VIC/P31, OTWAY BASIN, VICTORIA

MINERVA-1

MINERVA-2/2A

LA BELLA-1

SUMMARY OF GEOCHEMICAL DATA

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1 INTRODUCTION

Geochemical analyses were performed on samples from each of the Minerva-1, Minerva-2/2A and La Bella-1 wells in 1993. While some of these analyses were performed with the aim of characterising source rocks within the drilled sequences, others, more importantly, were aimed at characterising any liquid hydrocarbons which could be obtained from within the gas columns intersected by the wells. Such characterisation would, it was felt, indicate whether such liquids represented residua of earlier oil saturations displaced by the existing gases, or whether they represented liquids indigenous to, or very locally migrated within, the gas reservoir intervals.

Interpretative reports for the Minerva-1, Minerva-2/2A and La Bella-1 wells formed part of Volume 2 of the respective well completion reports, and are not presented here; however, the conclusions pages from these reports are assembled in an appendix to this document.

This document seeks to combine the conclusions drawn from the geochemical data from the individual wells, and to summarise their implications for the hydrocarbon prospectivity of the VIC/P31 permit and adjacent areas. Recommendations are then made for a pilot programme of geochemical analysis designed to test the inferences made to date.

2 GEOCHEMICAL INTERPRETATION

As stated in the Introduction, the main aim of the geochemical analyses in Minerva-1, Minerva-2/2A and La Bella-1 was to determine whether or not the existing accumulations of gas intersected in these wells had been preceded by accumulations of liquids. To this end, a number of SWCs from these wells were solvent-extracted for their contained hydrocarbons, and the resulting extracts analysed to varying degrees of detail, including GC and GC-MS (see relevant interpretative reports for resultant data). Condensates from the wells, obtained by the cold-trapping of gases recovered from RFT, were similarly analysed for comparison with the extracts.

The geochemical data which can be most directly applied to this issue are :

- Total extract yields
- GC character of the extracts and condensates
- thermal maturities of the extracts and condensates relative to the maturity profiles in the wells
- Biomarker character of the extracts and condensates.

2.1 Total Extract Yields

Total extract yields for five Minerva-2/2A samples and six La Bella-1 samples are plotted against depth in Figure 1. All extract yields were less than 800ppm, with the exception of the Minerva-2/2A 1860.3m sample.

These figures did not offer any strong indication that the extracts represented residual hydrocarbon saturations (which are normally characterised by extract yields an order of magnitude greater than those observed). Note that the higher (7000ppm+) yield of the Minerva-2/2A sample is consistent with its coaly nature, and does not necessarily represent migrated liquid saturation.

2.2 GC Character of Extracts and Condensates

The GC (sats) traces of four condensates, obtained by the cold-trapping of gases from La Bella-1 and Minerva-1, are shown in Figure 2. Normalised GC (sats) traces of five extracts from La Bella-1, and one from Minerva-2/2A, are shown in Figure 3.

The normalised GC traces from the extracts show few similarities, and their compound distributions are in fact more typical of immature fluids indigenous to the section (G. Woodhouse, pers. comm.). Mature, migrated fluids by contrast would tend to display more similar compound distributions.

The condensates, which we assume from their very nature to be migrated fluids, not surprisingly show very similar compound distributions. The greater proportion of C_{15}+ compounds in the La Bella-1 condensates relative to the Minerva-1 fluids may be associated with phase effects (either in the sub-surface, or during the cold-trapping of the associated gases), and is not necessarily an indication that different sources are involved.

2.3 Thermal Maturities of the Extracts and Condensates

The condensates and extracts shown in Figures 2 and 3 were subjected to SIR GC-MS analysis of their branched/cyclic saturate and aromatic fractions. The values of certain biomarker ratios obtained from this work, namely C_{29} 20S/(20S+20R) and MPI-1, were used to estimate the thermal maturities of the condensates and extracts relative to the maturity profile of the drilled section.

In Figure 4, values of the C_{29} 20S/(20S+20R) parameter are cross-plotted with another sterane-based maturity parameter, C_{29} $\beta\beta/(\beta\beta+\alpha\alpha)$. Samples in which values of both these parameters are reliable should plot on, or close to, the diagonal trend (which is calibrated with equivalent values of VR). As Figure 4 shows, the data points from the La Bella-1 extracts show considerable scatter, but occupy a maturity range (relative to both axes) of about 0.65-0.70% VR. By contrast, the La Bella-1 and Minerva-1 condensates display equilibrium values of C_{29} 20S/(20S+20R) though not of C_{29} $\beta\beta/(\beta\beta+\alpha\alpha)$, suggesting thermal maturities of <u>at least</u> 0.80% VR.

The MPI-1 values from GC-MS analysis of the aromatic fractions of the condensates and extracts can be converted to equivalent values of VR by one of two algorithms according to the perceived maturity of the sample (Radke et al, 1983), namely :

- Rc(a) = 0.6 MPI-1 + 0.40 for VR < 1.35%

<u>or</u>

- Rc(b) = -0.6 MPI-1 + 2.30 for VR > 1.35%

A third algorithm (Boreham et al, 1988), calibrated for Australian coals, is broadly commensurate with Rc(a) above :

- Rc(c) = 0.7 MPI-1 + 0.22 for VR < 1.70%

The maturity estimates based on the sterane-derived parameters (discussed above) suggest that the Rc(a) and Rc(c) estimates of VR are appropriate to the La Bella-1 and Minerva-2/2A extracts. When these algorithms are applied to the MPI-1 values from the extracts, the resulting estimates of VR (Rc(a) and Rc(c)) fall on, or close to, the profile of measured VR values obtained from well samples (see Figure 5). This provides further support to the earlier assertion that the extracts are indigenous to, or very locally migrated within, the reservoir intervals of La Bella-1 and Minerva-2/2A.

By contrast, $\delta^{13}C$ isotope data from the La Bella-1 gases indicate that they (together with their associated condensates) were expelled from their source rocks at thermal maturities greater than 1.30% VR. The Rc(b) algorithm would therefore appear to be appropriate for the conversion of MPI-1 values from the condensates (see Figure 5). Their advanced maturities relative to the well profile are consistent with their migrated nature.

2.4 Biomarker Character of the Extracts and Condensates

The La Bella-1 and Minerva-2/2A extracts are each characterised by the presence of C_{28}-bisnorhopane (Figures 6 and 7), a compound which is considered not to be generated from kerogen, but derived from the original free bitumen in the sediment. It tends to become less conspicuous with increasing maturity as it is swamped by, or co-elutes with, compounds formed by hydrocarbon generation. The compound is not identified in the La Bella-1 condensates, nor in the Minerva-1 1942.5m condensate; it does, however, appear in the Minerva-1 1649.8m condensate (Figure 7). Since this was extracted from formation water indigenous to 1649.8m, it seems likely that this was the source of the C_{28}-bisnorhopane in this sample.

The conspicuous presence of C_{28}-bisnorhopane in the extracts seems to rule out any genetic link with fluids from similar depths which are known to be migrated, namely the condensates. It appears that C_{28}-bisnorhopane may serve as a defacto immaturity indicator in the Late Cretaceous sequences of the Otway Basin, and may in future provide a useful criterion in distinguishing between indigenous (immature) and migrated (mature) hydrocarbons.

