Reservoir Characterisation of the Liffey/Faulkner Group

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Dedicated to Naomi,
for her love and patience....

Abstract

The Liffey/Faulkner Group comprises the "lower freshwater sequence" in the Lower Permian, Lower Parmeener Supergroup in the "Tasmania Basin".

Reservoir characterisation of the Liffey/Faulkner Group in central Tasmania shows that: the Liffey/Faulkner Group is made up of 7 units which are lithologically continuous (with some variation) of average thickness of 20-35 m with an average porosity of 10%. Diagenetic processes are responsible for both occluding porosity by compaction, quartz growth and cementation infilling pores and enhancing porosity by the dissolution of grains such as feldspar.

The structural continuity of the group is undetermined and the reservoir potential of sections from the deeper parts of the basin are poor because the sediment is very fine grained in these areas.

The depositional environment of the Liffey/Faulkner Group includes glacially influenced fluvial, coastal and marine elements.

The "Tasmania Basin" contains all the elements to make a play, with source rocks including Ordovician Gordon Group carbonates, and the Lower Permian Tasmanite Oil Shale; prospective reservoirs including the Ordovician Eldon Group and the Lower Permian Liffey/Faulkner Group; and potential seals including the Poatina Group mudstones, and Jurassic Dolerite sills. Comparisons between the "Tasmania Basin" and other Gondwana Basins, in particular, the Cooper Basin, South Australia and the Paraná Basin in Brazil are analogues for the petroleum potential in Tasmania.

Acknowledgements

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Introduction 1

1.1 Aims and Significance

Potential for onshore petroleum exploration has been emphasised in recent times by drilling which has supported work on oil seeps, organic geochemistry, geophysics, structural geology, and paleontology (Burrett et.al.,1995). The thermal maturity of conodonts from Ordovician and Siluro-Devonian carbonates from west and north west Tasmania, indicates that the units below the Tabberabberan unconformity were, or are, within the oil and gas windows (Bendall et al., 1991). Hydrocarbons from such sources, eg., from Ordovician carbonates, may have migrated to a suitable reservoir. Such reservoirs may exist within the Gordon or Eldon Groups or units of the overlying Parmeener Supergroup.

This study considers potential reservoirs in the "lower freshwater sequence" of the Parmeener Supergroup from central Tasmania. The focus of the reservoir characterisation is on the Liffey Group (= Faulkner Group in southern Tasmania), and reviews its extent and variability, porosity, permeability, petrography and diagenetic alteration.

After the prospectivity of the Liffey/Faulkner Group is established a number of petroleum plays can be considered with potential source and seal rocks available in the "Tasmania Basin".

1.2 Area

Due to the nature of weathering in the rocks, the most accurate information can be obtained from diamond drill core samples. In order to understand the extent and geometry of the units and the variation within the units, samples have been collected from a number of areas in central Tasmania, including Golden Valley, Poatina, Great Lake, Ross, Tunbridge and Bothwell (Fig 1.1). Relevant units from the Hobart area including Mt Nassau, near Granton (Clarke and Farmer, 1982); Porters Hill, Lower Sandy Bay (Clarke, 1985) and Harts Hill near Margate (Farmer, 1979) have also been examined to constrain the sequence in southern Tasmania.

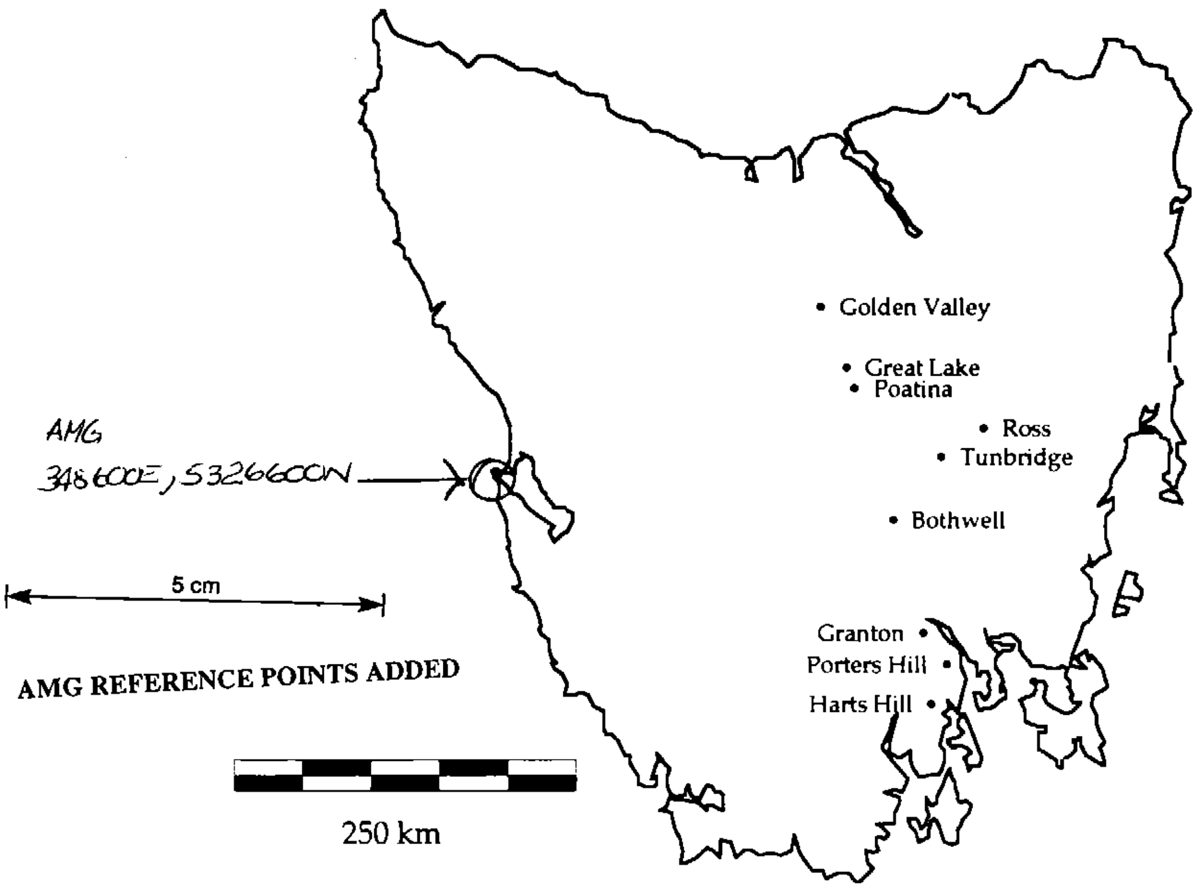

Figure 1.1 : Area and locations sampled around Tasmania

1.3 Previous Work

The geology of central Tasmania has been documented in Geological Survey explanatory reports including Pike (1973) and Forsyth (1989).

McKellar (1957) described the geology of a portion of the Western Tiers, in central Tasmania, and Wells (1957) described geology in the Deloraine-Golden Valley area. The Parmeener Supergroup was defined and subdivided into two members (the Upper and Lower Parmeener Supergroup) by Forsyth et al. (1974) and the palaeogeography of the "Tasmania Basin" was discussed by Banks and Clarke, (1987). Much of this work is reviewed by Clarke, Forsyth, Bacon, Banks, Calver and Everard in Burrett and Martin (1989).

Interest in hydrocarbon exploration in Tasmania (onshore) has increased with the work of Bendall, Volkman, Leaman and Burrett (1991). Their early exploration syntheses established the existence of true petroleum seepages, identified some potential sources, suggested the nature of structural trap possibilities and defined some exploration problems. The nature and location of reservoir rocks has remained ill-defined and several candidates can be proposed. This thesis examines the potential reservoirs of the Permian "lower freshwater sequence".

Regional Geology and Stratigraphy 2

2.1 Pre-Parmeener Geology

This study is concerned mainly with the stratigraphy of the Permian in the "Tasmania Basin" but it is necessary to provide a brief overview of pre-existing lithology and structures in order to develop a model for the formation and migration of petroleum. The "Tasmania Basin" is referred to in modern maps of Australian basins, and is taken to be the Permian - Triassic cover which extends over central and eastern Tasmania. The "Tasmania Basin" now forms a broadly synclinal area plunging SSE, in which the Parmeener Supergroup are sub-horizontal (Clarke and Forsythe, 1989); (Fig. 2.1).

The oldest rocks in Tasmania consist of Proterozoic quartzites, phyllites and dolomites. These rocks were overlain by late Proterozoic and early Cambrian shallow marine quartz sandstones and dolomites, marine turbidites, mudstones, and volcanics respectively. This dominantly marine package of sediments was overlain by Ordovician conglomerates (Owen Conglomerate), shallow marine sandstones, subtidal siltstones and mudstones, and a thick succession of tropical carbonates (Gordon Group). Late Ordovician-early Devonian siliciclastics (Eldon Group) overlie the Gordon Group carbonates.

Early in the Devonian, a fold-thrust belt developed during the Tabberabberan Orogeny resulting in general north-south trending folds, with some east-west trending folds in north western Tasmania. Between 395 and 320 Ma extensive granitoid intrusion resulted in metamorphism of some of the lower Palaeozoic rocks (Burrett et al., 1995); (Fig. 2.2).

