PGPC

Report prepared for:

BHP Petroleum Pty Ltd
120 Collins St
Melbourne
VIC 3001

PETROLOGY REPORT

MINERVA-1

OTWAY BASIN

Report prepared by:

Dr S E PHILLIPS
PGPC
1c Short Crescent
Beaumont SA 5066
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PHILLIPS-GERRARD PETROLOGY CONSULTANTS

Mobile: (61) 015-712 728 Fax/phone: (61) 08-379 8281 Email:sphillips@ncpgg.adelaide.edu.au

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1. INTRODUCTION

BHP Petroleum Pty Ltd submitted three sidewall cores from Minerva-1 in the Otway Basin, for detailed petrological description. The aims of the study were to:

1. Compare the Otway Group sample with petrological descriptions of sediments from Eric The Red-1, La Bella-1 and Loch-Ard -1.

2. Explain the poor reservoir quality of samples from the Upper and Lower Shipwreck Group.

The client provided copies of petrological reports for Eric The Red-1 and La Bella-1 to assist with the study. Sidewall cores from Loch-Ard -1 were described in conjunction with these samples from Minerva-1.

The following samples were examined:

Swc	Depth (mRT)	Formation
63	1969	Upper Shipwreck Group
120	2259	Lower Shipwreck Group
113	2340	Otway Group

3. METHODS

Sidewall cores were impregnated with araldite prior to thin section preparation. Blue dye was used in the araldite to facilitate description of porosity and permeability. Thin sections were systematically scanned to determine lithology, composition, porosity and textural relationships. All percentages given in thin section descriptions are based on counts of 500 points. Rock classifications are based on the work of Folk (1974) for clastics.

3. PETROLOGY

3.1 Minerva-1, Swc 63, depth 1969mRT

Thin section description

Rock classification: Quartzarenite

Texture:
Grain fracturing was extensive during sidewall coring and the sample has been fragmented into chips. There are patches where the texture has been retained adjacent to laminated and cemented zones. Laminae are crenulated and may represent dissolution seams. They are composed of dark brown clay and stringers of opaque material. In these areas it is apparent that the sample is a poorly sorted, medium to very coarse grained, mineralogically mature and texturally submature quartzarenite. Grain size ranges from approximately 0.10mm (very fine sand) to 2.05mm (granules) and typically grains are subrounded to subangular with low sphericity. Texturally the sample is grain supported with dominantly tangential grain contacts. Adjacent to the crenulated laminae the grain contacts are sutured due to intense mechanical compaction.

Porosity:
It is difficult to assess porosity due to the degree of disruption during sampling. However, the fact that the sample is poorly sorted suggests that primary intergranular porosity would not be good. There are rare examples of corroded feldspars which indicate minor honeycomb porosity. In addition there would be micropores associated with the pore filling and grain replacing kaolin. The abundance of micropores would not be accurately estimated by the point count because the pores are too small. The presence of crenulated laminae (Fig. 1) would significantly reduce vertical permeability.

Point count of Composition		%
Framework grains	Quartz	74.1
	Feldspar	1.7
	Lithics	1.7
	Mica	0.8
	Accessory minerals	0.2
Matrix	Clay	3.0
	Opaque material	1.3
Authigenic minerals and cements	Kaolin	13.9
	Pyrite	1.9
Porosity	Intergranular	0.2
	Dissolution	0.6
	Micropores	0.6

Framework grains:
Monocrystalline quartz is abundant, it has straight to slightly undulose extinction, scattered vacuoles and rare mineral inclusions of mica, zircon and tourmaline. Polycrystalline quartz is coarse grained, it has undulose extinction and either straight or sutured crystal boundaries. Rare feldspars with weak carlsbad twins have been partially corroded. Other feldspars have been either extensively corroded to leave a skeleton, sericitised, or have been replaced by kaolin. Scarce micaceous lithics of metamorphic origin are deformed. Highly altered flakes of biotite are bent and splayed. Muscovite flakes concentrate within the crenulated laminae. There is a silt size grain of tourmaline representing the accessory minerals.

Matrix:
Dark brown anhedral clay concentrates in the laminae. The clay is aligned tangentially to grain surfaces. Stringers of opaque material in the laminae are probably composed of organic matter.

