MINORA
RESOURCES NL



# SOURCE & RESEVOIR ROCK EVALUATION OF 5 WELLS

# ONSHORE OTWAY, VICTORIA

- EUMERALLA-1
- BELFAST-4
- BELFAST-11
- BOOTAHPOOL-2
- CODRINGTON-2

March 1986.

# SOURCE AND RESERVOIR ROCK EVALUATION OF FIVE WELLS, ONSHORE OTWAY BASIN, VICTORIA

EMERALLA-1, BELFAST-4,-11, BOOTAHPOOL-2, CODRINGTON-2.

Pan Pacific Petroleum N.L.

F3/0/0-F6370/86 March 1986

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17 March 1986

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Attention: Leigh Brooks

REPORT F 6370/86

YOUR REFERENCE: Letter from L. Brooks dated 17 January 1986

TITLE: Source and reservoir rock evaluation of five wells, onshore Otway Basin, Victoria

MATERIAL: Core (19 samples). Cuttings (1 sample)

LOCALITIES: BELFAST-4,11, BOOTAHPOOL-2, CODRINGTON-2, EUMERALLA-1

IDENTIFICATION: As in Table 1 of report

DATE RECEIVED: 20 January 1986

WORK REQUIRED: Source rock analysis: TOC, Rock-Eval pyrolysis, visual kerogen description, thermal alteration index, vitrinite reflectance, interpretation. Reservoir Evaluation: porosity, permeability, petrography.

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# 1. INTRODUCTION

Twenty (20) rock samples from five onshore wells in the Otway Basin were received for source rock analysis and reservoir evaluation (Table 1).

The aims of the investigation were to assess:

1. the hydrocarbon source potential (maturity, richness, kerogen type) of the

| | |
|---|---|
| Belfast Mudstone | Late Cretaceous |
| Eumeralla Formation | Early Cretaceous |

2. the reservoir potential (porosity, permeability, rock type) of the

| | |
|---|---|
| Pebble Point Formation | Basal Tertiary |
| Timboon Sandstone<br>Waarre Sandstone } | Late Cretaceous |
| Eumeralla Formation | Early Cretaceous |

in the five wells sampled.

Interim data reports were facsimilied to the client as follows:

| | |
|---|---|
| Vitrinite reflectance | 17/2/86 |
| Porosity, permeability | 17/2/86 |
| Visual kerogen, TAI | 28/2/86 |
| TOC, Rock-Eval pyrolysis | 7/3/86 |

# 2. SOURCE ROCK ANALYSIS

## 2.1 Methods

Details of the analytical procedures may be found in Appendix 1.

## 2.2 Results

Analytical data are summarised and presented herein as follows:

| | Table | Figure | Appendix |
|---|---|---|---|
| TOC, Rock-Eval pyrolysis | 2 | 1 | - |
| Vitrinite reflectance | 3 | - | 2 |
| Visual kerogen, thermal alteration index (TAI) | 4 | - | - |
| Dispersed organic matter (polished section) | 5,6 | - | - |

## 2.3 Interpretative Comments

### Maturity

Rock-Eval Tmax values (Table 2, Fig. 1) and vitrinite reflectance data (Table 3) concur in demonstrating that:

1. the Belfast Mudstone is *immature* (VR <0.5%) at Codrington-2 and Belfast-11; and

2. the Eumeralla Formation is *marginally mature* (VR = 0.50-0.56%) at Eumeralla-1.

None of these rock units is sufficiently mature to have generated significant quantities of liquid hydrocarbons from resinite-poor terrestrial organic matter (threshold VR ≈0.7%).

TAI values for Eumeralla-1 (Table 4) appear high in relation to Tmax and measured VR. This discrepancy can be attributed to partial oxidation of the spores in these samples (see Table 6).

The Tmax values reported for the Belfast-4 and Codrington-2 samples (Table 2) are unreliable because of the small, ill-defined $S_2$ peaks in their Rock-Eval pyrograms.

Source Richness

All the samples analysed (Table 2) have organic carbon contents in excess of TOC = 0.5%, the minimum considered necessary for the generation of producible hydrocarbons in clastic source rocks. In most cases, however, this organic carbon is largely inert (or dead) with respect to hydrocarbon genesis (pyrolysable carbon, PC <0.05%) and potential hydrocarbon yields are very low ($S_1+S_2$ <0.6 kg/tonne: Table 2).

An obvious exception is the *Eumeralla Formation* at Eumeralla-1 which displays *good to excellent source richness* (PC = 0.56-13.6%; $S_1+S_2$ = 7-163 kg hydrocarbons/tonne).

Kerogen Type and Source Quality

Belfast Mudstone Where sampled this formation contains inertinite-rich Type IV kerogen (HI = 2-29) (Tables 2 & 5, Fig. 1) and is a potential source of dry gas only.

The visual kerogen descriptions (Table 4) display a systematic bias in underestimating the relative amount of inertinite in these samples.

Eumeralla Formation Hydrogen index values in the range HI = 255-360 indicate the presence of good quality *oil-and gas-prone* Type II-III kerogen below 1800 metres depth at Eumeralla-1 (Table 2, Fig. 1). Optical examination (Tables 4-6) indicates that this organic matter comprises mostly vitrinite (30-70%) and exinite (15-40%). The major exinites are sporinite and cutinite.

Shales from 1769.00 and 1770.80 metres depth in Eumeralla-1 contain, respectively, gas-prone (HI = 53) and gas/condensate-prone (HI = 150) Type III kerogen (Fig. 1).

In Table 4, an anomalously high inertinite percentage is reported for the *coal* sample (6705 ft/2043.90 m, Eumeralla-1). Kerogens isolated from coals comprise particles that are a function of grinding during preparation, and therefore bear no genetic relationship to naturally occurring phytoclasts in shales and siltstones. Inevitably, many of these particles will be thick and opaque (black) when viewed in transmitted light, and hence identified as inertinite. Subsequent examination of this kerogen slide in reflectance mode under UV light at AMDEL revealed that many of these opaque fragments comprise vitrinite and exinite.