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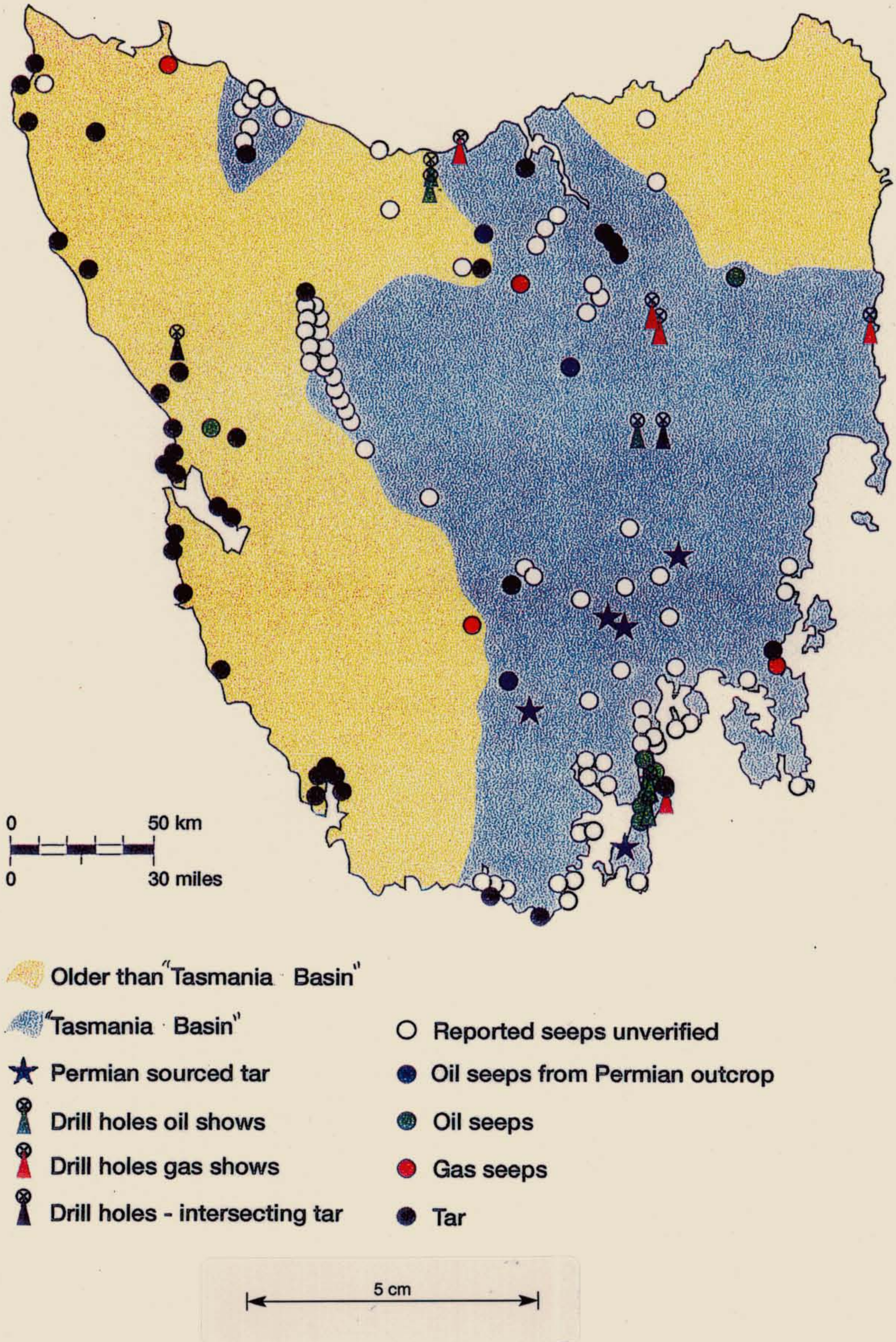

Figure 2.1 : The "Tasmania Basin".

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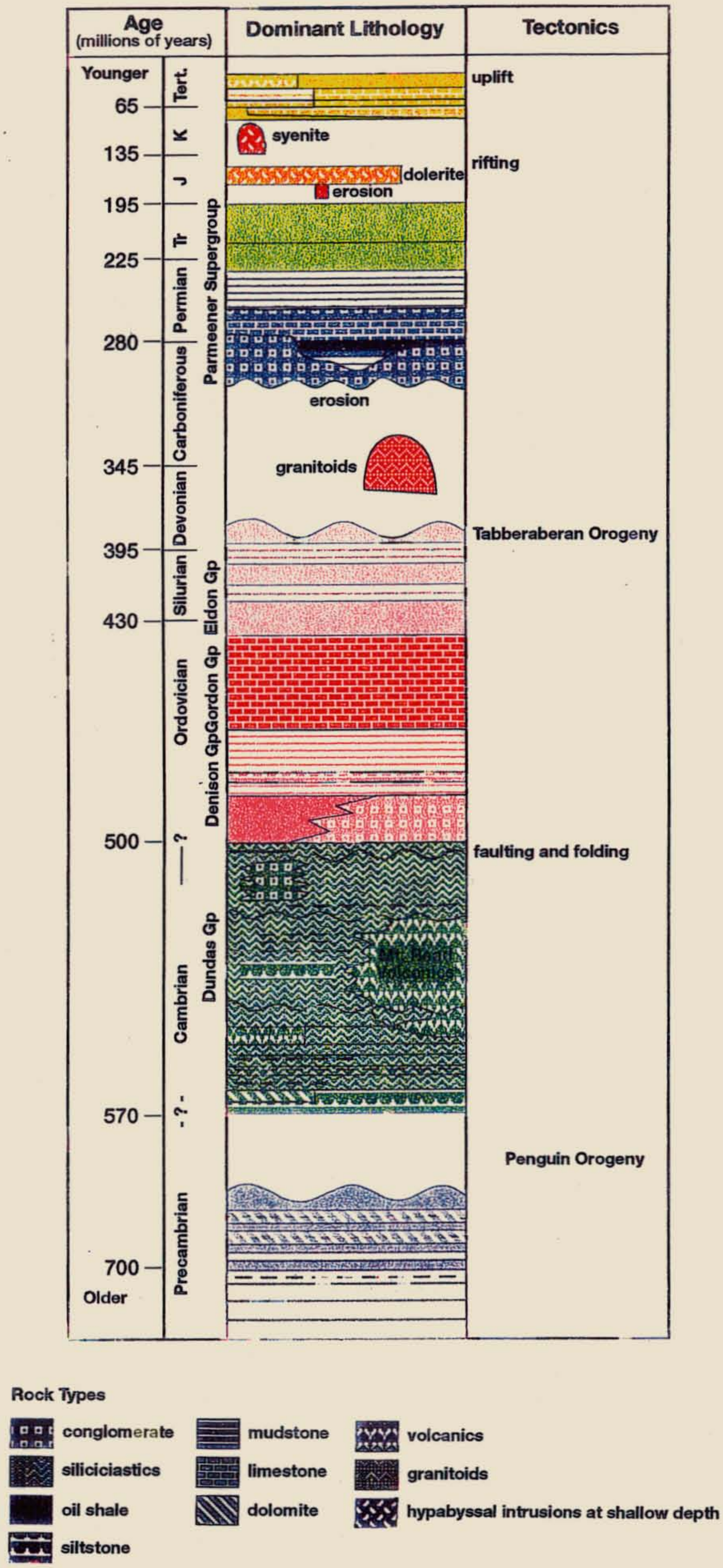


Figure 2.2 : Highly generalised geological column for Tasmania (after Burrett et al., 1995).

Uplift and rapid erosion followed by glaciation reduced the terrain to expose metamorphosed Precambrian rocks, the folded Devonian rocks and granites. "The Tasmania Basin" represents low intensity extension and sagging of an essentially planed terrain where some low zones (controlled by normally north-south fractures) had been etched by glaciers (Clarke, 1989). The extent of fault, sub basin or rift control within the basin is unknown. Deposition began in the late Carboniferous and continued through the Permian and into the Triassic (Clarke and Forsyth, 1989); (Fig. 2.3).

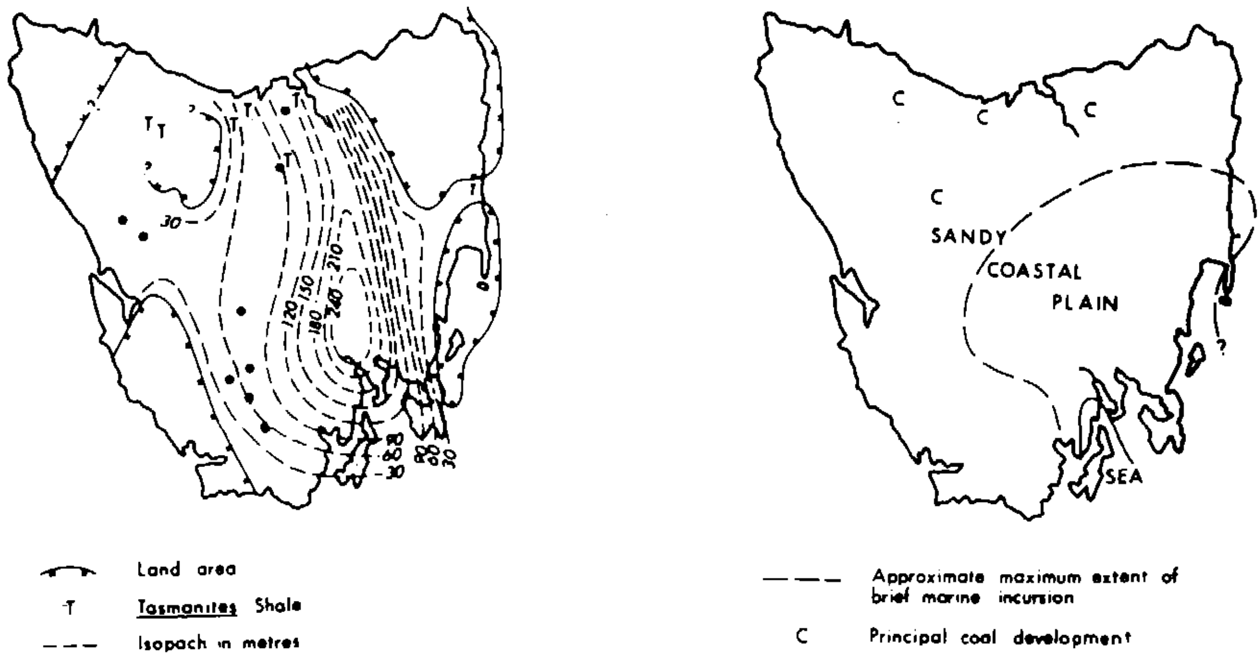


Figure 2.3 : (a) Isopach map for sediment deposition in the Lower Permian. (b) Palaeogeography during the deposition of the Liffey/Faulkner Group (Clarke and Forsyth, 1989).

Deposits in the basin are classified as the Parmeener Supergroup, which is divided into two groups (Forsyth et al., 1974). The Lower Parmeener Supergroup consists of Upper Carboniferous to Permian glacigene and glacimarine deposits with a non marine interval including coal measures. The Upper Parmeener Supergroup consists of fluvial sequences and thicker freshwater coal sequences, mainly of Triassic age (Clarke and Forsyth, 1989).