Authigenic minerals and cements:
Anhedral to subhedral kaolin booklets have replaced grains and filled pores. The booklets are up to 30 microns in diameter and appear to have ragged edges. Kaolin is pervasive throughout the section. Pyrite framboids which are up to 10 microns in diameter are clustered in groups along grain margins and within the clay laminae. Elsewhere there are patches several millimetres in diameter of massive pyrite cement which completely fills pores and embays framework grains.

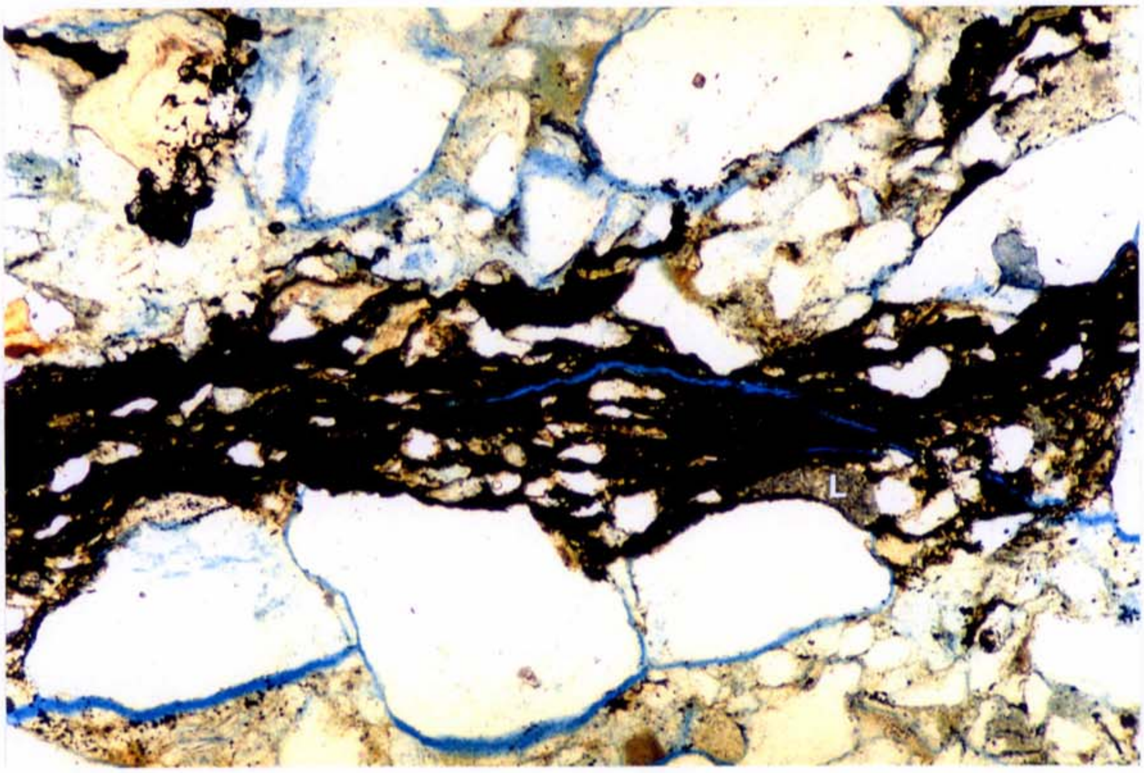

Figure 1.
Crenulated laminae (opaque) would limit vertical permeability. Note the poorly sorted nature of the sediment and the fracturing (blue) due to sidewall coring. A deformed metamorphic lithic (L) is also apparent. Minerva-1, Swc 63, depth 1969mRT. Plane light. Field of view 3.38mm.

Interpretation

This poorly sorted, medium to very coarse grained quartzarenite from the Upper Shipwreck Group is mineralogically mature. Reworking of older sediments, long distances of sediment transport or intense in situ alteration could explain the maturity. The poor sorting and coarse grain size can be attributed to rapid deposition in a relatively high energy environment. Intervening periods of quiescence are indicated by the clay rich laminae. There is no evidence to differentiate either a marine or terrestrial depositional environment.