## 3. RESERVOIR EVALUATION

Analytical data are summarised and presented herein as follows:

| | Table | Appendix |
|---|---|---|
| Porosity, permeability | 7 | - |
| Petrology | - | 3 |

## 4. REFERENCE

JONES, R.W. and EDISON, T.A., 1978. Microscopic observations of kerogen related to geochemical parameters with emphasis on thermal maturation. In : *Symposium in Geochemistry : Low Temperature Metamorphism of Kerogen and Clay Minerals*, (OLTZ, D.F., ed.), SEPM Pacific Section, Los Angeles.

TABLE 1: SAMPLES SUBMITTED FOR SOURCE AND RESERVOIR ROCK EVALUATION

| Well | Sample | Depth m | Formation | SR | RR |
|---|---|---|---|---|---|
| Belfast-4 | Core 9 | 891 | Pebble Point | | ✓ |
| | Core 10 | 911 | Timboon | | ✓ |
| | Core 18 | 1418 | Belfast | ✓ | |
| | Core 19 | 1545.5 | Eumeralla | | ✓ |
| | Core 22 | 1682 | Eumeralla | | ✓ |
| Codrington-2 | Core 15 | 1041 | Belfast | ✓ | |
| | Core 16 | 1095 | Belfast | ✓* | |
| | Core 17 | 1152 | Waarre | | ✓ |
| | Core 18 | 1202.5 | Eumeralla | | ✓ |
| | Core 18 | 1204.5 | Eumeralla | | ✓ |
| Belfast-11 | Core 16 | 978 | Pebble Point | | ✓ |
| | Core 24 | 1325.5 | Belfast | ✓* | |
| | Core 26 | 1420.5 | Eumeralla | | ✓ |
| Bootahpool-2 | Core 11 | 792 | Pebble Point | | ✓ |
| | Core 12 | 875 | Timboon | | ✓ |
| Eumeralla-1 | Core 10 | 1769 | Eumeralla | ✓ | |
| | Core 10 | 1770.8 | Eumeralla | ✓* | |
| | Core 15 | 2043.9 | Eumeralla | ✓* | |
| | Core 15 | 2047.6 | Eumeralla | ✓ | |
| | Cuttings | 1831.8-1834.9 | Eumeralla | ✓ | |

SR = TOC, Rock-Eval pyrolysis, visual kerogen description, thermal alteration index and vitrinite reflectance (asterisked samples only).

RR = porosity, permeability and petrography.

TABLE 2

AMDEL

ROCK-EVAL PYROLYSIS 03/03/86

Client PAN PACIFIC

Well OTWAY BASIN

| DEPTH (m) | T MAX | S1 | S2 | S3 | S1+S2 | PI | S2/S3 | PC | TOC | HI | OI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BELFAST-4 | | | | | | | | | | | |
| 1418.00 | 441 | 0.02 | 0.18 | 1.15 | 0.20 | 0.10 | 0.16 | 0.01 | 1.49 | 12 | 77 |
| COORINGTON-2 | | | | | | | | | | | |
| 1041.00 | 344 | 0.01 | 0.11 | 1.42 | 0.12 | 0.08 | 0.08 | 0.01 | 1.66 | 7 | 86 |
| 1095.00 | 360 | 0.00 | 0.05 | 1.70 | 0.05 | 0.00 | 0.03 | 0.00 | 2.05 | 2 | 83 |
| BELFAST-11 | | | | | | | | | | | |
| 1325.50 | 432 | 0.02 | 0.57 | 1.38 | 0.59 | 0.03 | 0.41 | 0.04 | 1.99 | 29 | 69 |
| EUMERALLA-1 | | | | | | | | | | | |
| 1769.00 | 438 | 0.04 | 0.51 | 0.21 | 0.55 | 0.07 | 2.43 | 0.04 | 0.95 | 53 | 22 |
| 1770.80 | 434 | 0.08 | 6.75 | 0.90 | 6.83 | 0.01 | 7.50 | 0.56 | 4.50 | 150 | 22 |
| 1831.80 | 432 | 0.34 | 14.81 | 1.46 | 15.15 | 0.02 | 10.14 | 1.26 | 5.80 | 255 | 25 |
| 2043.90 | 433 | 6.48 | 156.16 | 11.76 | 162.64 | 0.04 | 13.28 | 13.55 | 66.10 | 236 | 18 |
| 2047.60 | 434 | 0.16 | 47.91 | 3.80 | 48.07 | 0.00 | 12.60 | 1.37 | 13.30 | 360 | 28 |

# KEY TO ROCK-EVAL PYROLYSIS DATA SHEET

| | PARAMETER | SPECIFICITY |
|---|---|---|
| T max | position of $S_2$ peak in temperature program ($^{o}C$) | Maturity/Kerogen type |
| $S_1$ | kg hydrocarbons (extractable)/tonne rock | Kerogen type/Maturity/Migrated oil |
| $S_2$ | kg hydrocarbons (kerogen pyrolysate)/tonne rock | Kerogen type/Maturity |
| $S_3$ | kg $CO_2$ (organic)/tonne rock | Kerogen type/Maturity * |
| $S_1 + S_2$ | Potential Yield | Organic richness/Kerogen type |
| PI | Production Index ($S_1/S_1 + S_2$) | Maturity/Migrated Oil |
| PC | Pyrolysable Carbon (wt. percent) | Organic richness/Kerogen type/Maturity |
| TOC | Total Organic Carbon (wt. percent) | Organic richness |
| HI | Hydrogen Index (mg h'c ($S_2$)/g TOC) | Kerogen type/Maturity |
| OI | Oxygen Index (mg $CO_2$($S_3$)/g TOC) | Kerogen type/Maturity * |

*Also subject to interference by $CO_2$ from decomposition of carbonate minerals.