2.2 Lower Parmeener Supergroup

Tillites of variable thickness, deposited by retreating glaciers, in the late Carboniferous (Banks and Clarke, 1987), form the base of the supergroup. These may locally exceed a thickness of 500 m. Some of the tillite occurrences contain fragments of marine fossils and plants, indicating deposition by ice at or below sea level. Pyritic and carbonaceous siltstone with uncommon ice-rafted sediment, rare marine fossils and glendonites, was deposited on the basal tillite. Associated with this was a minor oil shale which was rich in spheroids of a probable green algae (Tasmanite Oil Shale[1]); (Domack, 1991). This siltstone succession appears to have been deposited in quiet marine waters, with restricted circulation. This sequence appears to be thickest east of the axis of the Tiers Fault (Leaman, 1992) and is greater than 265 m thick north of Hobart (Tasmanite Oil Shale, Quamby Mudstone and correlates; (Fig. 2.4).

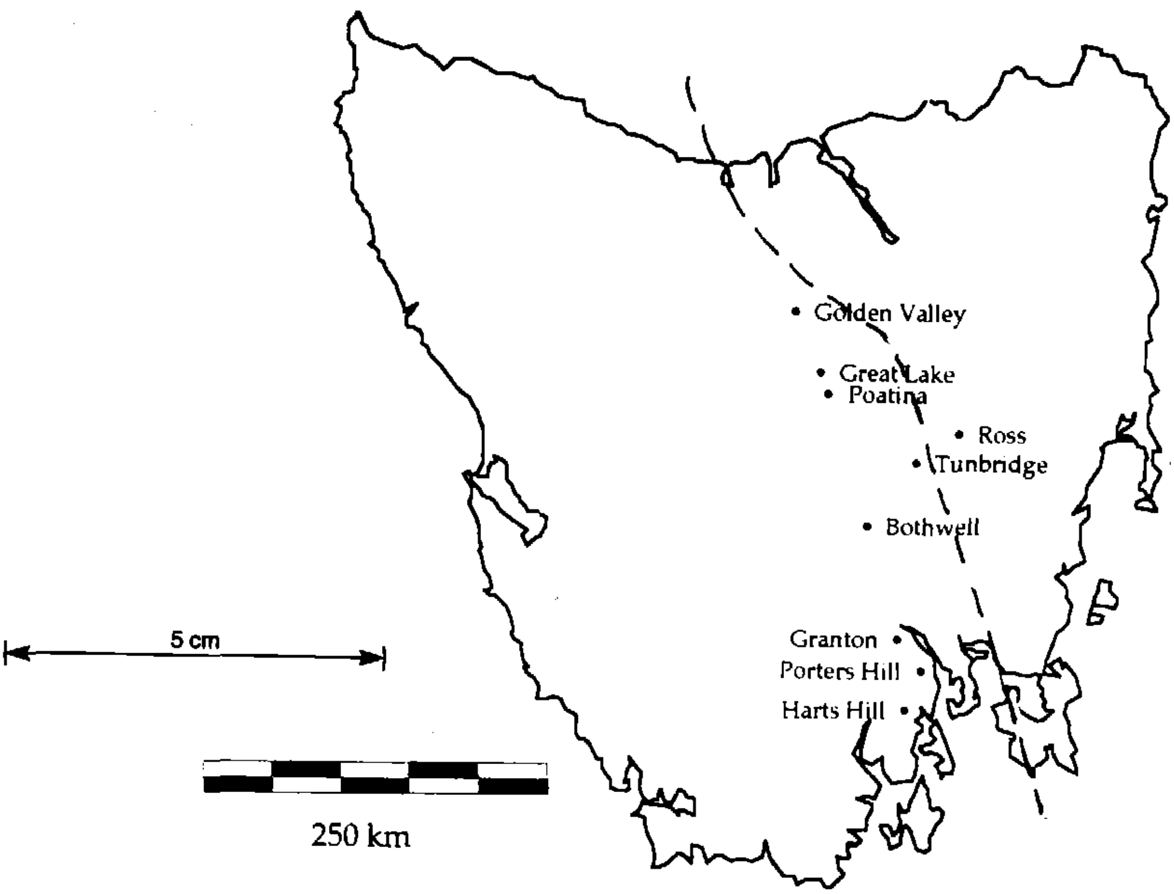


Figure 2.4 : Approximate location of the Tiers Fault (after Leaman, 1994).

[1] Tasmanite Oil Shale is used as a lithostratigraphic term which consists of seams of the rock tasmanite composed of *Tasmanites* .

The depocentre forming east of the Tiers Fault continued to fill with the deposition of up to 135 m of richly fossiliferous siltstone, and subordinate micrite often containing dropstones (Golden Valley Group and correlates). The environment of deposition changed to an open shelf marine environment rich in bottom dwelling faunas. As the sea gradually withdrew to the south of Hobart, deposits became more brackish, and in the north fluvatile conditions allowed the formation of coal measures (Mersey Coal Measures, Liffey Group and correlates). These exceed 40 m thickness in areas south of Devonport. In the south of Tasmania, the Faulkner Group (= Liffey Group) is up to 36 m thick, at Mt Nassau, near Granton. Further south, between Hobart and Cygnet, the sequence pinches out.

Later, sea level rose with shallow seas covering two lobes extending to the northeast and the northwest. Richly fossiliferous siltstone and limestone with dropstones reached a maximum thickness of about 90 m in the northwest lobe, and 100 m in the northeast lobe. Thin metabentonite layers within limestone beds in the Hobart area and Maria Island indicate "distant" volcanism (Williams, 1989). These units imply tectonic activity within the region of the basin and the layers may be remnants of thicker deposits.

Further subsidence along an axis (presumably) coincident with the Tiers Fault was accompanied by marine siltstone and sandstone deposition of up to 180 m. The beds contain dropstones and some are richly fossiliferous, while others are poorly fossiliferous having accumulated in a restricted environment. Siltstone and shallow water sandstone were deposited in the late Permian as the last of the marine sedimentation now preserved. These beds were deposited north and landward of an offshore barrier bar which developed in the south, in a restricted and brackish environment. The sediments include marine fossils and carbonaceous material, and in some localities, silicic volcanic ash (Clarke and Forsyth, 1989).

2.3 Lower Permian Stratigraphy

As this study is focusses on the Liffey Group (and its Faulkner Group equivalent), it is important to examine briefly the units stratigraphically below (Golden Valley Group) and above (Poatina Group); (Fig. 2.5).

2.3.1 Golden Valley Group

The Golden Valley Group (below) is divided into the Glencoe Formation, the Billop Sandstone and the Macrae Mudstone respectively (Clarke, 1968). In the Golden Valley area the Glencoe Formation consists of a sequence of richly fossiliferous (Table 2.1), calcareous, erratic rich, poorly sorted siltstone and mudstone with intervals of thin shelly limestone, up to 27 m thick (Clarke, 1968). The Billop Sandstone conformably overlies the Glencoe Formation There is a sharp contact between the units in the Golden Valley Area. The Billop Sandstone is 7.8 m thick in the Golden Valley drillhole. It is characteristically a sequence of light coloured, blue-grey to buff brown, poorly sorted micaceous sandstone. Fossils are abundant (Table 2.1), and both small and large well rounded erratics are very common (Clarke, 1968). The upper contact with the Macrae Mudstone is transitional. The Macrae Mudstone is 48.5 m thick in the Golden Valley drillhole. It is a monotonous sequence of poorly fossiliferous (Table 2.1), dark coloured, poorly sorted mudstone and siltstone. In the upper portion there is evidence of bioturbation with the

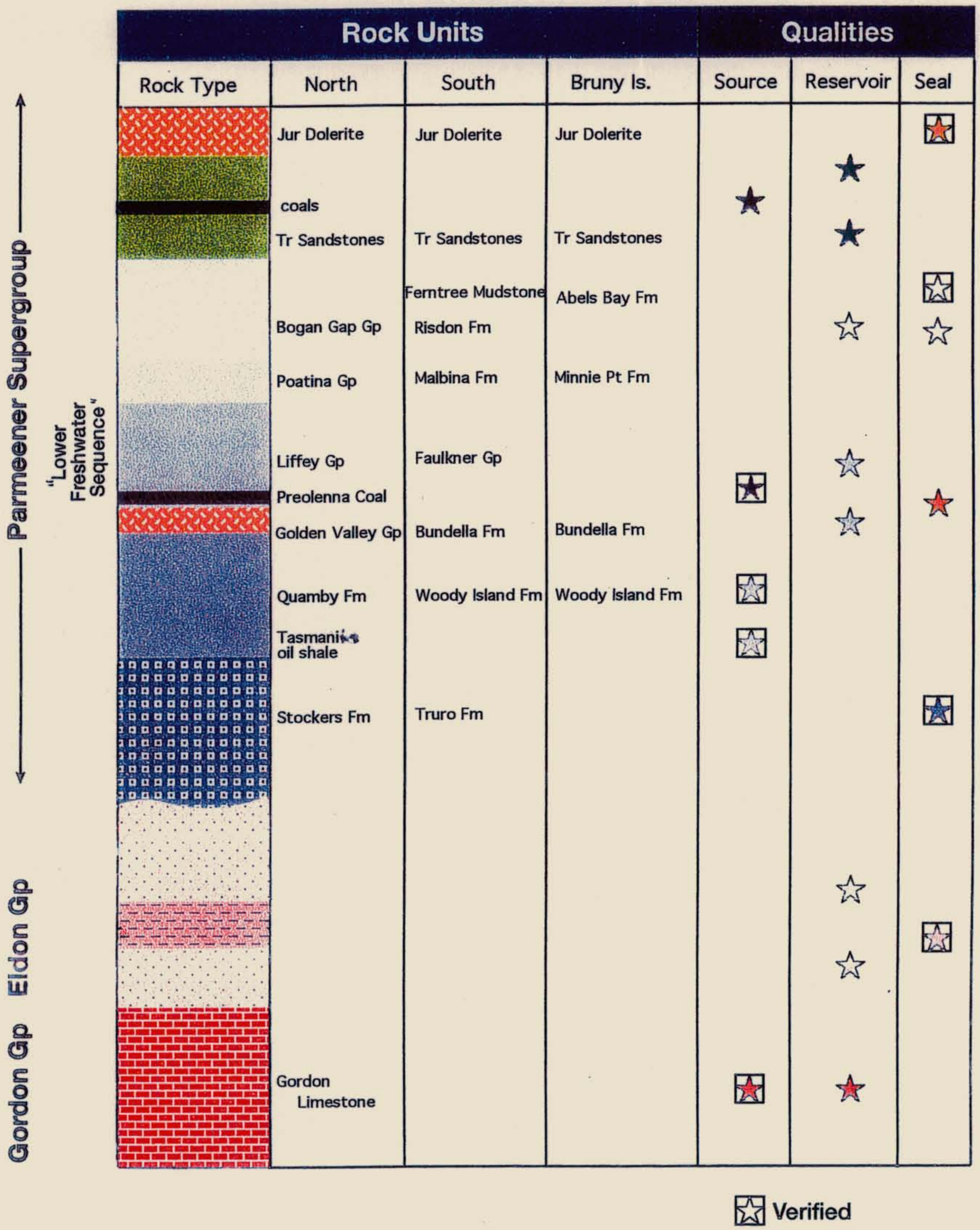


Figure 2.5 : Highly generalised geological column for the Parmeener Supergroup.

presence of worm burrows which disturb bedding. These structures are most abundant in the upper 5 m of the unit, below the contact with the Liffey Sandstone (Clarke, 1968).