Note that there are subtle differences between the biomarker distributions of the La Bella-1 and Minerva-1 condensates. For example, the values of Ts/Ts+Tm are lower in the La Bella-1 condensates, and while these contain the "unknown" compounds U2 and U4, the Minerva-1 condensates do not. However, these differences may be due to phase or fractionation effects, or to variations introduced during analysis, and do not necessarily imply separate sources for the La Bella-1 and Minerva-1 gases/condensates.

Note, too, that the La Bella-1 and Minerva-2/2A samples which contain C_{28}-bisnorhopane were extracted from sediments of Turonian-Santonian age (the P. Mawsonii - T. apoxyexinus biozones). Hydrocarbons from a Duntroon Basin well which were found to contain this biomarker were extracted from sediments of identical age; significantly, two source-rock extracts of Cenomanian age from the same well did not contain the compound. This suggests that the occurrence of C_{28}-bisnorhopane in sediments of the offshore southern margin of Australia is age specific, and strengthens the argument that the La Bella-1 and Minerva-2/2A extracts are essentially indigenous.

3 CONCLUSIONS

Geochemical data were obtained from the analysis of samples from Minerva-1, Minerva-2/2A and La Bella-1 in 1993. These samples included gases, associated condensates (obtained by cold-trapping), and solvent-extracted liquid hydrocarbons from SWCs. The main aim in analysing the latter was to identify any residual liquid hydrocarbon saturations within the gas-bearing intervals which might represent an earlier accumulation of liquids displaced by existing gas. Confirmation of the presence or absence of such liquids would have a profound effect on an understanding of the petroleum system(s) at work in the offshore Otway Basin of Victoria.

Based on total extract yield data, GC (sats) data, thermal maturity data, and biomarker (GC-MS) data, it appears that liquid extracts obtained from the gas-bearing interval in La Bella-1 do <u>not</u> represent mature, migrated hydrocarbons, but instead represent immature fluids indigenous to, or very locally migrated within, the Late Cretaceous Shipwreck Group sediments. The same is very likely to be true of the Minerva field gas-bearing intervals. This means that these reservoirs have only ever contained gas (or water), and that this gas did not displace pre-existing liquid hydrocarbons. It is possible that <u>if</u> source rocks down-dip of Minerva and La Bella-1 <u>did</u> expel liquids during an oil-generative phase in their progression to the gas-window, then they did so at a time before the formation of the Minerva and La Bella structures. Careful maturation modelling, calibrated by well data, may assist in determining the likelihood of this.

4 RECOMMENDATIONS FOR FURTHER WORK

Based on observations in both the Otway and Duntroon Basins concerning the occurrence of C_{28}-bisnorhopane in sediment extracts, it appears that this compound may provide a useful, or even diagnostic, criterion in the characterisation of source-rocks and fluids and in the evaluation of hydrocarbon shows in these areas. For example, its presence or absence, taken together with other corroborative data, seems to offer important clues as to whether a fluid is indigenous to the section from which it was recovered or was migrated into it. Of particular interest is its apparent restriction to two palynological zones in the early Late Cretaceous, since the Minerva and La Bella reservoirs are themselves of this age.

It is recommended that some attempt is made to characterise Late Cretaceous claystones in the offshore Otway Basin in terms of the presence or absence of C_{28}-bisnorhopane in fluids extracted from them. If the significance of this compound can be revealed, it may provide a powerful arbiter in the characterisation of hydrocarbon shows and in the assessment of the efficiency of Late Cretaceous petroleum systems throughout the southern margin of Australia.

The analytical programme should be initially restricted to a few samples from the Ceomanian to Santonian interval in selected wells, to confirm the patterns revealed by existing data. A judgement can then be made by the Joint Venture partners as to whether the study should be extended. The detailed nature of the analyses required (GC-MS of the branched and cyclic saturates) makes the per sample cost about A$600, but the small number of samples (10 or less) required for a pilot programme would mitigate the overall cost to the Joint Venture.

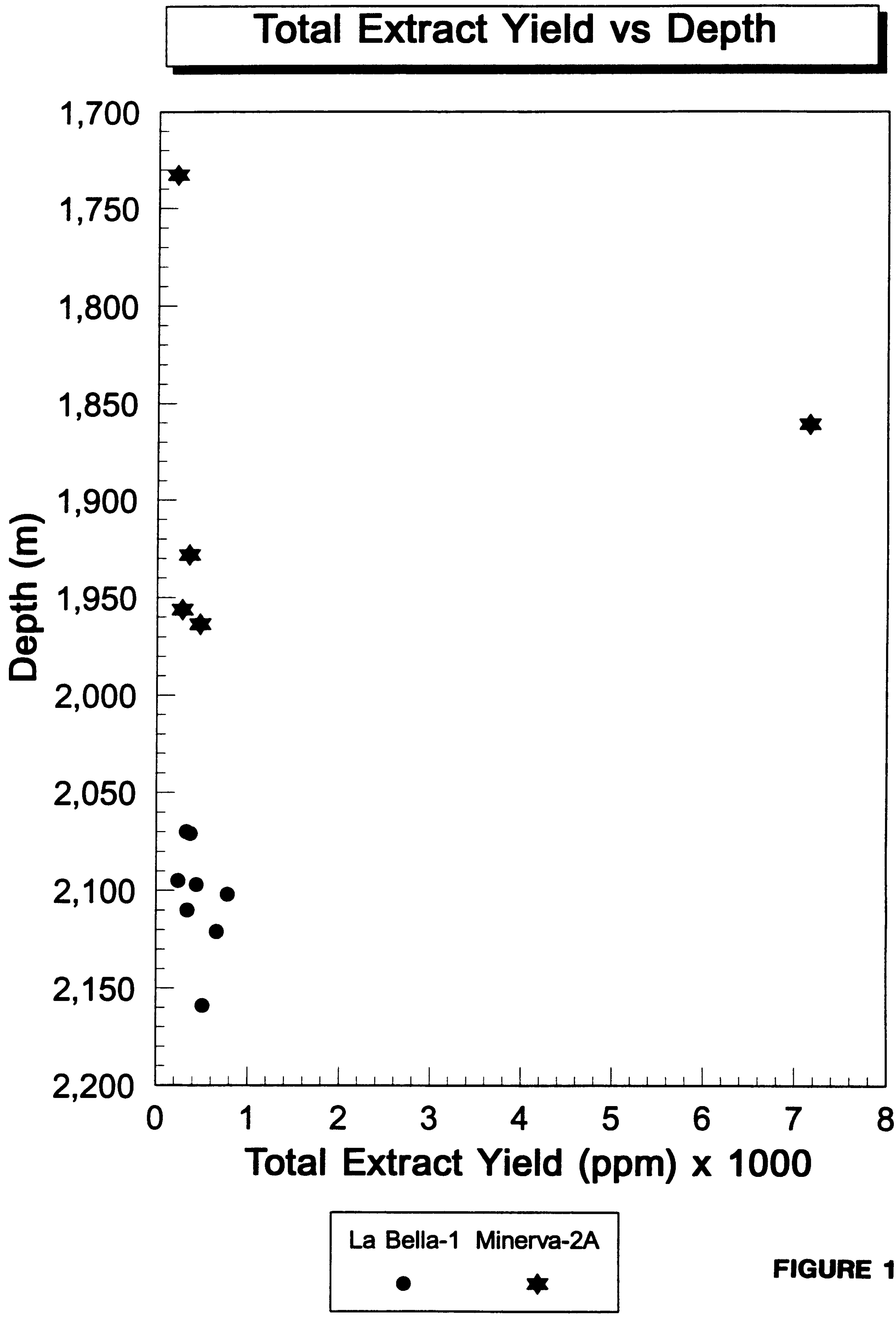
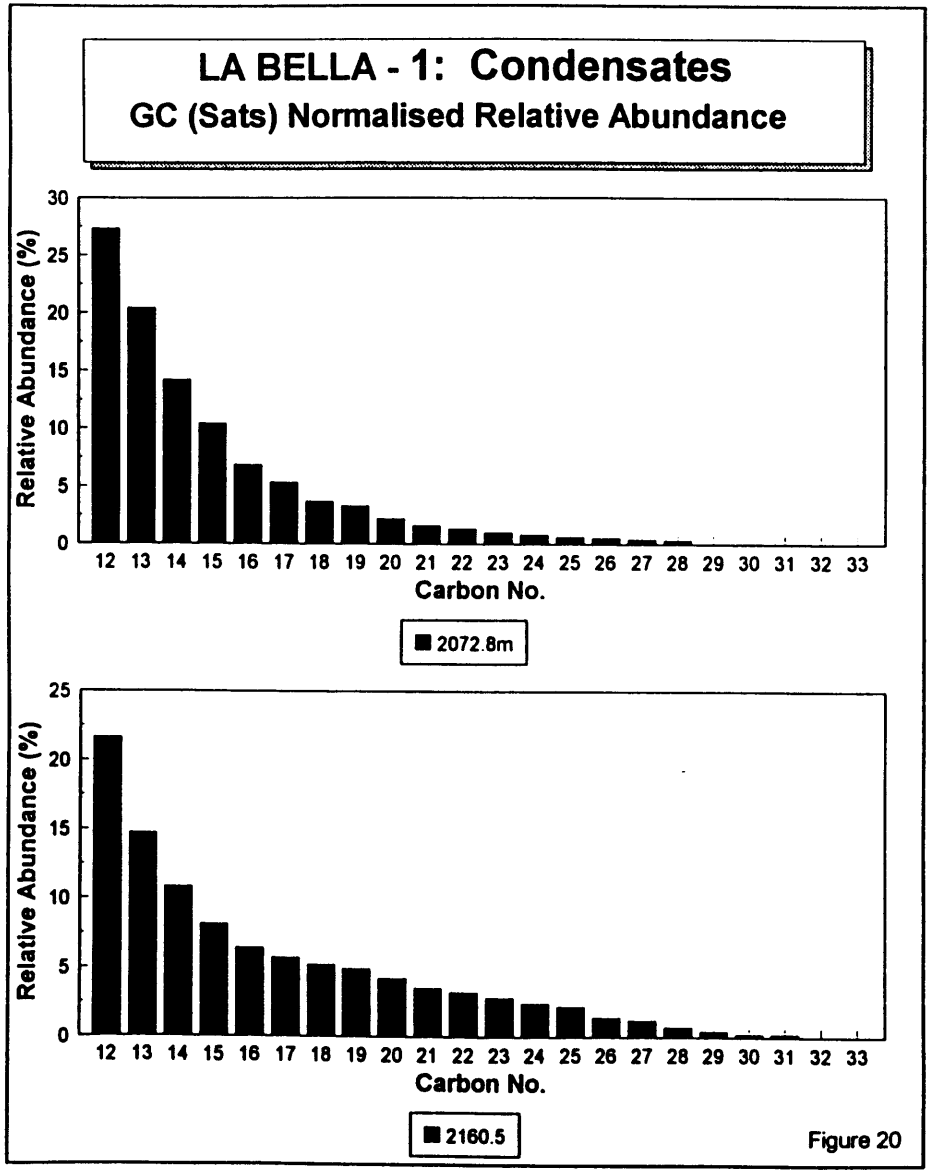