TABLE 3: SUMMARY OF VITRINITE REFLECTANCE DATA

| Depth m | Mean Maximum Reflectance (%) | Standard Deviation | Range | Number of Determinations |
|---|---|---|---|---|
| BELFAST-11 | | | | |
| 1325.5 | 0.44 | 0.04 | 0.36-0.51 | 22 |
| CODRINGTON-2 | | | | |
| 1095 | 0.48 | 0.06 | 0.37-0.59 | 27 |
| EUMERALLA-1 | | | | |
| 1770.8 | 0.47*(0.50) | 0.05 | 0.37-0.57 | 18 |
| 2043.9 | 0.56 | 0.06 | 0.41-0.66 | 32 |

*possibly influenced by bituminite.

()preferred value.

TABLE 4

VISUAL KEROGEN DATA SHEET - OTWAY BASIN

| SAMPLE | | ORGANIC CONTENT (cc/10gm) | KEROGEN TYPE (%) | | | | | | | | | | MATURITY (T.A.I.) | EVALUATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | INERTINITE | VITRINITE | | | | LIPTINITE | | | | | | GAS/ CONDENSATE | OIL |
| DEPTH | TYPE | | | Gel | Woody | Amor. | TOTAL | Cuticle | Spore | Algal | Amor. | TOTAL | | | |
| Belfast-4 1418.0m | Core | | 40 | 5 | 5 | 40 | 50 | - | 5 | 1 | 4 | 10 | 2.5 | immature:gas/ condensate prone | marginal-ly mature: not oil prone |
| Belfast-11 1325.5m | Core | | 40 | 2 | 3 | 40 | 45 | - | 3 | 7 | 5 | 15 | 2.4 | immature:gas/ condensate prone | marginal-ly mature: not very oil prone |
| Codrington-2 1041.0m | Core | | 40 | - | 3 | 37 | 40 | 2 | 2 | 2 | 4 | 10 | 2.4 | immature:gas/ condensate prone | marginal-ly mature not oil prone |
| 1095.0m | Core | | 30 | - | 5 | 45 | 50 | 9 | 4 | 2 | 5 | 20 | 2.6 | immature:gas/ condensate prone | marginal-ly mature fairly oil prone |
| Eumeralla-1 5804 ft. | Core | | 30 | - | 2 | 28 | 30 | 6 | 32 | - | 2 | 40 | 2.7 | immature: fairly gas/ condensate prone | mature oil prone |
| 5810 ft. | Core | | 40 | - | 10 | 15 | 25 | 5 | 30 | - | - | 35 | 2.7 | immature fairly gas/ condensate prone | marginal-ly mature oil prone |
| 6010-20 ft | Cutts. | | 20 | - | 25 | 25 | 50 | 10 | 25 | - | 5 | 40 | 2.7 | immature very gas/conden-sate prone | marginal-ly mature very oil prone |

TABLE 4 Continued

VISUAL KEROGEN DATA SHEET - OTWAY BASIN

| SAMPLE | | ORGANIC CONTENT (cc/10gm) | KEROGEN TYPE (%) | | | | | | | | | MATURITY (T.A.I.) | EVALUATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | INERTINITE | VITRINITE | | | | LIPTINITE | | | | | | |
| DEPTH | TYPE | | | Gel | Woody | Amor. | TOTAL | Cuticle | Spore | Algal | Amor. | TOTAL | | GAS/ CONDENSATE | OIL |
| 6705 ft. | Core | | 70 | 25 | 4 | - | 29 | - | 1 | - | - | 1 | 2.8 | immature fairly gas/condensate prone | mature not oil prone |
| 6718 ft. | Core | | 40 | - | 5 | 25 | 30 | 13 | 13 | - | 4 | 30 | 2.8 | immature gas/ condensate prone | mature oil prone |

TABLE 5: PERCENTAGE OF VITRINITE, INERTINITE AND EXINITE IN DISPERSED ORGANIC MATTER

| Well | Depth m | Percentage of | | |
|---|---|---|---|---|
| | | Vitrinite | Inertinite | Exinite |
| Codrington-2 | 1095 | 10 | 85 | 5 |
| Belfast-11 | 1325.5 | 10 | 85 | 5 |
| Eumeralla-1 | 1770.8 | 5 | 80 | 15 |
| | 2043.9 | 70 | 15 | 15 |

TABLE 6: ORGANIC MATTER TYPE AND ABUNDANCE

| Well | Depth m | Lithology | Estimated Volume of DOM % | Exinites | Exinite Macerals |
|---|---|---|---|---|---|
| Codrington-2 | 1095 | siltstone | 1-2 | Ra-Vr | spo,cut, res |
| Belfast-11 | 1325.5 | shaley siltstone | ≈1 | Ra | phyto,spo |
| Eumeralla-1 | 1700.8 | shale | 1-2 | Ra-Sp | bmite,cut, spo,lipto, |
| | 2043.9 | coal | | Ab | cut,spo, res,sub |