The authigenic mineralogy suggests there has been intense in situ alteration. Grains have been replaced and pores filled by kaolin. In situ replacement of feldspars and possibly rare lithics would occur when conditions were slightly acidic. Pore fluids became saturated with Si and Al because of feldspar dissolution thus kaolin was also able to precipitate in pores. Rarely the dissolution pores were preserved. Acidic conditions may have been introduced due to flushing by meteoric waters early in the diagenetic sequence. Prior to sediment flushing there could have been slightly reducing conditions which would have favoured replacement of detrital clays and organic matter by framboidal pyrite. The patchy pyrite cement is probably a later phase of diagenesis which could be due to biodegradation of bitumen in the reservoir.

Reservoir quality has been limited by at least 5 factors. Initially the poor sorting of the sediment and presence of clay rich laminae resulted in limited primary intergranular porosity and restricted vertical permeability. Furthermore, the ductile nature of detrital clays favoured mechanical compaction thus reducing reservoir quality adjacent to these zones. Development of secondary dissolution pores did not significantly enhance reservoir quality because these pores were filled with kaolin and would not have been interconnected. The abundance of pore filling kaolin has reduced pores to micropores which may be effective for gas but not for oil. The final factor is the patchy pyrite cement which has locally occluded porosity. Many of these characteristics are similar to those which limited reservoir quality in the fine-medium grained, sublitharenite of core plug 30 (depth 1833.50m) from Minerva-1. This sample had stylolites and authigenic cements of pyrite (4%) and kaolin (10%). Dissolution pores were dominant and routine core analysis showed a porosity of 9.4% and a permeability of 0.72md. Similar values would be expected for sidewall core 63.

3.2 Minerva-1, Swc 120, depth 2259mRT

Thin section description

Rock classification: Litharenite

Texture:
Chips of this sidewall core have either retained textural integrity or been completely crushed. This description is confined to those chips which appear to be intact. The sample is a medium grained, moderately sorted, mineralogically and texturally submature litharenite. Grains range in diameter from approximately 0.15mm (fine sand) to 0.80mm (coarse sand) and are typically subangular with low sphericity. The alignment of elongate grains could be due to rotation during compaction or may indicate the presence of bedding. Grain contacts are commonly tangential and concavo-convex in this grain supported litharenite. Deformation of ductile lithics and micas indicates that there has been significant mechanical compaction.

Porosity:
Porosity is restricted by the deformation of ductile grains, the presence of chlorite rims (Fig. 2) and patches of carbonate cement. There are dissolution pores preserved where grains have been partially dissolved but these are unlikely to be interconnected and hence permeability is probably poor. Primary intergranular pores have not been preserved due to mechanical compaction of the ductile grains. There could be traces of microporosity associated with the chlorite rims but the percentage is probably underestimated by the point count.

Point count of Composition		%
Framework grains	Quartz	33.0
	Feldspar	10.8
	Lithics	
	- metamorphic	15.6
	- volcanic	15.2
	Mica	1.3
	Accessory minerals	0.2
Matrix	Clay	0.2
Authigenic minerals and cements	?Anatase	3.2
	Chlorite	6.7
	Kaolin	4.8
	Carbonate	2.4
	Pyrite	0.6
Porosity	Intergranular	2.8
	Dissolution	3.0
	Micropores	0.2

Framework grains:
Monocrystalline quartz has straight to slightly undulose extinction and scattered vacuoles. Rare mineral inclusions of tourmaline and apatite are evident in the quartz. Polycrystalline quartz has either sutured or straight crystal boundaries and undulose extinction. Dusty corroded feldspars with remnants of albite twinning are apparent. In addition there are fresh feldspars with tartan twinning characteristic of microcline and micrographic intergrowths of quartz and feldspar. The micaceous metamorphic lithics have been deformed. Texturally the metamorphic lithics are gneissic and schistose. Rare examples of chert and very dusty ?volcanic lithics are also apparent. Other volcanic lithics have a groundmass of devitrified glass in which felsic laths float. Bent and broken biotite flakes are up to 1.2mm in length. Angular fine sand size fragments of epidote are rare.