Total Extract Yield vs Depth
Depth (m)
1,700
1,750
1,800
1,850
1,900
1,950
2,000
2,050
2,100
2,150
2,200
0
1
2
3
4
5
6
7
8
Total Extract Yield (ppm) x 1000
La Bella-1
Minerva-2A

FIGURE 1


LA BELLA - 1: Condensates
GC (Sats) Normalised Relative Abundance
Relative Abundance (%)
30
25
20
15
10
5
0
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Carbon No.
2072.8m
25
20
15
10
5
0
2160.5
Figure 20

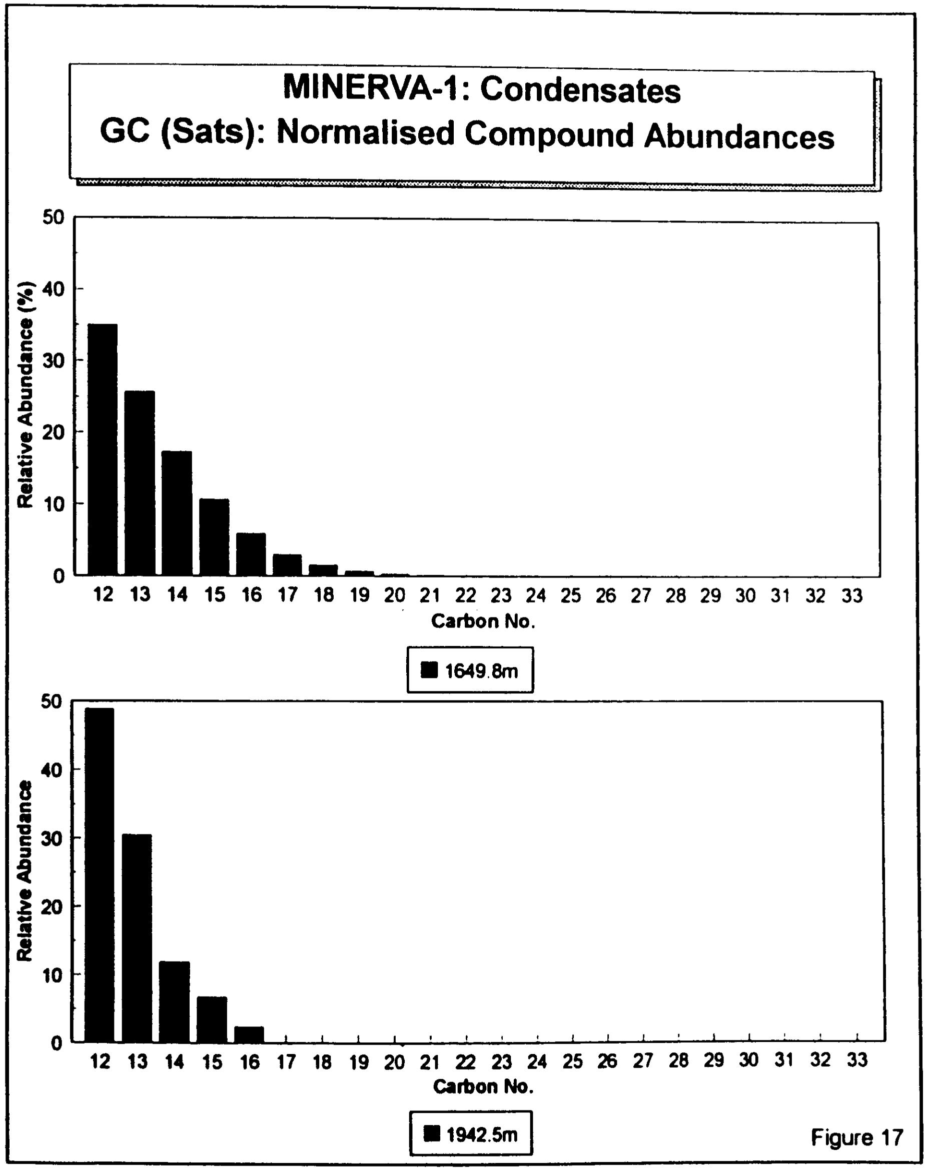
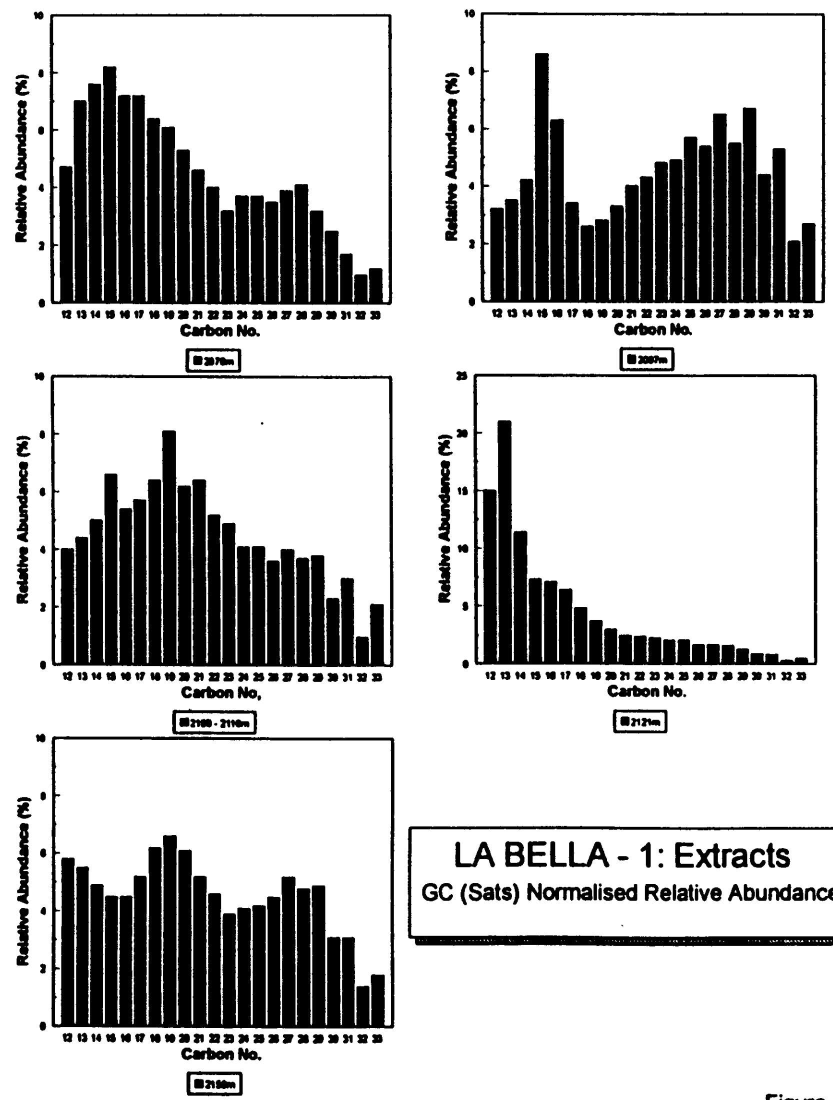