Comments

1. Most exinites appear to be slightly oxidised in the samples examined from Codrington-2 and Eumeralla-1.

2. Much of the vitrinite in the Codrington-2 sample is reworked.

3. Some coal fragments from Eumeralla-1, 2043.9 metres depth, contain up to 20% exinite.

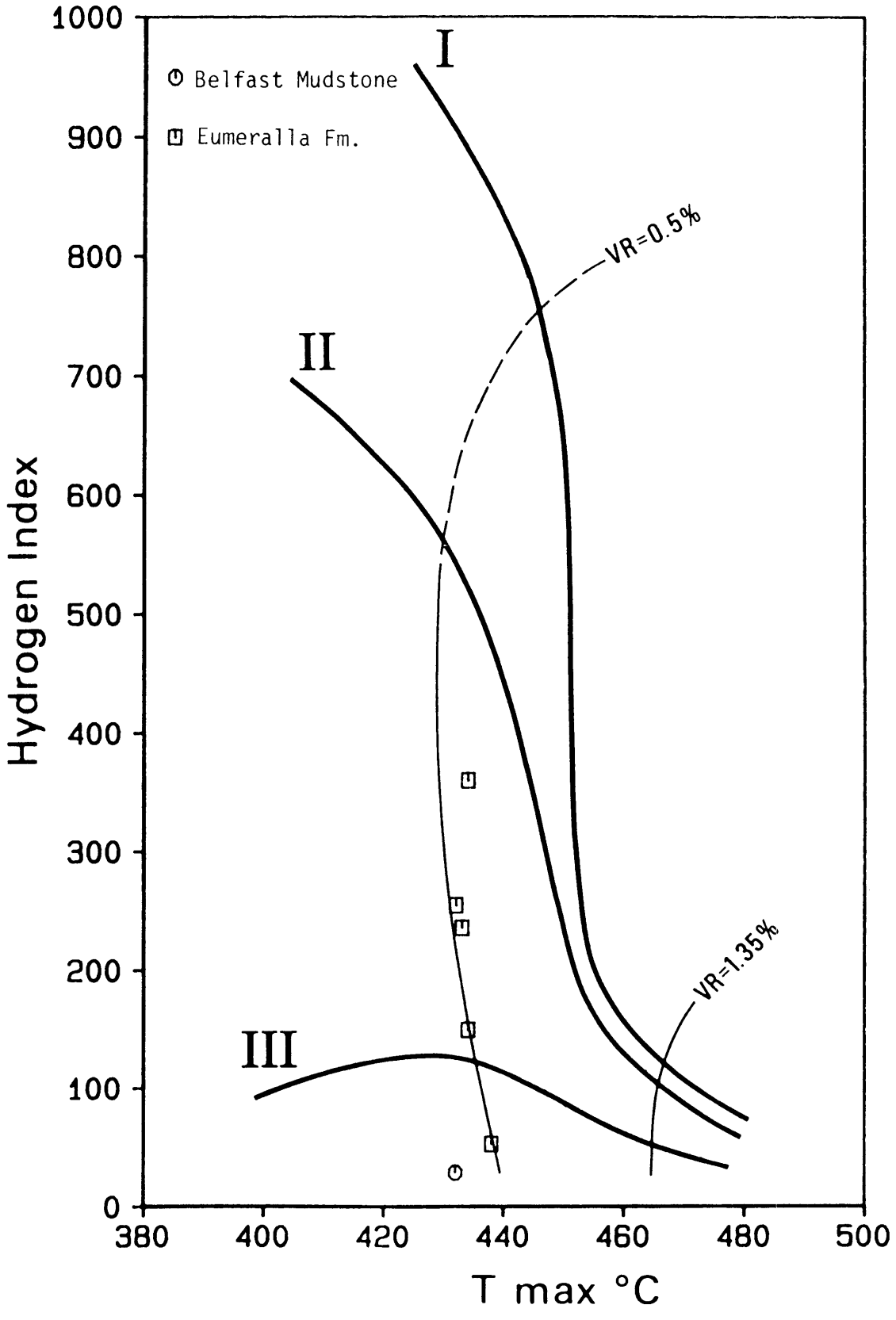
TABLE 7: CORE ANALYSIS DATA

| Well | Sample | Depth (m) | Permeability (md) | Porosity (%) |
|---|---|---|---|---|
| Belfast-4 | Core 9 | 891 | 0.906 | 25.3 |
| | Core 10 | 911 | * | 28.7 |
| | Core 19 | 1545.5 | 0.490 | 20.2 |
| | Core 22 | 1682 | 0.244 | 20.0 |
| Codrington-2 | Core 17 | 1152 | 2.6 | 24.2 |
| | Core 18 | 1202.5 | 11,350** | 28.9 |
| | Core 18 | 1204.5 | 36,220** | 30.9 |
| Belfast-11 | Core 16 | 978 | * | 33.1 |
| | Core 26 | 1420.5 | 4.7 | 21.0 |
| Bootahpool-1 | Core 11 | 792 | * | 36.8 |
| | Core 12 | 875 | * | 39.8 |

*Due to the friable nature of these samples, insufficient material remained intact for core plugs to be cut, and therefore permeability measurements were not obtained. Porosity measurements were made on fragments of the samples using the bulk volume method.

**The precision of permeability values greater than 10,000 md is likely to be less than for lower permeabilities since the differential pressure between the inlet and outlet faces of the core (on which the results depend) is extremely small.

Client : PAN PACIFIC
Well Names : BELFAST-11, EUMERALLA-1



# APPENDIX 1

## ANALYTICAL PROCEDURES FOR SOURCE ROCK ANALYSIS

## 1. TOTAL ORGANIC CARBON (TOC)

Total organic carbon was determined by digestion of a known weight (≈0.2 g) of powdered rock in 50% HCl to remove carbonates, followed by combustion in oxygen in the induction furnace of a Leco IR-12 Carbon Determinator and measurement of the resultant $CO_2$ by infra-red detection.

## 2. ROCK-EVAL PYROLYSIS

A 100 mg portion of powdered rock was analysed by the Rock-Eval pyrolysis technique (Girdel IFP-Fina Mark 2 instrument; operating mode, Cycle 1).

## 3. ORGANIC PETROLOGY

Representative portions of the core/cuttings samples (crushed to -14+35 BSS mesh) were obtained with a sample splitter and then mounted in cold setting Astic resin using a 2.5 cm diameter mould. Each block was ground flat using diamond impregnated laps and carborundum paper. The surface was then polished with aluminium oxide and finally magnesium oxide.

Reflectance measurements on vitrinite phytoclasts, were made with a Leitz MPV1.1 microphotometer fitted to a Leitz Ortholux microscope and calibrated against synthetic standards. All measurements were taken using oil immersion (n = 1.518) and incident monochromatic light (wavelength 546 nm) at a temperature at 24±1°C. Fluorescence observations were made on the same microscope utilising a 3 mm BG3 excitation filter, a TK400 dichroic mirror and a K510 suppression filter.

## 4. VISUAL KEROGEN

The visual kerogen work was undertaken by Dr Roger Morgan (Consultant Palynologist, Maitland, S.A.). TAI measurements are based on Chevron's version of the Staplin scale (Jones and Edison, 1978).