In the Ross, Tunbridge area, the basal part of the group consists of thick beds of muddy siltstone punctuated by thin sandy siltstone or thin calcareous beds. This sequence becomes more fossil rich up section and the occurrence of limestone increases (Forsyth, 1989).

Golden Valley Group		
Glencoe Formation	**Billop Sandstone**	**Macrae Mudstone**
Calcitornella stephensi	*Grantonia*	*Ambikella*
Strophalosia preovalis	*Spiriferella*	*Grantonia*
Strophalosiajukesia	*Peruvispira*	*Deltopecten*
Costalosia argentea	*Myonia carinata*	*Merismopteria*
Grantonia	*Deltopecten*	*Stenopora tasmaniensis*
Ambikella	*? Paromphalus ammonitiformis*	
Schuchertella	*Ambikella*	
Keenia platyschismoides	*Strophalosia*	
? Paromphalus ammonitiformis	*?Fletcherithyris*	
Aviculopecten tenuicollis	*Eurydesma cordatum*	
Deltopecten mitcheli		
Eurydesma cordatum		
Merismopteria macroptera		
Stenopora johnstoni		
Stenopora tasmaniensis		
Fenestillids		
Crinoid debris		

Table 2.1 : Fossils in the Golden Valley Group, at Golden Valley (after Clarke, 1968)

2.3.2 Liffey / Faulkner Group

The Liffey Group typically includes generally well-sorted massive, micaceous, quartz sandstone, which contains few or no fossils. The unit is pale grey-white in colour, and weathered areas are buff brown. In the Golden Valley area the sequence is 33-35 m thick. Cross-beds are present throughout, and it is interbedded with minor occurrences of coal and thin beds of carbonaceous mudstone (Clarke, 1968). Further south, in the Ross and Tunbridge area, the Liffey/Faulkner Group contains carbonaceous grey mudstone interbedded with current deposited sandstone. Some of the freshwater units here appear to be interbedded with poorly sorted sandstone with dispersed pebbles and granules, indicating glaciomarine conditions (Forsyth, 1989). This pattern is comparable with variations within the Faulkner Group in southern Tasmania. The type section for the group can be found at Mt Nassau, which is 16 km north-west of Hobart. The Faulkner Group overlies the Bundella Mudstone, which is a marine sequence. The Faulkner Group is 36 m thick at Mt Nassau and is made up of siltstones with flaser bedding, quartz sandstone, and carbonaceous quartz sandstones, and thin conglomerate units (Banks and Hale, 1957). The Cascades Group is the time equivalent of the Deep Bay Formation (Clarke, 1989; Farmer, 1985), and a substantial break in the section is indicated between the Faulkner Group and the Deep Bay Formation.

The Liffey/Faulkner Group is dominantly a freshwater sequence with glaciomarine influences, whereas the units above and below are dominantly marine sequences.

2.3.3 Poatina (Woodbridge) Group

In the north of Tasmania the Liffey/Faulkner Group is generally overlain by the Poatina Group (or Woodbridge Group). This is made up of a marine sequence up to 100 m thick. The Meander Formation is 60 m thick in the Western Tiers area, and is the basal unit of the Poatina Group. This formation is a sequence containing, interbedded fine-grained mica-sandstone, black mica-mudstone, and minor beds of grey, bioturbated sandstone, conglomerates and limestone (McKellar, 1957).

The Liffey/Faulkner Group is overlain by the Rayner Sandstone in the south, which is a 2.5 - 3 m thick sequence of medium-grained sandstone containing some marine fossils. This is overlain by the Cascades Group, which is made up of the Nasssau Siltstone, Berriedale Limestone and the Grange Mudstone. The Nassau Siltstone is the basal unit in the sequence and comprises alternations of fissile and non-fissile calcareous siltstones, or limestone (Banks and Hale, 1957).

2.3.4 Discussion

These units of the Liffey/Faulkner Group are not broadcast over the entire "Tasmania Basin". There are changes in thickness across the basin, and in southern and eastern Tasmania, the 'lower freshwater sequence' does not occur (e.g. Friendly Beaches, eastern Tasmania, and Cygnet southern Tasmania; Fig. 2.6). The unevenness of the fence diagram of stratigraphic columns through the Lower Parmeener Supergroup and the occurrence of a number of tuff bands (Bacon et al., 1989) in the section indicates tectonic/volcanic activity during deposition. With respect to the reservoir potential of the Liffey/Faulkner Group, these beds may not be laterally continuous due to possible syndepositional faulting. As sediment was deposited in the "Tasmania Basin", pre-existing faults may have been mobilised due to sediment loading and extension (pers comm Leaman, 1996). If this occurred across the basin it would result in discontinuous packages of the "lower freshwater sequence" (Fig. 2.7). The generation, migration and sealing in of petroleum could be limited to a number of these packages, which have the necessary geothermal history, reservoir and sealing mechanisms.

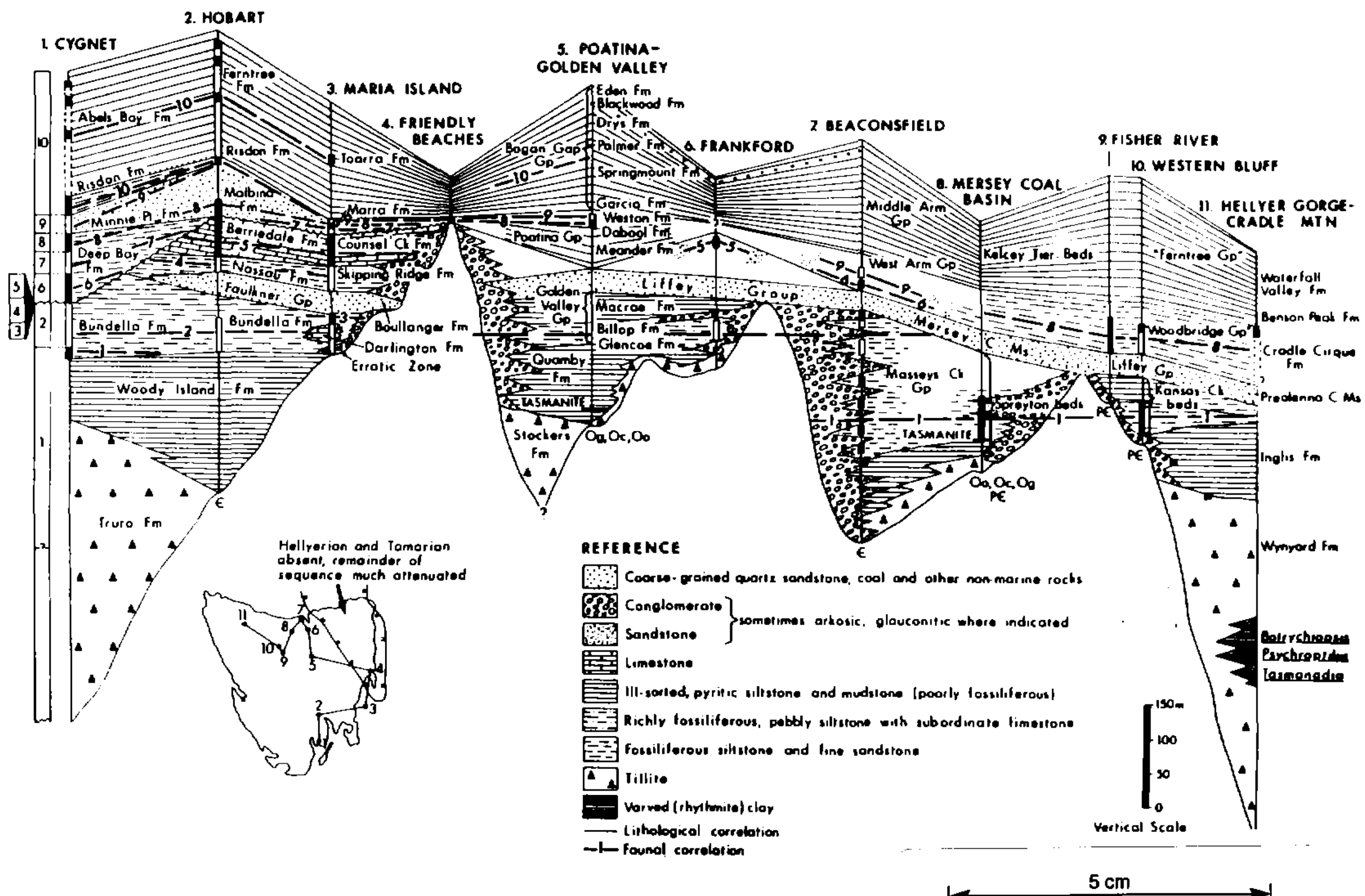
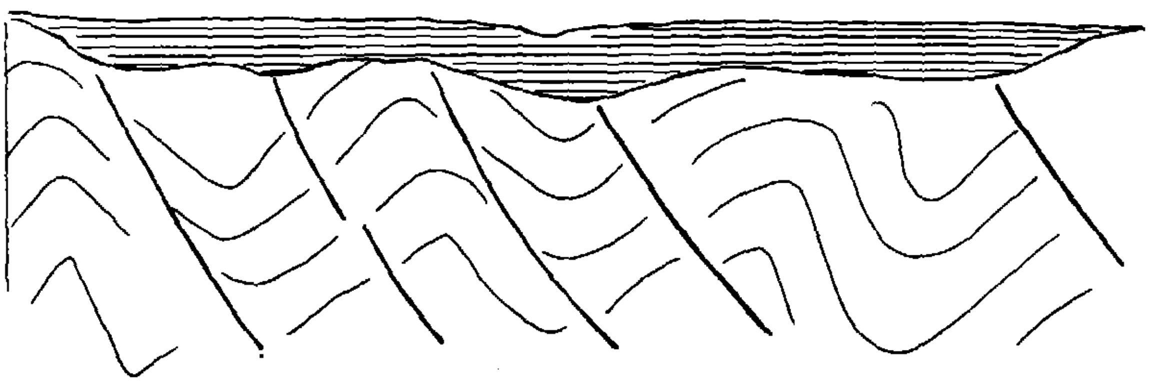
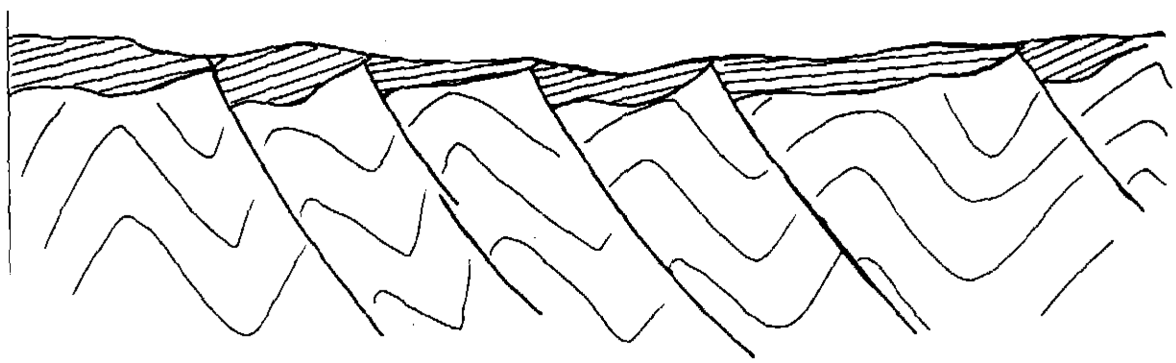