Authigenic minerals and cements:
Associated with the biotite and rimming isolated grains there is minor dusty to opaque material which is anhedral. This material could be anatase which precipitated prior to the chlorite. Bright green rims of chlorite are up to 5 microns in thickness. The chlorite occurs as platelets oriented at right angles to the grain surface. The rims are not continuous around grains and therefore probably formed after at least minor mechanical compaction. Chlorite has replaced selected grains including biotite. Other micas have been replaced by kaolin which has euhedral booklets that are up to 50 microns in diameter. Elsewhere grain replacing and pore filling kaolin is much finer (10 microns) and commonly anhedral. Poikilotopic clear carbonate spar forms a patchy cement. Pores are filled with spar and grains have been replaced. Along pore margins there are isolated framboids of pyrite which are less than 10 microns in diameter.

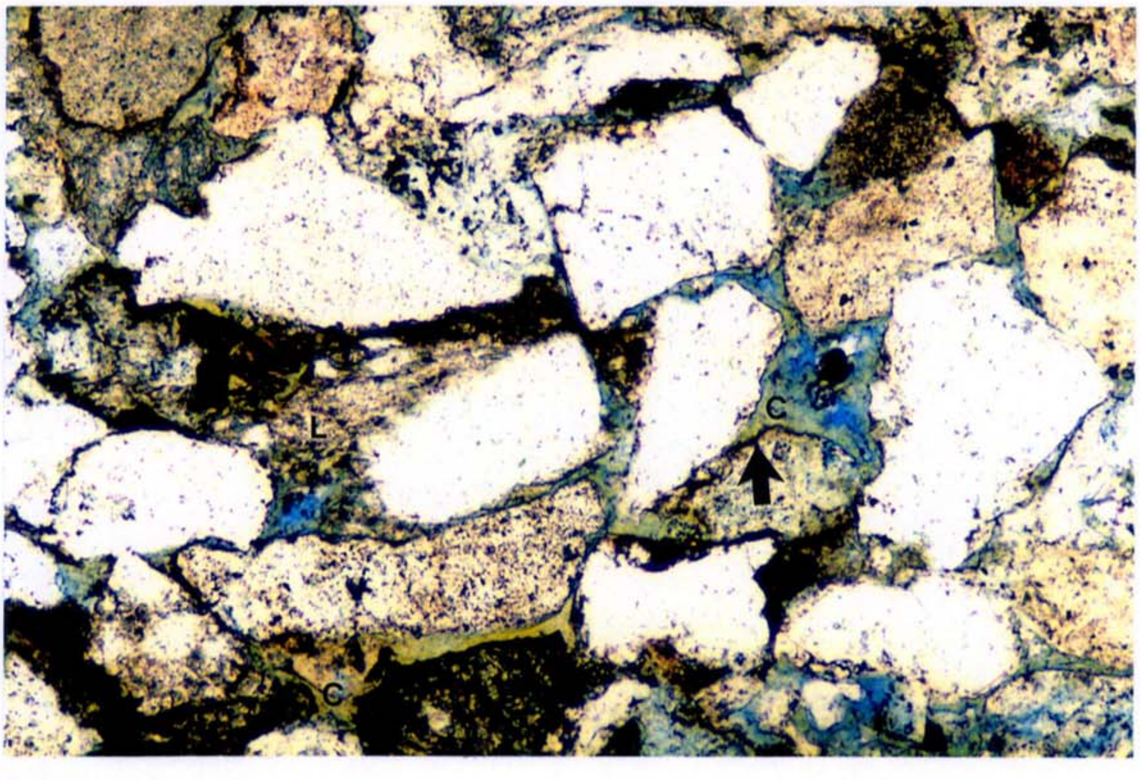

Figure 2
Chlorite (C) has filled and rimmed pores and ductile lithics (L) have been deformed to reduce intergranular porosity. Note the dark rim of ?anatase (arrow) before the chlorite rims. Minerva-1, Swc 120, depth 2259mRT. Plane light. Field of view 1.35mm.

Interpretation

This medium grained, moderately sorted litharenite from the Lower Shipwreck Group has a relatively high percentage of feldspars (10.8%) which means the lithology plots on the boundary between a litharenite and a feldspathic litharenite. Feldspars include both K-feldspars and plagioclase, and there are equal proportions of volcanic and metamorphic lithics. This suggests a balance between sediment provenance from volcanic and metamorphic terranes. Preservation of feldspars may indicate relatively short distances of sediment transport. There is no diagnostic evidence of the type of depositional environment.