# APPENDIX 2

## HISTOGRAM PLOTS OF VITRINITE REFLECTANCE MEASUREMENTS

# CODRINGTON #2

1095 M ;CORE 16

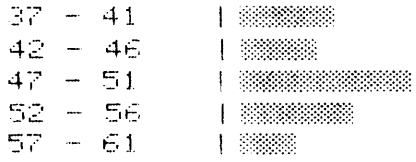
SORTED LIST

.37 .38 .39 .39 .4 .42 .42 .44 .45 .47
.47 .49 .49 .49 .5 .5 .51 .51 .52 .53
.53 .53 .54 .54 .57 .57 .59

Number of values= 27

MEAN OF VALUES .482
STD DEVIATION .061

HISTOGRAM OF RESULTS
Values are reflectance multiplied by 100



# BELFAST #11

1325.5 M ;CORE 24

SORTED LIST

.36 .37 .38 .39 .41 .42 .42 .42 .43 .43
.45 .46 .46 .46 .46 .46 .47 .49 .49 .49
.5 .51

Number of values= 22

MEAN OF VALUES .442
STD DEVIATION .042

HISTOGRAM OF RESULTS
Values are reflectance multiplied by 100

36 - 38 | ▒▒▒
39 - 41 | ▒▒
42 - 44 | ▒▒▒▒▒▒
45 - 47 | ▒▒▒▒▒▒▒▒▒▒
48 - 50 | ▒▒▒▒▒
51 - 53 | ▒

# EUMERALLA #1

1770.8 M ;CORE 10

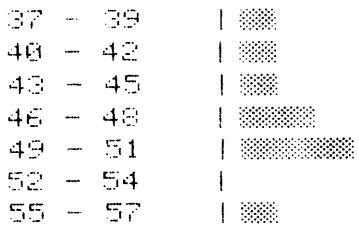
SORTED LIST

.37 .39 .41 .42 .43 .45 .46 .47 .47 .48
.49 .5 .5 .51 .51 .51 .57 .57

Number of values= 18

MEAN OF VALUES .473
STD DEVIATION .054

HISTOGRAM OF RESULTS
Values are reflectance multiplied by 100



# EUMERALLA #1

2043.9 M ;CORE 15

SORTED LIST

.41 .42 .48 .49 .5 .51 .52 .52 .54 .54
.54 .55 .55 .55 .56 .56 .56 .56 .56 .57
.58 .59 .59 .6 .6 .6 .61 .61 .61 .62
.63 .66
Number of values= 32

MEAN OF VALUES .556
STD DEVIATION .055

HISTOGRAM OF RESULTS
Values are reflectance multiplied by 100

41 - 43 | ▒
44 - 46 |
47 - 49 | ▒
50 - 52 | ▒▒▒
53 - 55 | ▒▒▒▒▒
56 - 58 | ▒▒▒▒▒▒
59 - 61 | ▒▒▒▒▒▒▒
62 - 64 | ▒
65 - 67 | ▒

# APPENDIX 3

## THIN SECTION DESCRIPTIONS

Sample: ISC46933; Location: Codrington No. 2, Core 17, 1152 m

Rock Name:

Compact litharenite

Hand Specimen:

A massive somewhat friable fine-grained sandstone characterised by a pale green colour.

Thin Section:

An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Lithic fragments | 70 |
| Quartz | 20 |
| Feldspar | 5 |
| Mica/chlorite | 3 |
| Opaques and semi-opaques | 1 |

The bulk of this rock consists of a heterogeneous mosaic of fine-grained phyllosilicates, clays and other indeterminate components. The material is more or less turbid and brown or orange in plane polarised light and commonly rather dark between crossed Nicols. The material has a texture on a scale commonly of about 0.1 mm and is taken to be the somewhat altered remnant of abundant lithic material which was deposited at the same time as the quartz and feldspar. The sample appears to be fairly well-sorted and compact and no porosity was identified in the thin section.

In detail the abundant lithic material can be seen to consist mainly of indeterminate phyllosilicate minerals including fine-grained mica and abundant clay. The material varies in colour and crystal size on a scale of about 0.1 mm and clearly is derived from original sedimentary and metasedimentary lithic fragments. These may have undergone some alteration and there is some evidence of authigenic clays intergrown with original detrital material. It is not possible to determine with certainty whether any of the clay material was an orginal fine-grained argillaceous matrix because of difficulties in distinguishing such material from the bulk of the lithic fragments, but there is no specific evidence for the presence of such a matrix and the rock has therefore not been described as a greywacke.

Other detrital components are apparently well-sorted but rather angular equant grains of quartz, plagioclase and potassium feldspar. The feldspar is fairly fresh and generally still retains evidence of twinning. Biotite and chlorite also show shades of pleochroism and, in the case of biotite, moderate birefringence and this, also, suggests little alteration in the diagenetic environment.

This sample shows considerable chemical immaturity of the detrital material and most grains are rather angular; however, the rock appears to be well-sorted about an average grain size of approximately 0.1 mm. Because of the abundance of clay and probably some abrasion or compaction and deformation of the soft lithic fragments, the sample may well have rather poor reservoir quality.

Sample: ISC46734; Location: Codrington No. 2, Core 18, 1202.5 m

Rock Name:
Feldspathic litharenite

Hand Specimen:
A friable sandstone with a relatively well defined bright green colour. The hand specimen appears to be essentially massive.

Thin Section:
An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Lithic fragments | 65-70 |
| Feldspar | 15 |
| Quartz | 10 |
| Pores | 5 |
| Clay | 1-3 |
| Mica/chlorite | 1 |

This is a well-sorted sandstone in which grains of quartz, feldspar and lithic material have an average size of approximately 0.2 mm. Most identifiable grains are within the range of about 0.1 to 0.4 mm. The rock shows some porosity which appears to consist of both primary and secondary types. Primary pores tend to be rather small (compared to the average grain size) and are commonly lined with authigenic clay. Secondary pores are distinctly more variable, tend to be larger and are associated with rather altered and deformed soft lithic fragments. The rock does show a thin selvedge of authigenic clay on many of the grains and the development of this may have reduced pore throat sizes and hence the permeability.