Figure 2.6: Correlative stratigraphy of the Lower Parmeener Supergroup (Clarke and Forsyth, 1989).



Deposition of Permian Sediments



Reactivated basement faults

Figure 2.7: Schematic representation of possible syn-depositional faults disrupting the Permian sequences across the Tasmania Basin (Burrett et al., 1995).

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Reservoir Characterisation 3

3.1 Introduction

The Permian "lower freshwater sequence" is thought to be the most prospective reservoir in the Lower Parmeener Supergroup, as most of the Lower Permian dominantly consists of marine mudstones. Reservoir potential is determined by: thickness; the composition of the sediments; the environment of deposition; the compaction and cementation and dissolution patterns that the sediments have been subjected to and the affects of the above on porosity and permeability. In this chapter, the lithology and results of facies analysis of the sediments will be documented. Diagenetic processes and the affects on porosity will be discussed in chapter 5. These factors define the reservoir potential of the Liffey and Faulkner Groups.

3.2 Methodology

The Liffey/Faulkner Group was intersected in 8 drill holes around central Tasmania including: the Glencoe Road Hole 3093 at Golden Valley (Fig.3.1); the Great Lake Tail Race Tunnel Hole 5113 (Fig.3.2); Great Lake Penstock Hole 5005 at Poatina (Fig.3.3); the Ross RG146 Hole (Fig.3.4); the Tunbridge Tier Hole RG145 (Fig.3.5), and Bothwell BH1 (Fig.3.6). Representative units throughout the sequence were sampled at the different localities, and thin sections made from samples vacuum-impregnated with green araldite (Appendix 1). Approximately 500 grains were point counted from selected thin sections in order to classify the sandstones in a Folk quartz, feldspar, rock fragment-ternary diagram

(Folk, 1974; Appendix 3). Porosity and permeability of preliminary samples were analysed using Helium Injection, and Air Permeability determination techniques (Appendix 1). Unfortunately funding did not permit representative porosity and permeability measurements of sandstone units throughout the Liffey/Faulkner Group. Pores were point counted from thin sections, in order to quantify porosity, where they could been seen due to impregnation of pores with green araldite. Point counted pore analysis was 2 to 4 % lower than porosity measured using Helium Injection. The thin sections were also examined for diagenetic effects. An Environmental Scanning Electron Microscope (ESEM) was used to further examine grain habits, cementation patterns and to examine the effects of diagenesis on porosity. X-ray Diffraction (XRD) analysis was also used to identify clay mineralogy within selected units (Appendix 2).

3.3 Lithology

The Liffey /Faulkner Groups conformably overly the Macrae Mudstone, a marine mudstone unit across the "Tasmania Basin". This unit is dark grey - black, contains glacial erratics ranging in size from 2-5 mm and has been subject to bioturbation. The Macrae Mudstone is part of the Golden Valley Group in the north of Tasmania and equivalent to the Bundella Formation in the south. The group is overlain by the Meander Mudstone (and correlates, which is part of the Poatina Group.

The Liffey/Faulkner Group has been divided into 7 packages in the study area using the results of drill core analysis. The section described here crosses the Tiers Lineament, with the holes from Ross and Tunbridge on either side, and the holes from Golden Valley, Great Lake, Poatina, Bothwell and Granton to the west (Fig. 3.7).

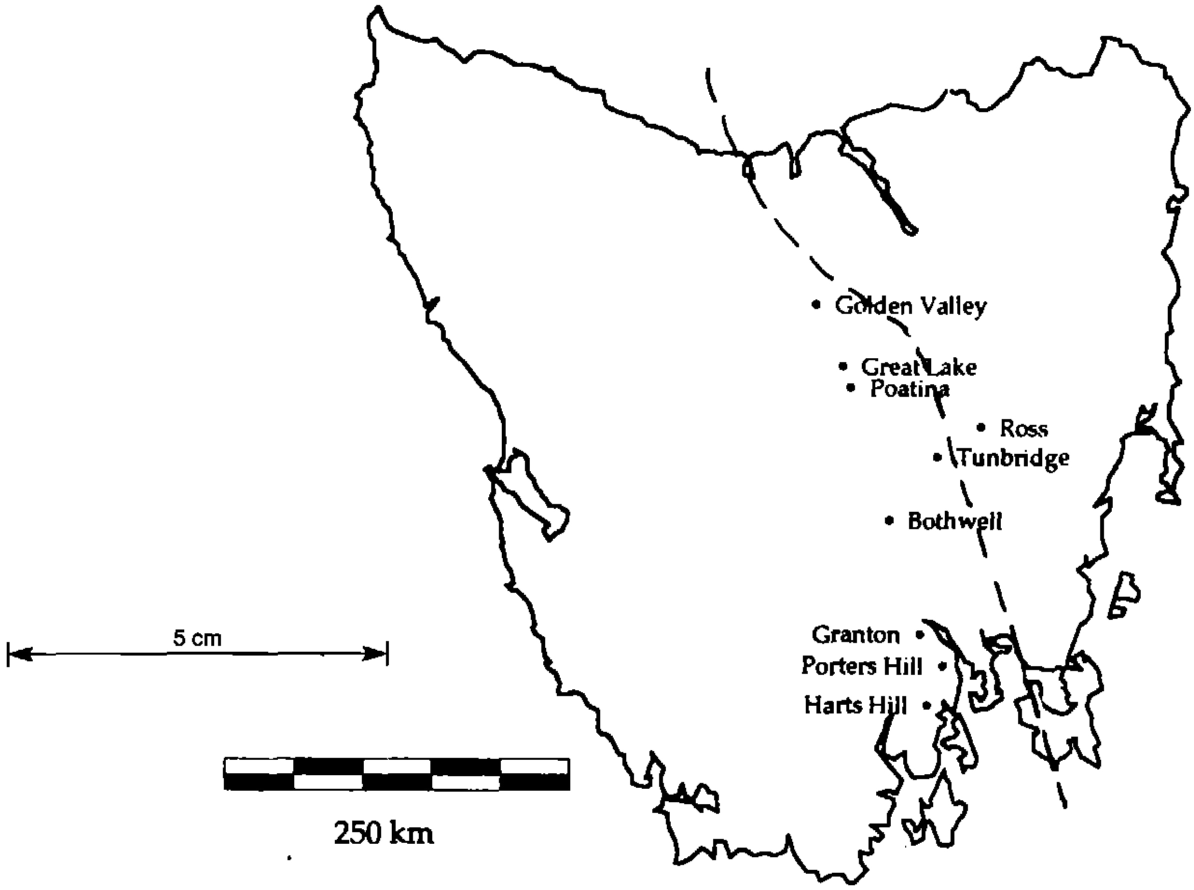

Figure 3.7: Drill hole locations with respect to the Tiers Fault.

3.3.1 Unit 1

Unit 1 conformably overlies the Macrae Mudstone. It is a grey to white-grey, medium to fine-grained, quartz-rich sandstone also containing feldspar and mica. This unit contains some cross-bedding but is generally massively bedded. The composition ranges from litharenite to feldspathic litharenite, based on Folk's classification (1974). There are thin (mm-cms) mud/silt laminae, with some organic material throughout the sandstone unit (Plate 3.1).

The sandstone unit is 10 m thick, with a coal seam approximately 50 cm thick towards the base, at Golden Valley (15 m depth). The 'silty' and organic laminae are more common towards the base of the unit. Some display deformation consistent with bioturbation. The sandstone is well sorted, sub-angular to sub-rounded, with an average grainsize of 0.2 mm. It is composed of 75% quartz grains with lithic fragments, including clay and feldspar. Detrital mica and minor silica cementation is also evident. Two beds of coarse-grained, quartz rich, sandstone, containing lithic clasts, weathered to an orange colour disrupt the grey sandstone towards the top of this unit (6.5 to 7.5 m depth). Porosity in this unit ranges from 11 to 14 %. (Fig. 3.1).