Diagenetic alteration may have been initiated with the precipitation of pyrite framboids. Slightly reducing conditions with sulphate reduced by bacterial action and Fe derived from the early alteration of ferromagnesian minerals in the lithics could have resulted in the pyrite. The irregular opaque rims on grains and opaque material associated with biotite may be composed of anatase. This mineral forms at low temperatures (less than 60°C) as an alteration product of micas, sphene, rutile and mafic minerals. The latter were probably present in the volcanic lithics. Whilst conditions remained slightly reducing and pore waters were saturated with Fe and Mg as a result of ferromagnesian minerals altering, the precipitation of chlorite was favoured. Chlorite forms rims on pores after the ?anatase, and probably precipitated after minor mechanical compaction. The exact time when kaolin formed is unclear but it would have been related to a phase when pore waters were more acidic and labile grains such as feldspars were dissolved. These conditions could have been introduced by flushing of meteoric waters due to near surface exposure or the upwards migration of acidic groundwaters expelled by mechanical compaction. The final phase of authigenic cement was the precipitation of clear carbonate spar which fills pores and partially replaces grains. The poikilotopic nature of this cement is characteristic of a burial cement which reflects a return to alkaline conditions.

Reservoir quality has been limited by the number of ductile lithics, the authigenic cements (kaolin, chlorite and carbonate) and the dominance of dissolution pores. The abundance of secondary pores means that there is no interconnection between pores and hence limited permeability. Furthermore, the kaolin and chlorite both have associated micropores which would not favour good reservoir quality.

It is interesting to note that none of the other Lower Shipwreck Group samples from La Bella-1 and Eric The Red-1 contain chlorite rims. In this respect this litharenite from Minerva-1 is more like the Otway Group sediments. The presence of chlorite is controlled by the abundance of volcanic lithics in this sample.

3.3 Minerva-1, Swc 113, depth 2340mRT

Thin section description

Rock classification: Litharenite

Texture:
The sidewall core has been disaggregated into chips with disrupted textures and fractured grains. This description is based on the least disturbed chips. The sample is a moderately sorted, medium grained, mineralogically and texturally immature litharenite. Grains are typically subangular with low sphericity and range in diameter from approximately 0.10mm (very fine sand) to 0.75mm (coarse sand). There are no sedimentary structures apparent. Texturally the litharenite is grain supported with tangential and concavo-convex grain contacts dominant. The latter have resulted from the deformation of ductile lithics and bent micas.

Porosity:
Porosity is difficult to accurately describe due to disruption during sampling. There are remnants of primary intergranular pores (Fig. 3) which have been decreased in size by the presence of chlorite rims. Pore throats are blocked by pore rimming chlorite and this suggests that permeability could be limited. Typically intergranular pores appear to be filled with chlorite. Microporosity is probably associated with the chlorite but may be underestimated by the point count. Rare corroded feldspars have resulted in honeycomb porosity and grain size pores are filled with chlorite.

Point count of Composition		%
Framework grains	Quartz	29.9
	Feldspar	9.0
	Lithics	
	- metamorphic	16.2
	- volcanic	22.6
	Mica	0.2
Matrix		nd
Authigenic minerals and cements	?Anatase	0.9
	Chlorite	14.6
	Carbonate	1.6
Porosity	Intergranular	4.3
	Dissolution	0.5
	Micropores	0.2

Framework grains:
Quartz is both monocrystalline and polycrystalline. Monocrystalline quartz has straight to slightly undulose extinction, scattered vacuoles and rare mineral inclusions of apatite. Polycrystalline quartz with either straight or sutured crystal boundaries and undulose extinction is less abundant than the monocrystalline quartz. Angular feldspars with remnants of carlsbad and pericline twinning have been corroded. Other feldspars have been sericitised. Feldspars with tartan twinning characteristic of microcline are fresh. Volcanic lithics are dominant and comprised of felsic laths with a groundmass of devitrified glass. Rarely albite twinning is apparent in the laths. There are scarce examples where minute crystals can be seen in the groundmass and phenocrysts float in the groundmass. There are also examples of metamorphic lithics with schistose and gneissic texture and lithics of chert. Chloritised biotite is bent and splayed due to mechanical compaction.