MINERVA-1: Condensates
GC (Sats): Normalised Compound Abundances
Relative Abundance (%)
50
40
30
20
10
0
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Carbon No.
1649.8m
Relative Abundance
1942.5m
Figure 17

FIGURE 2



LA BELLA - 1: Extracts

GC (Sats) Normalised Relative Abundance

Figure 23

MINERVA-2A: Extract 1860.3m

GC(Sats) Normalised Relative Abundance

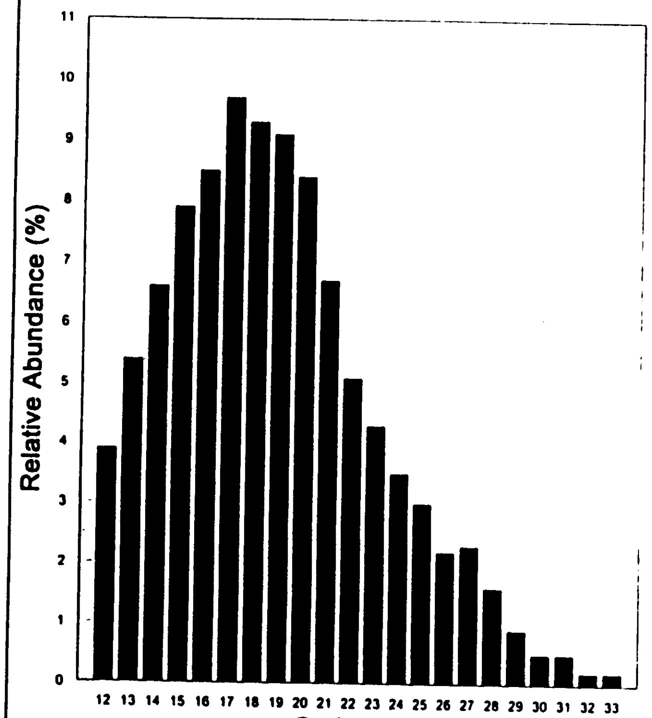
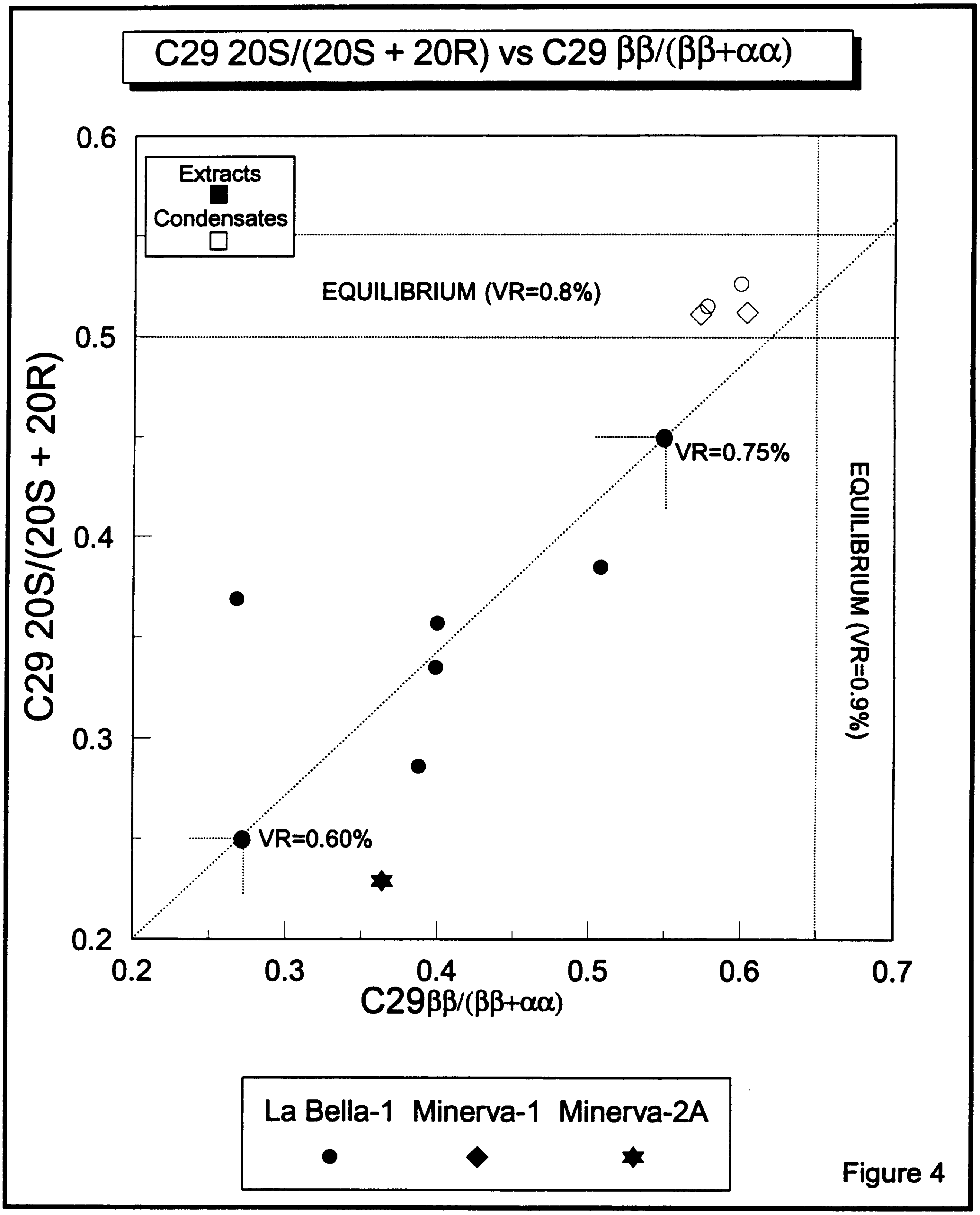