The sandstone is a medium to fine-grained (0.2 mm), well-sorted, sub-angular, quartz rich (75%) feldspathic litharenite at Great Lake. The unit is about 5 m thick and has some minor mud laminae (Fig. 3.2). It also contains lithic clasts and clay, feldspar, mica, opaques (possibly pyrite). Minor silica cementation is noted and the sandstone has a porosity of 10%.

The white-grey sandstone is about 3.5 m thick with mud/silt laminae, and some clasts composed of mud sized particles (2-5 mm) at Poatina. Porosity in this unit is relatively poor, ranging from 1 to 5 % (Fig. 3.3).

To the south-east at Ross, unit 1 is a very fine-grained grey sandstone. The section contains silty laminae which are common towards the base and are deformed by bioturbation throughout. The sandstone is a sublitharenite, and is 2.5 m thick (Fig. 3.4; Plate 3.2).

The unit is a 3 m thick very fine-grained grey sandy siltstone with some, mud laminae at Tunbridge (Fig. 3.5).

South and west at Bothwell the grey sandstone unit is 1 m thick and medium to fine-grained, pinching out between Bothwell and Granton (Fig. 3.6).

3.3.2 Unit 2

This unit is characterised by interbedded white-grey sandstone and dark grey - black mudstone which contain flaser bedding. This unit occurs in the Great Lake area and the sequence generally thickens towards the south. At Great Lake, the sequence is about 5 m thick, and has some cross-bedding.

The unit is 1 m thick at Poatina and thickens to a much finer grained 3.5 m thick sequence of sandstone at Ross.

The sequence is 3 m thick and dominated by mudstone with minor silt interbeds at Tunbridge.

At Bothwell the unit is locally 4.5 m thick increasing to approximately 11 m at Granton.

Because of the nature of the interbedding within this unit, a representative section was difficult to analyse in thin section. The porosity is therefore considered to be variable due to abundance of silty layers.

3.3.3 Unit 3

This package occurs between Great Lake and Tunbridge. The unit is a medium to fine-grained, cross bedded quartz-rich sandstone with mud laminae similar to unit 1.

The unit is 5 m thick at Poatina. The average grainsize is about 0.2 mm and porosity ranges from 2 - 10% (maximum value from Helium injection porosity analysis). The sandstone is classified as a sublitharenite, containing over 75% quartz, some feldspar, and lithic clasts. Clay occurs in the matrix, with some detrital mica. There is minor silica cementation in the unit.

The unit is 10 m thick, with porosity of up to 25% at its base, in the Ross section. The unit is very fine-grained (<0.1 mm), moderately well sorted with sub-angular grains. It is composed of quartz, feldspar, mica, opaques, lithic clasts and clay in the matrix.

3.3.4 Unit 4

Unit 4 is a dark-grey, sandy mudstone, with lithic clasts up to 10 mm. It is heavily bioturbated, with worm burrows, and worm-cast textures. The unit is coarse-grained at the base and generally grades upward into fine mudstone at the top. This unit does not occur in the Golden Valley area. The unit overlies the unit 2 and is 3.5 m thick at Great Lake.

The sequence has a similar thickness at Poatina, and dominantly mud rich with lithic clasts occurring towards the top of the unit. It overlies unit 3.

Unit 4 thickens towards Ross where the lower 3 m is coarse, heavily bioturbated sandstone. The unit is moderately poorly-sorted and contains sub-angular to sub-rounded grains consisting of quartz (70%), with feldspar, lithic clasts and detrital mica. It fines upwards and the upper 4 m is mainly mudstone with some silt lenses. This unit appears to have a more open framework, with clay between the grains. The porosity at the base of the bioturbated unit is up to 9 %.

Similarly, the lower bioturbated sandstone is approximately 2 m thick, with porosity values of up to 27 % at Tunbridge. This fines into a 6 m sequence of mudstone with minor bioturbation, silt lenses and some lithic clasts. This is also poorly sorted, with a relatively open framework. Unit 4 thins towards Bothwell, with 2.5 m of bioturbated sandstone fining into 3.5 m of mudstone with lithic clasts. The bioturbated sandstone is medium-grained, with silt and mud lenses, and also cross-cutting veins of pyrite. The section here is coarser grained than Ross and Tunbridge, but is also poorly sorted.

The package at Granton comprises 5.5 m of bioturbated sandstone, fining upwards into 3 m of mudstone.

3.3.5 Unit 5

This unit is a coarse to fine-grained, white to grey, quartz-rich sandstone. It contains cross-bedding and some bioturbation of mud laminae towards the top of the sequence. Unit 5 has similar characteristics to units 1 and 3 but in general is thicker and more porous.

At Golden Valley, the sandstone is a well sorted, sub-angular sublitharenite, consisting of quartz (70-80%), feldspar, lithics and detrital mica (Plate 3.3). There is some clay in the matrix, and the rock has an orange colour in hand specimen due predominantly to weathering. There is also some silica cement between grains. Grainsize averages 0.4 mm. Approximately 4 m down the Glencoe Rd drillhole at Golden Valley a thin, coarse sandstone bed with pebbles up to 20 cm occurs. This can be correlated with a coarse bed at 17 m depth in the Great Lake hole, and also at 137 m in the Ross drill hole.

Unit 5 overlies the bioturbated sequence of sandstones and mudstones of unit 4 in the Great Lake area. This is a 10.5 m package of medium-grained (0.4 mm) sub-angular to sub-rounded quartz-rich, feldspar, mica sandstone with cross-bedding and some dark grey mud laminae. The unit is classified as a sublitharenite, and porosity is approximately 15% (Plate 3.4). Minor silica cementation is also present.

Similarly, the section is approximately 10 m thick, of white grey sandstone, with cross-bedding at Poatina.

The sandstone is very fine-grained (0.1 - 0.05 mm) with some areas of silt at Ross. It contains quartz, feldspar, mica, clay and opaques (possibly pyrite). Porosity ranges from <5% to 10%, with silica and carbonate cement present. The sandstone is grey in with cross-bedding and ripples present. Mud seams are common towards the top of the 5 m section and are disrupted by bioturbation. A coarse sandstone bed occurs at 137 m in the RG146 drillhole the hole, which is 3 cm thick, quartz-rich, with lithic clasts (5 mm) and coarsens upward.

The grey sandstone unit is 10 m thick at Tunbridge with common mud laminae at the base, and less throughout the section. The section also contains lithic clasts (1-10 mm). This unit is classified here as a feldspathic litharenite. It is moderately well sorted, sub-angular and very fine grained. The porosity ranges from 0 - 1.2 % towards the base and 8% further up the section.

The unit is 11 m thick at Bothwell. The sequence is a well sorted, fine grained (0.2 mm), sub-angular to sub-rounded, quartz-rich feldspathic litharenite. There is minor silica cementation and moderate carbonate cementation. The unit has a coarse base and some mud laminae occur throughout the section.

The Granton section, to the south, has approximately 18m of fine-grained sandstone to siltstone (after Woods,1996).

3.3.6 Unit 6

Overlying unit 5 at Great Lake is 1 m of sandstone and mudstone interbeds containing cross-bedding similar to unit 2. This is not observed at Poatina due to an incomplete section.

Unit 6 is 3 m thick at Tunbridge and is comprised of mainly dark grey to black mudstone, with light grey mudstone lenses. The unit is 2 m thick at Bothwell and pinches out towards Granton.

Porosity is considered variable due to interbedding of mud and silt with negligible intergranular pore space (as unit 2).

3.3.7 Unit 7

The upper package of the Liffey/Faulkner Group is a heavily bioturbated sandstone with mud and lithic clasts similar to unit 4. The sandstone contains mud and lithic clasts in the Great Lake area, and is classified as a feldspathic litharenite. Unit 7 is a poorly sorted, sub-angular to sub-rounded sandstone containing quartz, feldspar and mica, grains of 0.1-0.2 mm. The framework is relatively more open in this unit, with clay filling intergranular pores and minor silica cementation. The porosity is approximately 5%.

Unit 7 is 2.5 m thick at Ross with a porosity of 7%. The unit is also poorly sorted with sub-angular to sub-rounded grains in a relatively open framework, with a thickness of 7 m at Tunbridge. The package is 2 m thick at Bothwell and pinches out before Granton.

There are a number of coarse conglomerate beds evident throughout the Granton section.

The correlation of the units in the Liffey/Faulkner Group from Golden Valley to Bothwell and Porter Hill and Harts Hill in the south is shown in Figure 3.8.