Lithic fragments are better defined in this sample than in that described immediately above and tend to include, not only argillaceous types but also chert and medium grained igneous rocks. Some of these rocks are clearly rigid fragments whereas the argillaceous lithic fragments have been somewhat deformed and distorted during compaction. Even so, most of the lithic fragments show equant outlines but are generally subround to round in shape. In contrast, quartz and feldspar grains tend to be distinctly more angular. Amongst the lithic fragments are some distinctly volcanic types and these are characterised by small laths of feldspar which suggest that they are intermediate or possibly acidic types. Quartz and feldspar grains are clear and well defined and the feldspar invariably shows evidence of excellent twinning. This is particularly the case for plagioclase and there are some types which also show a zonation characteristic of volcanic plagioclase.

The rock shows authigenesis in that many of the detrital grains have a thin selvedge of brown clay. This selvedge is generally not more than about 0.02 mm in width but it probably comprises up to about 2% of the total volume of the rock. Apart from the presence of this phase, lithification has occurred largely by distortion and some alteration of the lithic fragments.

Sample: ISC46935; Location: Codrington No. 2, Core 18, 1204.5 m

Rock Name:
Friable feldspathic litharenite

Hand Specimen:
This is essentially a loose sand which has a somewhat grey to green colour. The remaining fragments are too small to distinguish any sedimentary structures or significant textures.

Thin Section:
An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Lithic fragments | 60 |
| Pores | ≈20 |
| Quartz | 10 |
| Feldspar | 10 |
| Opaques and semi-opaques | 1 |
| Heavy minerals | Trace |

This is a distinctly loose and friable sandstone and several fragments are included in the thin section and these have a porosity which is approximately estimated as 20%. Some of this porosity may result from fragmentation of the sample during collection and preparation of the thin section. For the most part, the solid material in the thin section is well-sorted sand grade grains which have an average size of about 0.25 to 0.3 mm. Most of the grains are of lithic material and they are fine-grained, more or less argillaceous fragments. Many are equant and fairly well rounded and may be classified as sedimentary and metasedimentary types. In addition to these there are some fine to medium grained igneous rocks and rare examples of chert.

Quartz and feldspar fragments are equant, rather angular single crystals and those of feldspar are notably fresh. Plagioclase is the predominant type and one or two crystals show zoning indicative of a volcanic origin. Heavy minerals are represented by one angular fragment of what is tentatively identified as hornblende. The presence of such a labile mineral indicates the paucity of weathering and abrasion that the sample has undergone before deposition.

There is little evidence of a specific intergranular phase and the few areas of indeterminate fine-grained material could well be interpreted as having been derived from adjacent broken and/or abraded lithic fragments. As a result the sample has an apparently high porosity and little evidence of much lithification.

This is a chemically immature sandstone showing evidence of a provenance which includes both volcanic and sedimentary areas. There is no evidence of diagenesis and the rock appears to retain a relatively high porosity. The pores are of primary origin representing the original intergranular voids.

Sample: ISC46938; Location: Bootahpool No. 2, Core 11, 792 m

Rock Name:
Immature argillaceous sandstone

Hand Specimen:
A brown friable sandstone with some evidence of the presence of large mica flakes.

Thin Section:
An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Quartz | 70 |
| Iron-stained intergranular material | 20 |
| Pores | 5 |
| Mica | 2 |
| Feldspar | 1-2 |
| Heavy minerals | Trace |

The detrital quartz and feldspar grains are ill-sorted in this rock and commonly range in size from less than 0.1 mm to more than 0.7 mm. There are also variations in different parts of the thin section rather than a random mixing of grains of different sizes. Most of the grains are equant in shape and many are distinctly well-rounded. In the more quartz-rich parts of the thin section there is evidence of pressure solution effects on the grains and of overgrowths. For the most part, however, there is an intergranular fine-grained matrix and the presence of this appears to have inhibited extreme diagenesis effects on the quartz grains.

Minor detrital components are a few rather stained and altered flakes of mica and a small proportion of both potassium feldspar and plagioclase. The latter tend to be fresh and the plagioclase commonly shows polysynthetic twinning. Most of the feldspars are amongst the smaller grains in the rock.

The sample is characterised by the presence of an almost contiguous mosaic of fine-grained material which is dark brown to opaque in plane polarised light and very dark between crossed Nicols. The material is commonly rather indeterminate but there are places where a fine-grained texture can be seen and it seems likely that this material is a melange of fine-grained quartz and clays probably with a grain size of not more than 0.03 mm. The material has been obscured by the dark brown staining but it is likely that it is a homogeneous matrix deposited at approximately the same time as the main bulk of quartz and feldspar grains. There is a little porosity which shows an inverse distribution to that of the brown material but the presence of the latter has probably contributed markedly to a diminution of the reservoir quality of this rock.

Sample: ISC46939; Location: Bootahpool No. 2, Core 12, 875 m

Rock Name:

Friable, porous sandstone

Hand Specimen:

This is a loose sand or sandstone which appears to be rather fine-grained and has an overall medium brown colour.

Thin Section:

An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Quartz | 65 |
| Pores | 30 |
| Clay | 3 |
| Heavy minerals, mica and feldspar | Trace |

As the list above indicates, this is an extremely porous sand or sandstone and it appears to have been lithified by the rather patchy accumulation of a small amount of clay. There is little evidence of diagenesis of quartz and there are no separate diagenetic phases. As a result, pores are abundant and widely distributed and most are thought to be essentially of primary origin. The pores are probably well interconnected in three dimensions.

Detrital grains of quartz and feldspar are moderately well-sorted about an average size of approximately 0.2 mm. Many of the grains are distinctly angular in shape and range to subround varieties. The grains have tangential contacts and there is no evidence of pressure solution effects or of overgrowths. There are rare larger quartz grains up to about 0.4 mm in size. Feldspar is fairly fresh and most grains show some evidence of twinning or exsolution effects. There are also one or two grains of somewhat altered colourless mica and of fresh zircon and tourmaline.