Authigenic minerals and cements:
Opaque material which rims volcanic lithics and quartz grains, and has partially replaced grains could be composed of ?anatase. This opaque material was precipitated before the chlorite. Chlorite rims on intergranular pores are pervasive throughout the sample and there

are examples of grains replaced by chlorite. The chlorite occurs as platelets oriented at right angles to the grain surface and rims are up to 25 microns in thickness. Clear carbonate spar filled isolated pores after the chlorite. Spar has also partially replaced corroded feldspars.

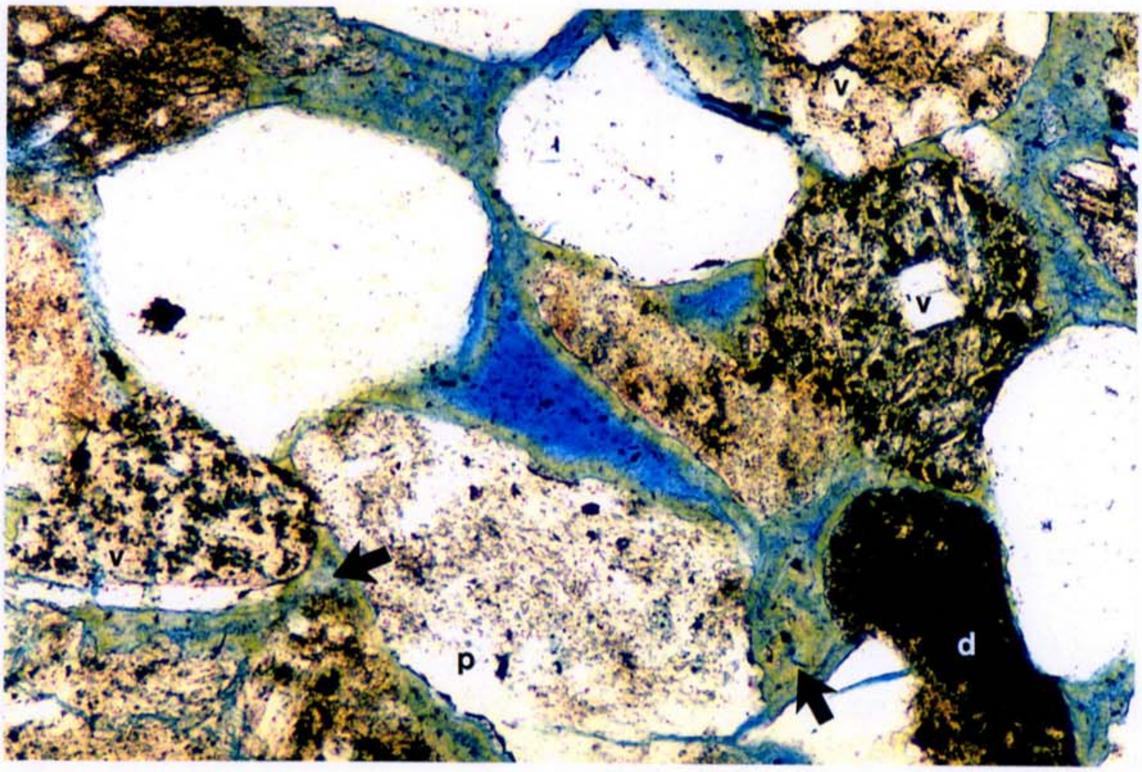

Figure 3
Pores (blue) are rimmed by chlorite and filled with chlorite (arrows). Volcanic lithics (v) are abundant and there are examples of devitrified glass which are deformed (d). Grains of polycrystalline quartz (p) have a dusty appearance. Minerva-1, Swc 113, depth 2340mRT. Plane light. Field of view 1.35mm.

Interpretation

The mineralogical immaturity of this Otway Group litharenite indicates either short distances of sediment transport or uplift in the source region. The dominance of volcanic lithics probably reflects the closer proximity of this terrane but a metamorphic provenance was also important. These two sediment sources would also account for the nature of quartz grains and feldspars. There are no sedimentary or mineralogical features diagnostic of the depositional environment, it could be either terrestrial or marine.