Figure 4

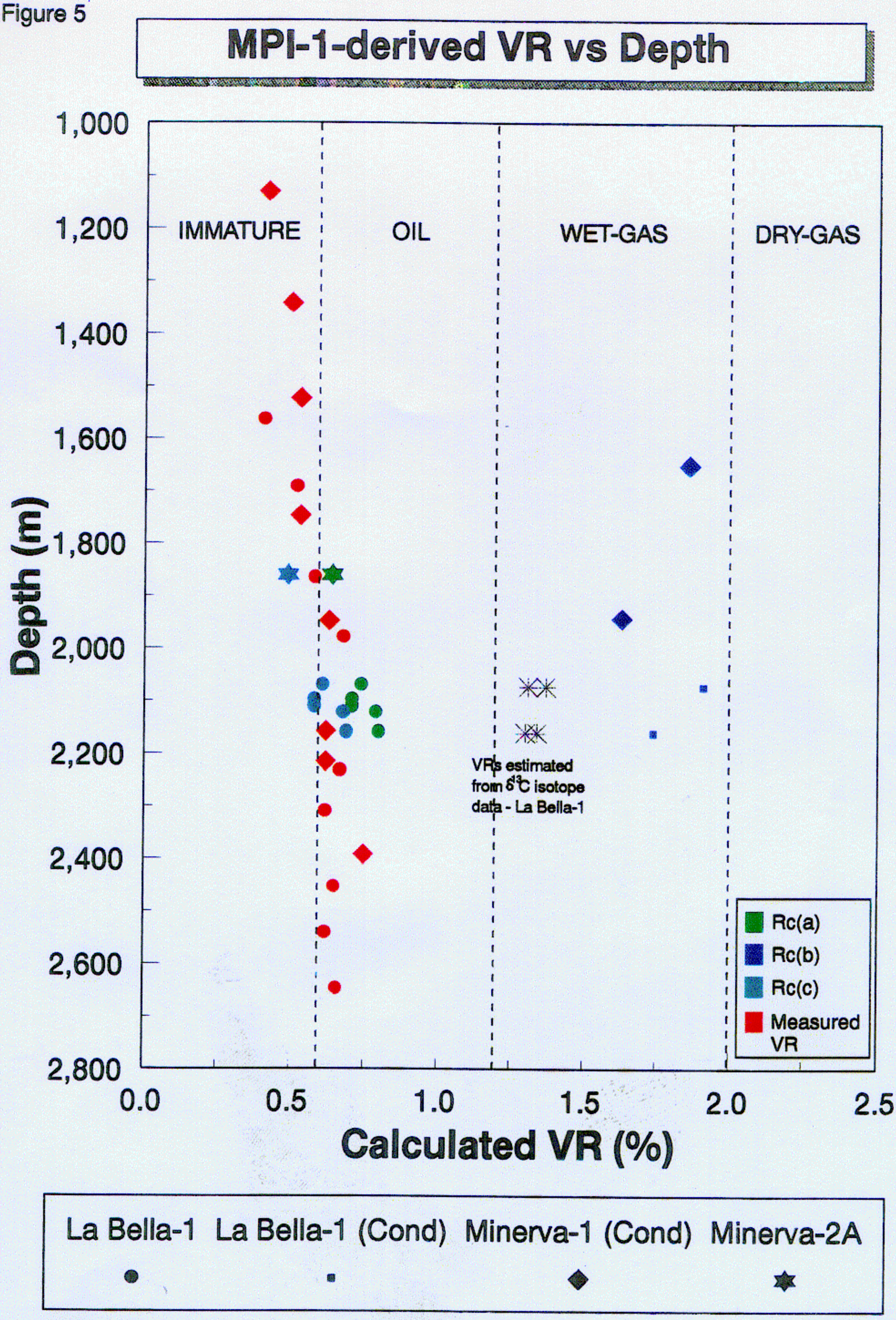
FIGURE 3

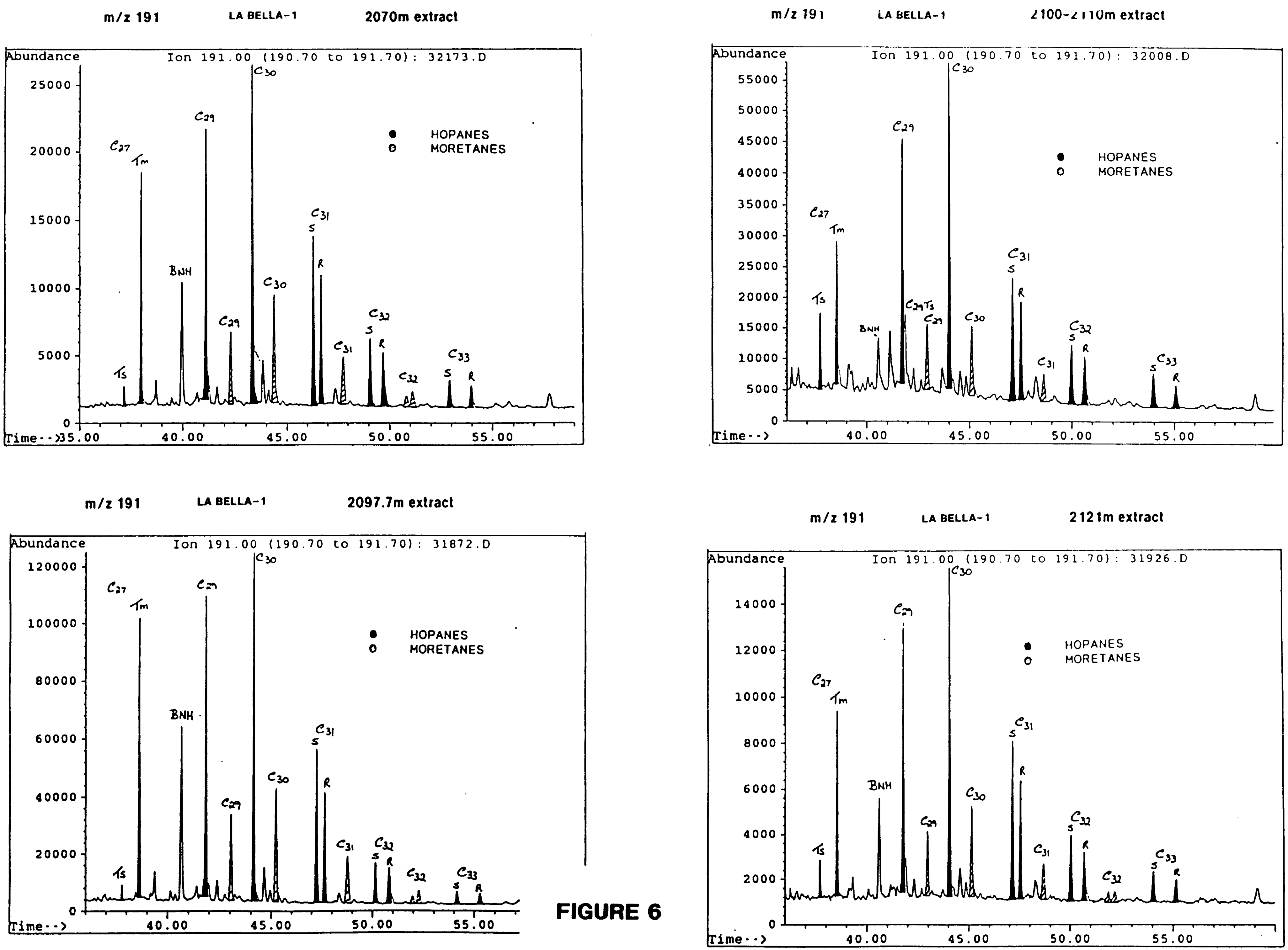


C29 20S/(20S + 20R) vs C29 ββ/(ββ+αα)
Extracts
Condensates
EQUILIBRIUM (VR=0.8%)
VR=0.75%
EQUILIBRIUM (VR=0.9%)
VR=0.60%
C29 20S/(20S + 20R)
C29ββ/(ββ+αα)
0.6
0.5
0.4
0.3
0.2
0.2
0.3
0.4
0.5
0.6
0.7
La Bella-1
Minerva-1
Minerva-2A

Figure 4

Figure 5


MPI-1-derived VR vs Depth
IMMATURE
OIL
WET-GAS
DRY-GAS
Depth (m)
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
2,600
2,800
0.0
0.5
1.0
1.5
2.0
2.5
Calculated VR (%)
VRs estimated from δ13C isotope data - La Bella-1
Rc(a)
Rc(b)
Rc(c)