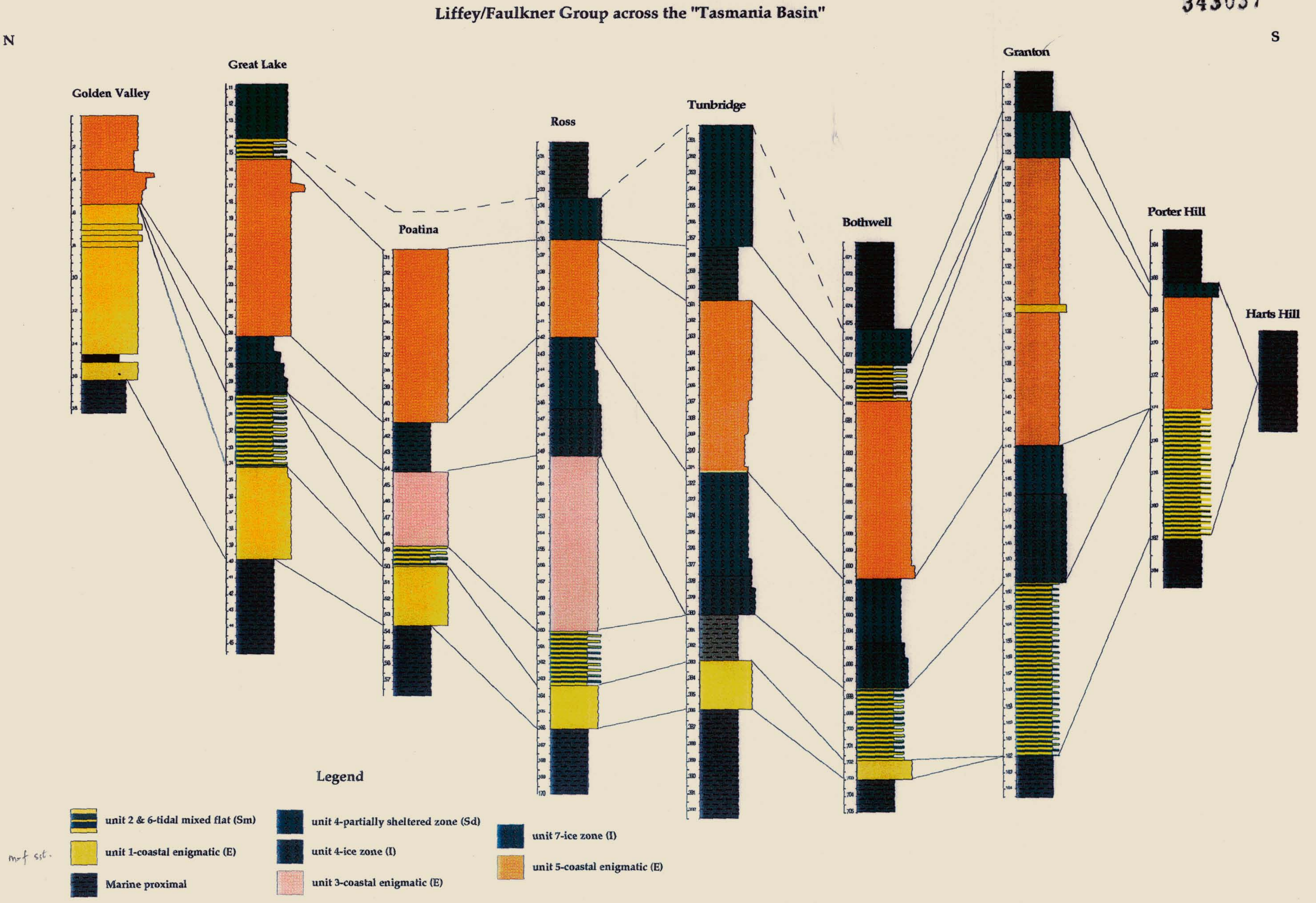

Figure 3.8 : Correlation of the units in the Liffey/Faulkner Group

3.4 Facies Analysis

Martini and Banks (1989) assigned facies to the Liffey/Faulkner Group in eastern Tasmania. The facies have been grouped into:

- marine facies
- coastal - alluvial plain facies
- alluvial facies
- piedmont facies

These analyses can be applied to the defined packages in the group, and are summarised in Table 3.1. Depositional environments range from freshwater alluvial to shallow marine environments affected by glaciation.

The Liffey/Faulkner Group overlies a marine mudstone. The mudstone is thought to have been deposited in an inner shelf environment, with dropstones from melting ice rafts.

3.4.1 Unit 1

Unit 1 is representative of the 3 units of white to grey sandstone, with massive beds, some crossbeds, ripple laminations and minor bioturbation of silty laminations. This has characteristics similar to the enigmatic coastal facies (E) associated with nearshore and coastal deposits as defined by Martini and Banks (1989). Unit 1 is interpreted to have been related to either sandy distributary channels of low-sinuosity, or migrating coastal bars and sand waves in the fringe of a delta. The sequence has a coal seam towards the base at Golden Valley which indicates wet lacustrine conditions (F). Towards the top of the unit are thin coarse sandstone beds with cross laminations, which may have been deposited in alluvial splay channels (A_y).

Facies		Characteristics	Depositional Environment
Marine Facies			
Md	marine distal	bioturbated mudstone, with dropstones, abundant fossils	outer shelf environment
Mp	marine proximal	bioturbated mudstone, dropstones, rare or absent fossils	inner shelf environment
Ms	storm layers	well-sorted, fine to very fine sandstone. Some conglomeratic basal layers grading into plane beds, ripple laminations	various coastal nearshore and shelf environments
I	ice zone	poorly-sorted coarse sandstone, disseminated pebbles, some pebble layers, often at top, heavily bioturbated	nearshore area affected by ice push and ice rafting
Sd	nearshore, partially sheltered zone	heavily bioturbated, fine to very fine sandstone & siltstone burrows	nearshore shallow swale or channel sheltered from ice rafting and strong waves, low rates of sedimentation
Sb	sand bar	winnowed, well sorted, fine- to coarse-grained sandstone, massive to plane bedded, some cross laminations	nearshore setting, perhaps sand bar
Sm	tidal mixed flat	thinly interlaminated & interbedded well-sorted, fine sand and argillaceous dark grey mudstone. Some escape structures and flaser bedding.	tidal mixed flats, in shallow subtidal zones
Sw	nearshore swale	well sorted argillaceous, carbonaceous silt to silty shale, increasing laminae and thin flat beds of sorted silt and fine sand towards the top of sequence	sheltered environment, prodeltaic or high flats, inland from sheltering intertidal bars and beach ridges, with storm layer, or splays
Coastal - alluvial plain facies			
Cw	coastal swale or marsh	dark carbonaceous mudstone, rare laminae of well sorted lighter coloured silt.	muddy swale and /or marsh deposit
Cb	coastal floodplain	sand to silty wavy bedding, with flaser bedding and plane bedded sandy interlayers. Rare bioturbation affecting one or two laminae	wet floodplain to shallow lacustrine conditions. Has also been attributed to lacustrine delta fill, abandoned distributary channel fill, to distributary mouth bar
Cy	coastal splay fan	thin flat bottomed beds of well-sorted fine to medium sandstone, massive to ripple-cross laminated, interstratified with mudstone	prograding fan splay deposit, finer parts are formed by "levee progradation"
Cd	coastal channels, topsets	fining upwards sequence, cross beds at base, upwards change from plane beds to ripple cross laminations, to flaser bedding and thin silty interbeds.	secondary channel deposits
E	coastal enigmatic	well-sorted light grey, medium sand, massive, in places cross-bedded and ripple cross-laminated sandstone separated into subunits by thin intervals of irregular and deformed silty laminations (minor bioturbation).	associated with coastal and nearshore units, probably genetically related to either low-sinuosity, sandy distributary channels or migrating sand coastal bars, and sand waves in the delta fringe.

Alluvial facies

Am	alluvial meandering	well developed, sandy fining and thinning upward sequence, cross beds at the base, massive and plane beds, capped with cross-laminations, some units have a few basal, fine, well-rounded pebbles in thin layers.	bar and flood plain deposits of meanderingstreams
Af	alluvial floodplain	recurring thin sequences of well-sorted fine sandstone, with plane beds overlain by ripple cross-stratification. Also flaser beds and thin caps of interlaminations of fine sand and comminuted organic-rich silt, and thin coal layers	silty and sandy floodplain deposits
Ay	alluvial splay	thin sandy lensing layers of fine to medium sand, massive bedding to cross laminations. Thin coal laminations occur, sandstone units are bioturbated by roots.	shallow alluvial splay channels
Aw	shallow pond	highly carbonaceous mudstone, similar to coastal plain but within alluvial sequence	organic rich shallow lake or pond
F	fen	coal seams	wet lacustrine or fen-like conditions
Ab	braided stream	composed of either sandy conglomerates (Ac) or of coarse sand with rare pebbles (As)	braided stream deposits
Ad	debris flows	poorly sorted, gravelly units, with random clast orientation, and some inverse grading in lower part of the beds	debris flow

Piedmont facies

Ps	scree slope	breccia layers, sandy, poorly sorted with clasts derived from local bedrock	scree slope deposit
Pc	sand sheet	coarse grained arkose, well sorted, occurs as regolith on granite base or as sand sheet interstratified with basal breccia	possibly emplaced by grain flow

Table 3.1: Sedimentary facies and their environmental interpretation of the 'lower freshwater sequence.' (After Martini and Banks, 1989).

3.4.2 Unit 2

The occurrence of white-grey sandstone interbedded with fine dark grey mudstone (flaser bedding), with cross-bedding, is indicative of a tidal mixed flat environment (S_m), in shallow sub-tidal zones.

3.4.3 Unit 3

Unit 3 is similar to unit 1, and is assigned to the enigmatic coastal zone (E). There is no evidence for alluvial influence in this section.

3.4.4 Unit 4

Unit 4 is made up of poorly sorted, heavily bioturbated sandstone, containing dropstones, and is interpreted to have formed in a nearshore environment affected by ice rafting, and ice push (I). The upper part of this package is thought to have been deposited in sheltered nearshore areas, like nearshore shallow swale or channels. This is thought to have been sheltered from waves and ice rafting with low rates of sedimentation as it is more fine grained and relatively well sorted.

3.4.5 Unit 5

Unit 5 is similar to unit 1 and 3, and is assigned to the enigmatic coastal zone (E).

3.4.6 Unit 6

Unit 6 is characteristically similar to the tidal mixed flat (Sm) facies of unit 2. This facies is present at Great Lake, possibly Poatina, and also between Ross and Granton.

3.4.7 Unit 7

Unit 7 is made up of heavily bioturbated, poorly sorted sandstone. Deposition is influenced by ice rafting or pushing, evident from drop stones and distortion of bedding due to drop stones and bioturbation.

The overlying Meander Mudstone was deposited in an inner shelf environment similar to that of the Macrae Mudstone, below the base of the Liffey Faulkner Group. The depositional environment of the group is represented in Figure 3.9.