Diagenetic alteration has been strongly influenced by the abundance of volcanic lithics. Weathering of biotite, sphene, rutile and/or mafic minerals could have released the Ti necessary for the precipitation of ?anatase which forms partial rims prior to the chlorite. Whilst conditions remained reducing and ferromagnesian minerals in the lithics were altering there would have been sufficient Fe and Mg in the pore waters for the precipitation of chlorite. Where chlorite has filled dissolution pores it is apparent that there was a phase of corrosion prior to chloritisation. This dissolution of labile grains probably resulted from the flushing of acidic meteoric waters through the sediment after initial burial. At a later stage when conditions became alkaline after burial there was minor carbonate spar precipitated in the pores. At least some of the Ca could have been derived from the alteration of feldspars.

Primary intergranular pores have been preserved despite the chlorite rims but many pores are filled with chlorite. This reduction of pore space and blockage of pore throats suggests that reservoir quality is moderate to poor. There would be more microporosity than has been estimated from the point count and this could be important adjacent to intergranular pores.

When compared to other Otway Group litharenites from Loch-Ard -1 (Swc 32, depth 1326mRT), La Bella-1 (Swc 63, depth 2683.0m) and Eric The Red-1 (Swc 32, depth 1790m) the greatest similarity is evident with samples from Loch-Ard -1 and Eric The Red-1. Although the percentage of lithics in Minerva-1 (38.8%) is less than the other wells, there is a dominance of felsic volcanic lithics. This abundance appears to have controlled later diagenetic alteration with the precipitation of ?anatase and chlorite. Minor amounts of carbonate spar noted in Minerva-1 are not evident in Loch-Ard-1 nor Eric The Red-1. However, in the sample from La Bella-1 there is 10% carbonate cement. It is possible that the distribution of carbonate is depth related since the La Bella-1 and Minerva-1 samples are significantly deeper than litharenites from Loch-Ard -1 and Eric The Red-1.

In terms of the detrital mineralogically there is only a slight difference between the Lower Shipwreck Group and the Otway Group in Minerva-1. The most significant difference is the increase in the percentage of volcanic lithics in the Otway Group. This increase has resulted in more chlorite, whilst the Lower Shipwreck Group contains kaolin and pyrite. Kaolin was also noted in the Otway Group litharenite from La Bella-1. It would appear that there are similarities in both the detrital and authigenic mineralogy of the Lower Shipwreck and Otway Groups. Therefore it may be inadvisable to use the mineralogy as a means of differentiating these sediments.

4. CONCLUSIONS

1. Reservoir quality in the Upper Shipwreck quartzarenite from Minerva-1 has been limited by poor sorting, clay rich laminae, mechanical compaction, abundance of kaolin and patchy pyrite cement.

2. Reservoir quality in the Lower Shipwreck litharenite has been limited by the number of ductile lithics, the authigenic cements (kaolin, chlorite and carbonate) and the dominance of dissolution pores.

3. Lithologically the Otway Group sample is similar to litharenites from Loch-Ard -1 and Eric The Red-1 due to the dominance of volcanic lithics, the alteration of which has resulted in the precipitation of chlorite and possibly anatase.

5. GLOSSARY OF TERMS

Boehm lamellae
: Parallel trails of vacuoles in quartz that are thought to form during deformation (metamorphism) of grains.

Framboid
: A cluster of pyrite crystals with a spheroidal outline.

Glaucony
: A term used to describe green minerals without any genetic connotations. If the green minerals can be identified, a specific mineral name is given.

Granophyric Texture
: A variety of micrographic intergrowth of quartz and alkali feldspar that is either crudely radiate or is less regular than micrographic texture.

Honeycomb Porosity
: Secondary porosity produced by the corrosion (etching) of detrital grains.

Micrographic Intergrowth
: A regular intergrowth of two minerals.

nd
: Abbreviation meaning not detected.

Neomorphism
: All transformations between a mineral and the same mineral, or another of the same general composition.

Poikilotopic
: A sedimentary textural term denoting a single crystal of carbonate enclosing more than one framework grain.

Trachytic
: A textural term applied to the groundmasses of volcanic rocks in which there is a subparallel arrangement of microcrystalline, lath shaped feldspars. The term is not restricted in use to rocks of trachyte composition.

Vacuole
: Gas or liquid filled inclusion.