Measured VR
La Bella-1
La Bella-1 (Cond)
Minerva-1 (Cond)
Minerva-2A



m/z 191
LA BELLA-1
2070m extract
Ion 191.00 (190.70 to 191.70): 32173.D
HOPANES
MORETANES
m/z 191
LA BELLA-1
2100-2110m extract
Ion 191.00 (190.70 to 191.70): 32008.D
HOPANES
MORETANES
m/z 191
LA BELLA-1
2097.7m extract
Ion 191.00 (190.70 to 191.70): 31872.D
HOPANES
MORETANES
m/z 191
LA BELLA-1
2121m extract
Ion 191.00 (190.70 to 191.70): 31926.D
HOPANES
MORETANES

FIGURE 6

m/z 191 LA BELLA-1 2159m extract

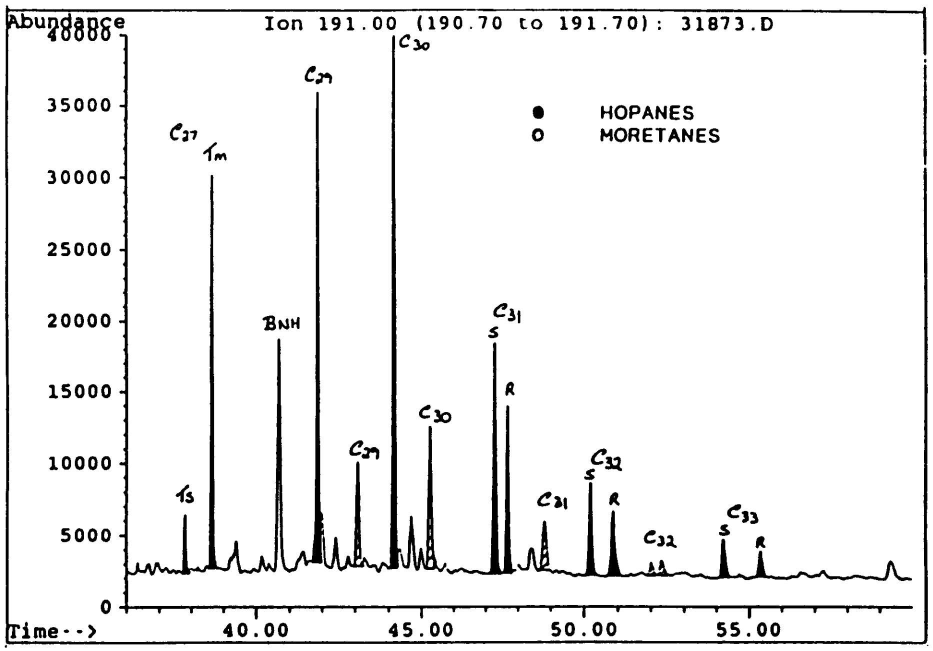
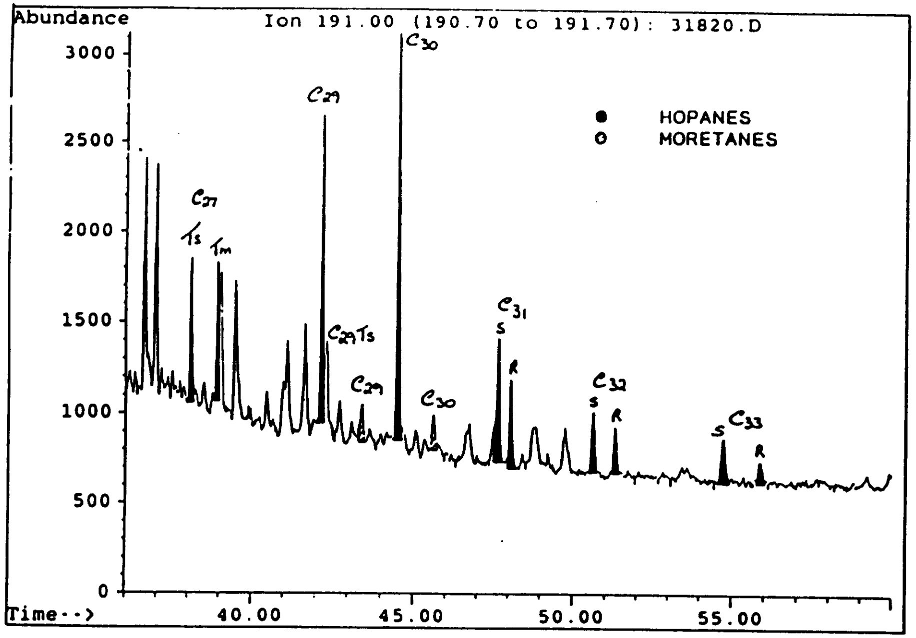
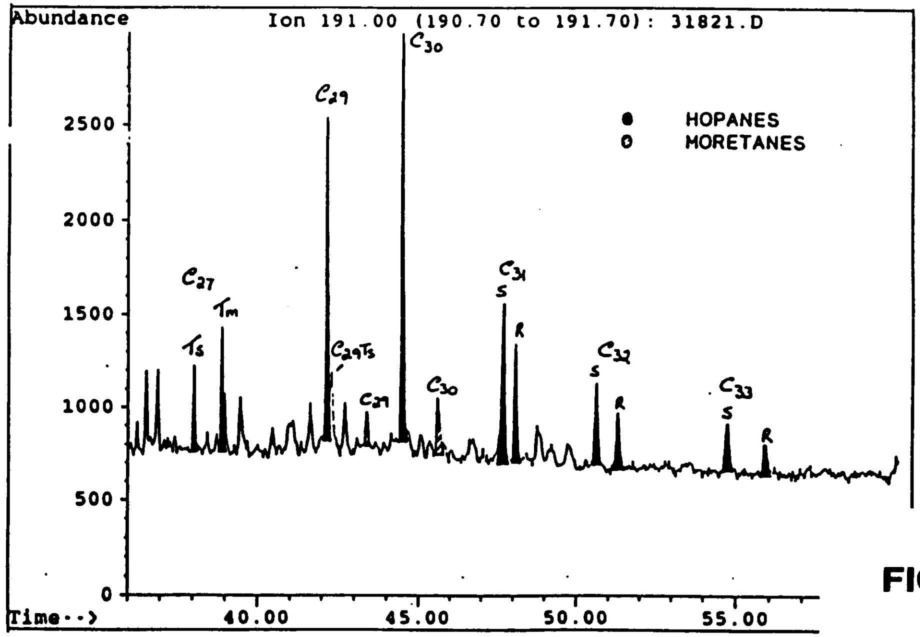


