIRETUS
41 GLEICHENIIDITES
42 OSMUDACIDITES WELLMANII
43 PHYLLOCLADIDITES EUNUCHUS
44 PODOSPORITES MICROSACCATUS
45 RETITRILETES WATHAROOENSIS
46 STEREISPORITES ANTIQUISPORITES
47 TRIPOROLETES RADIATUS
48 TRIPOROLETES RETICULATUS
49 VELOSPORITES TRIQUETRUS
50 AEQUITRIRADITES VERRUCOSUS
51 ARAUCARIACITES AUSTRALIS
52 ARCELLISPORITRES SP.
53 BALMEISPORITES HOLODICTYUS
54 CERATOSPORITES EQUALIS
55 DICTOPHYLLIDITES SPP
56 MATONISPORITES COOKSONIAE
57 RETITRILETES EMINULUS
58 CICATRICOSISPORITES CUNEIFORMIS
59 CONTIGNISPORITES COOKSONIAE
60 CYCADOPITES FOLLICULARIS
61 DACRYCARPITES AUSTRALIENSIS
62 SESTROSPORITES PSEUDOALVEOLATUS
63 DILWYNITES GRANULATUS
64 PROTEACIDITES SP
65 NOTHOFAGIDITES ENDURUS



67 PHYLLOCLADIDITES MAWSONII
68 TRICOLPITES GILLII
69 NOTHOFAGIDITES EMARCIDUS
70 PEROTRILETES MAJUS
71 TRICOLPORITES SP.
72 PHYLLOCLADIDITES VERRUCATUS
73 CYCLOSPORITES HUGHESI
74 FORAMINISPORIS WONTHAGGIENSIS
75 LEPTOLEPIDITES VERRUCATUS
76 CICATRICOSISPORITES LUDBROOKIAE
77 LYGISTEPOLLENITES FLORINII
78 RETITRILETES NODOSUS
79 COPTOSPORA "PILEOSA"
80 AMOSOPOLLIS CRUCIFORMIS
81 GAMBIERINA RUDATA
82 MICROFOVEOLATOSPORIS SP.
83 AUSTRALOPOLLIS OBSCURUS
84 HERKOSPORITES ELLIOTTII
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SPECIES LOCATION INDEX

Index numbers are the columns in which species appear.

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29	AEQUITRIRADITES TILCHAENESIS
50	AEQUITRIRADITES VERRUCOSUS
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51	ARAUCARIACITES AUSTRALIS
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6	WUROIA CORRUGATA

IV CONCLUSIONS

A The zonal breakdown indicates that the Durroon Mudstone appears to be entirely of C. triplex zone age, deposited during the Turonian to Coniacian (91.5 - 87.5m according to the time scale of Haq et al).

B At the top, the absence of the lower N. senectus to T. pachyexinus zones indicates a Santonian to lower Campanian time gap of about 5my (87.5-82my). This corresponds to the intra senectus Tasman Sea breakup unconformity of Lowry (1987).

C At the base, the absence of the A. distocarinatus and P. pannosus zones indicates a latest Albian to Cenomanian time gap of about 9.5my (91.5m to 101my). This corresponds to the pannosus Southern Ocean breakup unconformity of Lowry (1987).

D These age relationships indicate that the Durroon Mudstone is age equivalent to the Golden Beach Formation in the Gippsland Basin, as discussed by Lowry (1987). This affinity is closely seen in the associated distinctive suite of algal cysts described from the Golden Beach Formation of Kipper-1 (2296.5 - 2839m) and Sunfish-1 (2480.7 - 2485m) as well as some Bass Canyon dredge sites by Marshall (1989).

Notably, these algal cysts occur interbedded with the reservoir section in Kipper-1. However, they are much more common in the Durroon Mudstone than in the Gippsland Basin samples. These algal cysts are expected to be excellent oil source material, if present in sufficient quantities. They reach 50-60% of palynomorphs in two distinct and distinctive horizons, and are likely to indicate times of maximum algal productivity in large lake systems formed during highstands. The rare spiny acritarchs suggest, but do not definitely indicate, minor and intermittent saline penetration into the system. The low algal percentages probably represent lowstand intervals with greater palaeoslope and so more fluvial rather than lacustrine influence.

E Vail sea level charts show a total of around six cycles during the time span of the triplex zone. Within the upper Durroon Mudstone, at least three distinct cycles are evident on the logs. The oldest (1540m to 1455m) shows coarsening up and corresponds to transgression with slight saline influence at the base (kipperi zone herein) passing to maximum lake development and an algal acme (eversa acme zone) then decreased algal production with shallowing (eversa partial range zone).

The second cycle (1455m to 1398m) shows good shale developments at top and base, but is essentially unsampled palynologically, (if 4660ft cutts = 1420m is entirely caved).

The third cycle (1398m to 1369m) shows maximum algal production throughout (psilata to verrucosa zones).

In the lower (volcanic) part of the unit, shale peaks at 1648m 1627, and 1603m may represent flooding shales, but correlation to sea levels is doubtful due to poor lithologies for palynology, and the volcanic influence which could easily mask depositional features.

Conceptionally, all of these sequence stratigraphic boundaries are unconformities and can thicken up into new section laterally. Detecting the extent of the break is beyond the resolution of the palynology at the present state of knowledge. Extensive drilling in the area would be necessary to develop such detail.

F Spore colour suggests marginal maturity for the Durroon Mudstone, although burial below 2000m offstructure should bring it within the oil window. Algal kerogens however, tend to mature at slightly lower spore colours, and so the section may be early mature on structure. Instrumental geochemistry should yield more accurate estimates.

G Clearly the potential exists for new section to be developed offstructure, as the major bounding unconformities diminish, and as the sequence stratigraphic unconformities are traced laterally. If these result in sand development, then reservoir potential may be enhanced. If these result in shale development, additional source rocks may enhance the hydrocarbon potential. Also, the Durroon Mudstone itself offstructure may become even more algal rich with increasing water depth into the lowlying lake systems, filling the developing rifts.

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