Intergranular material consists of brown-stained fine-grained phases and one or two examples of dispersed and rather indeterminate turbid clay. These components tend not to be randomly distributed over the area of the thin section but concentrated in irregular large areas. Even in these, however, there are still some remnants of pores. In clay-poor areas the clay tends to form discontinuous rims around some of the grains and in some of the narrow interstices between the grains.

This is a friable sand or sandstone which shows little evidence of a clay matrix and an absence of diagenetic phases such as carbonate, kaolinite or quartz. The sample probably has good to excellent reservoir properties.

Sample: ISC46929; Location: Belfast No. 4, Core 9, 891 m

Rock Name:

immature litharenite

Hand Specimen:

A somewhat friable dark brown to grey sample. The rock appears to be fine-grained and only a small proportion of sand-grade quartz grains can be identified positively.

Thin Section:

An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Quartz | 60 |
| Brown matrix and lithic fragments | 40 |
| Mica | 1 |
| Feldspar | Trace |
| Heavy minerals | Trace |

This is an ill-sorted, immature sandstone in which much of the material between the quartz grains is dark and indeterminate. Some of the material is definitely derived from somewhat altered and stained lithic fragments but much appears to be a fine-grained argillaceous matrix in which abundant clays are mixed with smaller amounts of fine-grained quartz, mica and iron oxide/hydroxide secondary minerals. As a result of the abundance of the matrix material the thin section shows no porosity which can be regarded as an integral part of the rock (some large pores are probably the result of plucking material from the rather soft sample during preparation of the thin section).

Quartz grains are distinctly ill-sorted and commonly range in size from about 0.1 mm to 0.8 mm and the average size is of the order of 0.2 to 0.3 mm. Some of the grains are distinctly of volcanic origin and have re-entrant angles and sharp vertices whereas others appear to be recycled sedimentary grains and show excellent rounding. There is even some evidence of the presence of rounded overgrowths. Feldspar is present in the rock only to a very small extent and a few corroded small grains of both potassium feldspar and plagioclase were identified.

The material between the quartz grains shows a speckled or mottled appearance generally on a scale of less than 0.01 mm. In places, however, there are dark, brown aggregates of extremely fine-grained material which show rounded outlines and the size commonly ranging from 0.1 to 0.2 mm. These are clearly clay clasts of some kind. In addition to these there are quartz-clay aggregates which probably represent metasedimentary lithologies. The remainder of the intergranular material is fine-grained and contains varying amounts of quartz and mica as well as dark indeterminate material probably containing significant amounts of both clay and secondary iron oxide/hydroxide materials. Throughout much of the thin section the dark material forms a contiguous network between the quartz grains and the rock therefore appears to be matrix-supported.

This is a distinctly immature sandstone which probably contains a significant amount both of detrital soft lithic clasts and of a genuine argillaceous muddy matrix. Both of these constituents appear to have undergone significant alteration particularly with the deposition of secondary iron oxide/hydroxide minerals. The rock probably has very limited reservoir properties.

Sample: ISC46930; Location: Belfast No. 4, Core 10, 911 m

Rock Name:
Porous sublitharenite

Hand Specimen:
A dark and very friable fine-grained sandstone. Some of the small fragments show reflective cleavage faces of mica but no other significant mineralogical or textural features.

Thin Section:
An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Quartz | 70-75 |
| Opaques and semi-opaques | 10 |
| Clay | 7 |
| Pores | 5-7 |
| Feldspar | 2 |
| Mica | 2 |
| Heavy minerals | 1 |

This is a rather ill-sorted sandstone in which the quartz grains have an average size of approximately 0.2 mm. The largest grains in the thin section are of the order of about 0.5 to 0.8 mm in size. There is one patch in the thin section of a more even grained sandstone in which the average grain size is of the order of 0.1 mm and there is a considerable concentration of heavy minerals. This appears to be some kind of fragment included in the bulk of the material. The quartz grains are generally equant in shape but most are subangular in outline with a few tending towards well rounded shapes. Both potassium feldspar and plagioclase were identified and both minerals, although corroded, appear to be essentially fresh. Biotite and muscovite were both identified as detrital fragments and the biotite is characterised by a brown pleochroic shade rendered somewhat turbid by alteration.

Over much of the thin section, the intergranular space is void and the pores appear to be principally of primary origin somewhat reduced by the presence of a small amount of a yellow authigenic clay mineral. This is thought likely to be a smectite and it has a rather patchy distribution. Most of the clay in the rock is indeterminate rather dark material which is distinctly patchy. There are some relatively large aggregates of this material which may well represent original lithic clasts but much of it is finer grained than quartz grains and distributed in relatively small intergranular spaces. It is thought likely that the bulk of the material described as clay and opaque and semi-opaque material in the list above is in fact derived from original lithic fragments probably somewhat broken and altered during diagenesis and compaction of the rock.

As far as can be determined in thin section the sample does contain a suite of stable heavy minerals and tourmaline, rutile and zircon were all specifically identified. The patch of fine-grained sandstone contains rather abundant heavy minerals of which rutile and opaques were particularly noted.

The sample appears to have relatively high porosity and probably permeability but more detailed analysis of the clay types would be necessary in order to assess the potential of the rock for adverse reactivity with drilling and completion fluids, for example.

Sample: 1SC46931; Location: Belfast No. 4, Core 19, 1545.5 m

Rock Name:
Feldspathic litharenite

Hand Specimen:
A slightly friable, apparently massive sandstone with a medium green colour.

Thin Section:
An optical estimate of the constitutents gives the following:

| | % |
|---|---|
| Lithic fragments | 55 |
| Feldspar | 30 |
| Quartz | 10 |
| Clay | 5 |
| Mica | 1 |
| Epidote/calcite and ?Talc | Trace |

This is a homogeneous, even grained sandstone which is characterised by the abundance of lithic fragments and feldspar. There is a small amount of clay which forms generally as a selvedge on many of the grains. The presence of this clay and the plastic deformation of some of the lithic fragments has resulted in the thin section apparently lacking any porosity whatsoever.