FIGURE 6 (contd)

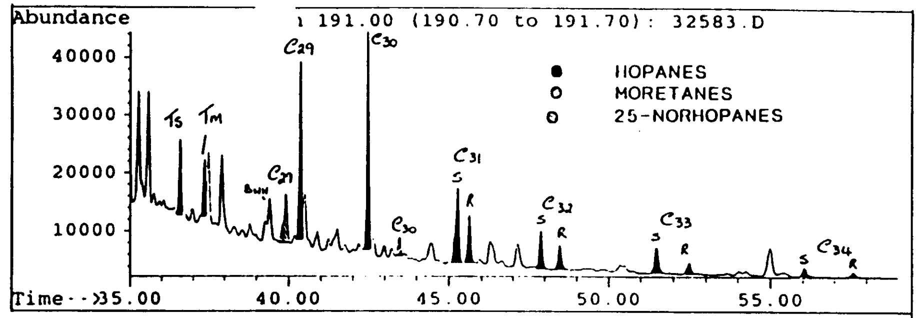
m/z 191 LA BELLA-1 2072.8m condensate



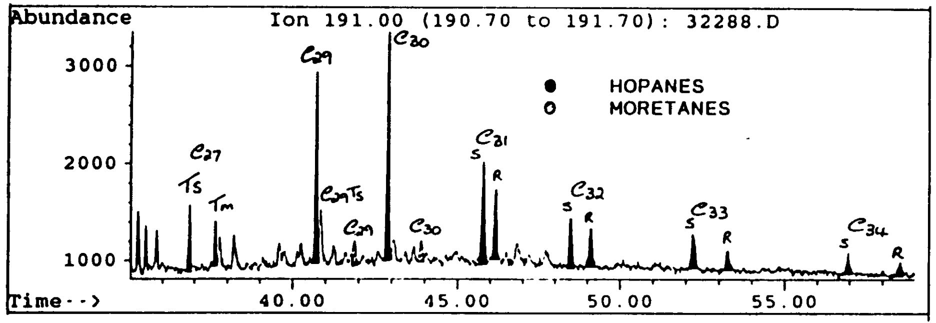
m/z 191 LA BELLA-1 2160.5m condensate



191 MAR TRA 16 n W Ext. RVA



m/z 191 BIOMARKER TRACE : 1942.5m Condensate MINERVA-1



m/z 191 MINERVA-2/2A 1860.3m Extract

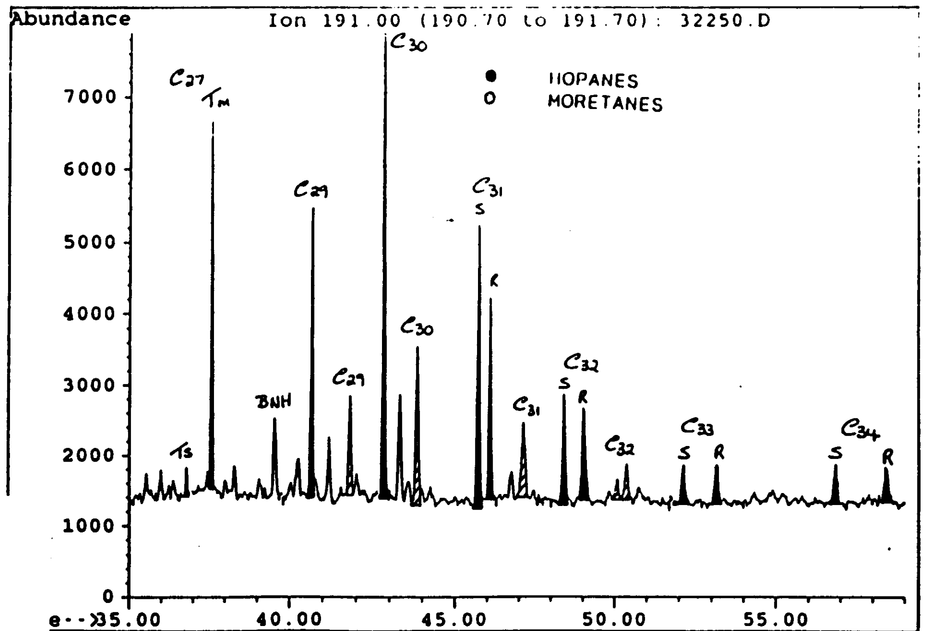


FIGURE 7

APPENDIX

CONCLUSIONS FROM INTERPRETATIVE GEOCHEMICAL REPORTS ON MINERVA-1, MINERVA-2/2A AND LA BELLA-1

4 CONCLUSIONS

Four SWC samples, from the Late Cretaceous Sherbrook and Shipwreck Groups, were analysed for their TOC content. Three samples (including one coal) yielded values greater than 1.0%, and were accordingly analysed by Rock-Eval pyrolysis. The resulting data revealed a predominance of Type II/III to Type III, mainly gas-prone organic matter with HI values less than 150, with the exception of the coal sample (1837.1m) characterised by more strongly liquids-prone organic matter. While liptinitic/exinitic (Type II) macerals were identified in most samples (supplemented by a sparse alginitic component), suggesting some liquids potential, it is clear from the S1+S2 yields that expulsion from these samples would be possible only at relatively advanced levels of thermal maturity; at such levels, secondary cracking of liquids to gas would occur, such that these source rocks would, in the event, become even more gas-prone than indicated by the source character data.

Thermal maturity data, namely Tmax, PI and vitrinite reflectance measurements, suggest that the 1130-1747m interval is thermally immature, the 1947.5-2215m interval marginally mature, and the interval down to 2392.5m early oil-generative mature. The generative potential of the sediments has therefore not been realised at the Minerva-1 location.