The quartz, feldspar and lithic fragments are all well-sorted and have an approximate average size of 0.15 mm. Most of the grains are angular and there is little evidence of much modification of the detrital material during diagenesis and lithification. The feldspar grains are principally plagioclase and this mineral in perfectly fresh. Some grains show zonation which is characteristic of plagioclase derived from volcanic rocks. The importance of an igneous provenance is also shown by the abundance of identifiable volcanic rock fragments amongst the lithic grains in the thin section. Such fragments are generally feldspathic in composition and have distinctly fine-grained texture. Other lithic grains are apparently argillaceous or have a secondary altered mineralogy and their original nature is more difficult to determine. It seems likely that at least 25% of the lithic grains are identifiably of volcanic origin. Most of the others are probably fine-grained sedimentary or possibly metasedimentary types. Associated with some of the more turbid and altered lithic fragments are small patches of secondary minerals such as the three listed above.

The rock contains small amounts of detrital biotite.

As indicated above, there is a network of a brown clay which appears to form on grain surfaces. It is most likely that this is an early diagenetic phase but it is thought that its crystallisation probably contributed little to occlusion of the original porosity. The thin section contains no porosity largely as a result of the abundance of the lithic fragments and some alteration and deformation of these during lithification of the rock.

Sample: ISC46732; Location: Belfast No. 4, Core 22, 1682 m

Rock Name:
Feldspathic litharenite

Hand Specimen:
A compact and apparently massive sandstone with a notably even medium green colour.

Thin Section:
This rock is very similar to that described immediately above (from 1545.5 m) and a detailed description is not, therefore, warranted. In mineralogical terms, the present sample contains somewhat more detrital biotite and fewer lithic fragments can be specifically identified as being of volcanic origin. It is likely that the sample contains a larger amount of indeterminate clay in lithic fragments.

The thin section shows no visible porosity and this is a result of some compaction and deformation of lithic fragments, distortion of the mica flakes and, probably, the presence of a little original clay matrix. The average grain size is about 0.2 mm and most of the identifiable grains of quartz and feldspar are equant but distinctly angular in shape.

The sample has not been described as a greywacke because of problems in distinguishing genuine muddy matrix (an integral constituent of greywackes) from clays which were originally present as constituents of lithic fragments. The rock is, however, an immature sandstone derived from an adjacent provenance area containing very abundant fine-grained volcanic rocks.

Sample: ISC46936; Location: Belfast No. 11, Core 16, 978 m

Rock Name:

Pure quartz sand

Hand Specimen:

An extremely friable buff coloured sand or sandstone. As far as can be determined from the few fragments surviving the rock is massive and shows no sedimentary structures. Cut surfaces contain a small proportion of widely disseminated white fragments which may well be somewhat altered feldspar.

Thin Section:

An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Quartz | 70–75 |
| Pores | 25 |
| Feldspar | 1–2 |
| Lithic fragments | <1 |
| Heavy minerals | Rare |

As the list above indicates, more than 95% of the solid constituents of this rock consist of quartz. The mineral forms well-sorted subangular to subround grains which have an average size of about 0.2 to 0.25 mm. Most of the grains are of the common or plutonic variety. There are touching contacts between the grains and very little evidence of post-depositional modifications. In view of this and of the absence of authigenic components or argillaceous matrix, the sample has been lithified to only a small extent.

As well as quartz the sample contains a small amount of detrital feldspar and both microcline and plagioclase were identified. There is probably a preponderance of the former but both feldspars can readily be identified partly from the presence of twinning and partly from some slight turbidity due to pervasive alteration. There are a few ragged crystals of tourmaline and one or two small clay aggregates thought to have been derived from rather broken argillaceous lithic fragments.

Pores are of the primary type and are clearly well interconnected in three dimensions and the sandstone no doubt shows excellent reservoir properties both in terms of its large porosity and permeability and the lack of any reactive clays.

Sample: ISC46934; Location: Belfast No. 11, Core 26, 1420.5 m

Rock Name:
Feldspathic litharenite

Hand Specimen:
A slightly green but mostly medium grey sandstone which is fairly compact in the hand. The fragments remaining appear to be completely massive and homogeneous.

Thin Section:
An optical estimate of the constituents gives the following:

| | % |
|---|---|
| Lithic fragments | 60-65 |
| Feldspar | 15-20 |
| Quartz | 10 |
| Authigenic clay | 10 |
| Mica | 1 |

The thin section of this sample does show some very large pores but these are thought to be a function of the preparation of the thin section and a removal of some of the constituents. In the better-preserved parts of the rock porosity appears to be virtually absent. Any measured porosity and permeability in these lithic sandstones probably occurs within aggregates of clay rather than as pores which will be visible in thin section.

The rock is well-sorted and both quartz and feldspar on the one hand and the lithic fragments on the other tend to have an average size of about 0.25 mm. Some of the lithic fragments are distinctly elongate but most are subround to round in shape and have rather oval outlines. Quartz and feldspar grains tend to be somewhat more angular. Feldspar is fresh and essentially unaltered and most is plagioclase. There are some zoned grains which are remnants of original volcanic crystals and there are rare examples of slightly turbid untwinned feldspar which may be orthoclase or microcline.

The lithic fragments include some varieties which are definitely of volcanic origin and others which are schistose or slatey rocks. As is commonly the case, however, the majority of the lithic fragments are fine-grained argillaceous rocks of somewhat indeterminate origin but probably could be classified as sedimentary and metasedimentary types. Compared to other litharenites and feldspathic litharenites described above, this sample definitely contains a greater proportion of schistose metamorphic rocks which contain a well defined assemblage of quartz and mica. Even volcanic rocks can also be clearly identified, particularly those containing microphenocrysts of feldspar. The sample contains a small proportion of surprisingly fresh detrital biotite.

Many of the grains have a distinct selvedge of a green to brown authigenic clay. Typically this selvedge is of the order of about 0.02 mm in thickness but it is sufficiently pervasive to comprise a significant proportion of the total volume of the rock. The material may well be chlorite or possibly some kind of smectite mineral.