A further inference is that the quality of these source rocks can not be linked to advanced maturity, their relative leanness being more a function of the type and preservation state of their contained organic matter.

A condensate and a water-extract, acquired from the cold-trapping of the 1942.5m and 1649.8m RFT gases, were subjected to whole-oil GC and whole-extract GC (as appropriate), saturates-GC, GC-MS (branched/cyclics) and GC-MS (aromatics) analysis. Paraffin Index data from the condensate suggest that it was expelled from its source rock at about 135°C (close to peak-oil generation). Saturate fraction GC data from the water-extract suggest that it was generated from higher land-plant-derived organic matter within source sediments deposited under strongly oxic conditions. Biomarker data, from SIR GC-MS analysis of the saturates and aromatics fractions, suggest that the fluids were generated from aquatically derived organic matter incorporated into clastic source sediments deposited under relatively oxic conditions, possibly in a marine to marginally marine environment. Isomeric equilibria were found to be exceeded in the case of those biomarker indicators appropriate to lower levels of thermal maturity, others (such as the relative abundances of Ts/Tm, and moretanes/hopanes) indicating advanced maturities. Values of R_c(b)%, calculated from MPI-1 using an algorithm appropriate to maturities greater than 1.35% VR, fall in the 1.63-1.86% range, consistent with the 1.5-1.6% (or greater) values obtained from stable carbon isotope data from the 1649.8m and 1931.0m gases. These data further confirm that the gases were generated by the thermal cracking of liquids at depth rather than in association with liquids within the oil-generative window.

Caution should be exercised when biomarker data from condensates are used to make inferences regarding source organic matter type, provenance, and thermal maturity. The absolute values of compound abundances, and ratios based on them, may not be a true reflection of these source characteristics, in that they are either maturity- or phase-affected, or both. However, such data may still be useful for comparative purposes, being sufficiently similar to infer the co-genesis of the Minerva-1 gas/condensates, and being of potential value for correlation with hydrocarbons recovered from nearby wells.

3 CONCLUSIONS

Five core-chips from the 1732.8-1963.7m interval in Minerva-2/2A were solvent-extracted in an attempt to identify any residual hydrocarbons within the gas column. Four of the extracts amounted to less than 500ppm, too low to represent genuine hydrocarbon saturations, even residual; the fifth sample, a coal from 1860.3m, yielded over 7000ppm.

The extract from 1963.7m (472ppm) was analysed by whole-extract GC, but did not reveal the presence of true hydrocarbons.

The extract from the 1860.3m coal was subjected to whole-extract GC, liquid chromatography, saturates-GC, SIR GC-MS (branched/cyclics) and SIR GC-MS (aromatics) analysis. Saturate-fraction GC data from the extract suggest that it was generated from higher land-plant-derived organic matter within source sediments deposited under strongly oxic conditions, consistent with its origin in a coal. Biomarker data, from SIR GC-MS analysis of the saturates and aromatics fractions, support this. Isomeric equilibria were not exceeded in the case of those biomarker indicators appropriate to lower levels of thermal maturity, indicating thermal immaturity. A value of $R_c(a) = 0.64\%$ was calculated from MPI-1. These GC-MS data, in particular the presence of C_{28} bisnorhopanes in the extract, point to it being indigenous to the 1860.3m coal.

None of the five extracts, therefore, is considered to represent thermally mature, migrated hydrocarbons.

4 CONCLUSIONS

Nine SWC samples, from the Late Cretaceous Sherbrook and Shipwreck Groups, were analysed for their TOC content. All these samples yielded values greater than 1.0%, and were accordingly analysed by Rock-Eval pyrolysis. A core sample from 2095.15-2095.20m was similarly analysed. The resulting data revealed a predominance of Type II/III to Type III, mainly gas/condensate-prone organic matter with HI values less than 200, with the exception of one coal sample (2540.5m) characterised by a more strongly Type II, liquids-prone organic facies. While liptinitic/exinitic (Type II) macerals were identified in most samples (supplemented by a sparse alginitic component in the Sherbrook Group), suggesting some liquids potential, it is clear from the S1+S2 yields that expulsion from these samples would be possible only at relatively advanced levels of thermal maturity; at such levels, secondary cracking of liquids to gas would occur, such that these source rocks would, in the event, become more gas-prone than indicated by the source character data.

Thermal maturity data, namely Tmax, PI and vitrinite reflectance measurements, suggest that the Sherbrook Group is thermally immature and the Shipwreck Group marginally mature. The generative potential of the source rocks discussed above has therefore not been realised at the La Bella-1 location. A further inference is that the quality of these source rocks can in no way be linked to advanced maturity, their relative leanness being more a function of the preservation state of their contained organic matter.

A trace of hydrocarbon was reported during petrographic analysis of the 2095.15-2095.20m core sample. The sample was therefore solvent-extracted to determine the character of any contained hydrocarbons. A further seven samples (two core fragments, four SWCs, and one cuttings sample), from four separate reservoir units and one intra-formational claystone, were solvent-extracted in an attempt to identify any residual hydrocarbons (namely, any hydrocarbons which represent the remains of an earlier saturation displaced by the existing gas accumulation).

The resulting extract yields were low (less than 800ppm). Each was analysed by the whole-extract GC method, and the nature of the GC traces, taken together with the low extract yields, did not offer any strong indication that the extracts represented residual hydrocarbon saturations. However, to be certain of this, five of the extracts were subjected to more detailed analysis, namely saturate-GC, GC-MS (branched/cyclics) and GC-MS (aromatics). Two condensates, acquired from the cold-trapping of the 2072.8m and 2160.5m RFT gases, were subjected to the same analytical sequence to determine any similarity between the compositions of the extracts and those of known migrated fluids.

The condensates and extracts alike revealed Pr/Ph ratios, and ratios of Pr/nC_{17} to Ph/nC_{18}, typical of land-plant derived organic matter in sediments deposited under relatively oxic conditions. However, the saturate-GC traces of the extracts showed significant variation. Three of the extracts contained high molecular-weight, odd-preferenced, waxy components within their alkane distributions (consistent with derivation from land-plants), while in a fourth only a subtle waxy hump was evident; the fifth showed a symmetrical hump of unresolved compounds typical of contamination.

The characters of the saturates-GC traces of the extracts compared with those of the condensates support the view that the extracts do not represent thermally mature, migrated hydrocarbons. GC-MS analysis of the branched/cyclic alkanes revealed fundamental differences in the biomarker distributions of the extracts and condensates which appear to be due more to differences in maturity than to differences in organic facies (though these may exist). In particular, C_{28}-bisnorhopanes, thought to be derived from post-diagenetic free bitumens in thermally immature claystones, are present in the extracts but not the condensates. Maturity estimates based on MPI-1 values from GC-MS analysis of the aromatic fractions of the extracts appear to concur with other maturity indicators from the interval, indicating the marginal maturity of the Shipwreck Group.

The analytical data, taken together, therefore suggest that the La Bella-1 extracts do not represent a residuum of thermally mature migrated fluids, but are instead indigenous to, or very locally migrated within, the marginally mature Shipwreck Group.

Two gas samples were recovered by RFT from 2072.8m and 2160.5m, consisting of 76-77% methane, 4.5-4.8% ethane, 12-13% carbon-dioxide, and 3.4-3.9% nitrogen. Interpretation of stable carbon isotope data from the gases suggests that they were expelled from their source rocks at thermal maturities equivalent to about 1.30-1.35% VR, early in the wet-gas-generative window, having been generated by the thermal cracking of liquids rather than in association with them.