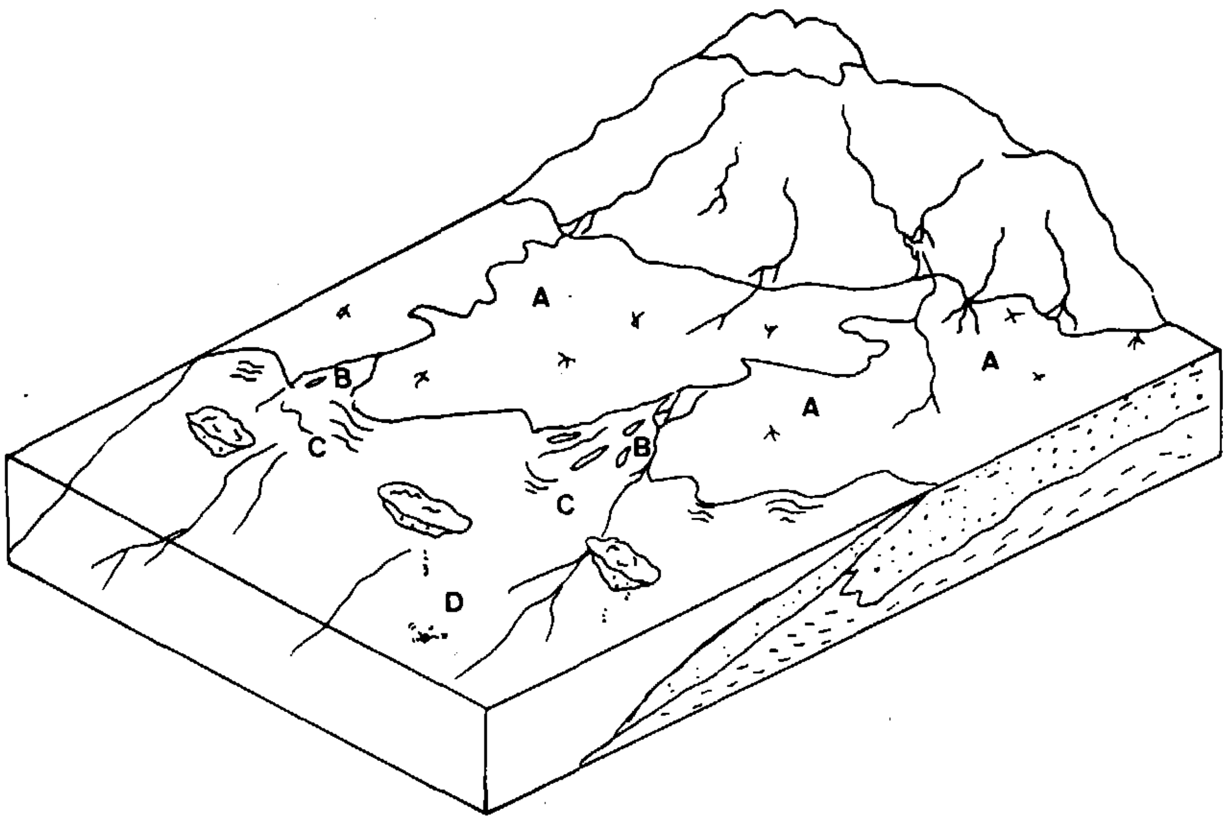

Figure 3.9 : Depositional environment for the Liffey/Faulkner Group during the early Permian (A) Tidal mixed flats; (B) Coastal zone, channel bar sands; (C) Nearshore, ice rafted, bioturbated zone; (D) Shallow-deep marine.

3.5 Discussion

Units 1, 3, 4, 5, 7 can be considered as potential reservoir units. Variation of thickness, grainsize and porosity in each of the units across the basin can locally affect the reservoir potential. These variations may impede the flow of migrating fluids in the reservoir and depending on the nature and extent of these variations they may effectively exclude parts of the Liffey/Faulkner Group being accessed by migrating petroleum fluids.

The sandstone units 1, 3 and 5 are compositionally mature, with a high quartz content, and texturally mature, as they are well sorted with subrounded grains. Unit 1 is a prospective reservoir to the north, especially in the Golden Valley and Great Lake area, where the sequence is 5-10 m thick with a porosity of 11 to 14%. Porosity values are much lower at Poatina (1 to 5%). Fine grained sediments occur at Ross and Tunbridge therefore porosity is low, greatly reducing the units reservoir potential in these areas. Unit 1 thins and pinches out towards Granton.
Unit 3 is present at Poatina (5 m) and Ross (10 m). This is a prospective reservoir at Ross with fair to good porosity.
Unit 5 is the thickest package of sandstone and is the most prospective reservoir unit in the Liffey/Faulkner Group. Porosity values range from fair to good, but poor at Ross and Tunbridge.

Units 2 and 6 are considered to have poor reservoir character, due to the interbedding of fine mudstone and siltstone, making the unit relatively impermeable. It is hard to determine from drill core how laterally continuous the mudstone interbeds are, i.e. they could be limited and discontinuous on the metre scale. Even if this were the case, the mud:sand increases at Ross and Tunbridge, with mudstone being dominant in the section. The interbedded mud seams are also much thicker at Granton.

Unit 4 has a relatively consistent thickness throughout the basin ranging from 7-10 m. The reservoir character is highly variable due to is poor sorting, and contains silt and mud within the framework. Unit 7 is similar to unit 4 except variable in thickness and generally lower porosity. A summary of the characteristics of the units is given in Table 3.2.

A study of lithology, deposition and grain morphology alone is not sufficient to understand the reservoir character of the Liffey/Faulkner Group. Further examination of the porosity variation of the units and causes for this are required. Chapter 5 will go on to discuss this with respect to diagenesis. Some conclusions can then be as to the reservoir potential of each of the units and also the combined reservoir potential of the stacked Liffey/Faulkner sequence throughout the "Tasmania Basin".

	unit 1	unit 2	unit 3	unit 4	unit 5	unit 6	unit 7
Lithology	white-grey sandstone	interbedded white-grey sandstone, and dark grey mudstone	white-grey sandstone	heavily bioturbated sandstone, to mudstone	white-grey sandstone	interbedded white-grey sandstone, and dark grey mudstone	heavily bioturbated sandstone
Composition	quartz (75%), feldspar, mica, clay	-	quartz (>75%), feldspar, mica, clay	quartz (70%), feldspar, mica, clay	quartz (>70%), feldspar, mica, clay	-	quartz (70%), feldspar, mica, clay
Grain Size	medium to very fine	medium to silt	fine to very fine	medium to very fine	coarse to very fine (Ross)	medium to silt	medium to very fine
Grain Morphology	sub-angular to sub-rounded	-	sub-angular to sub-rounded	sub-angular to sub-rounded	sub-angular to sub-rounded	-	sub-angular to sub-rounded
Sorting	well sorted	-	well sorted	moderately poorly sorted	well sorted	-	moderately poorly sorted
Framework	close packed	-	close packed	relatively open framework	close packed	-	relatively open framework
Cement	minor silica	-	minor silica	minor silica (mainly clay matrix)	minor silica & some carbonate	-	minor silica (mainly clay matrix)
Porosity	10 - 15% (1-5% at Poatina)	variable	2 - 5% at Poatina, up to 25% at Ross	9 - 27%	10 - 25%	variable	5 - 7%
Thickness	10 m (at Golden Valley) to 1 m	1 to 11 m	5 to 11 m	3 to 9 m	average 11 m	1 to 3 m	3 to >7 m

Table 3.2: Summary of lithologic characteristics of the units in the Liffey/Faulkner Group in the "Tasmania Basin"

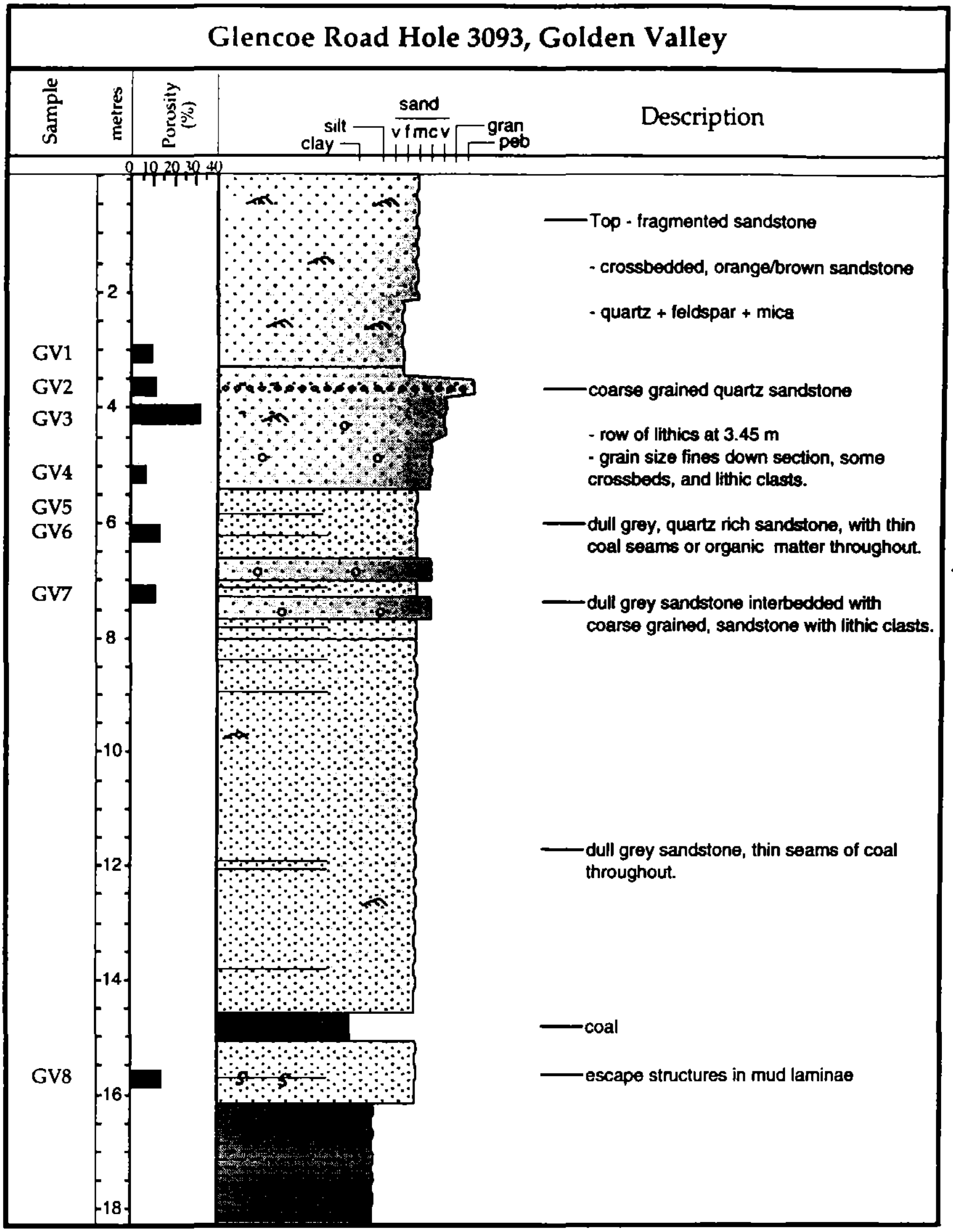

Figure 3.1 : Glencoe Road Hole 3093 at Golden Valley

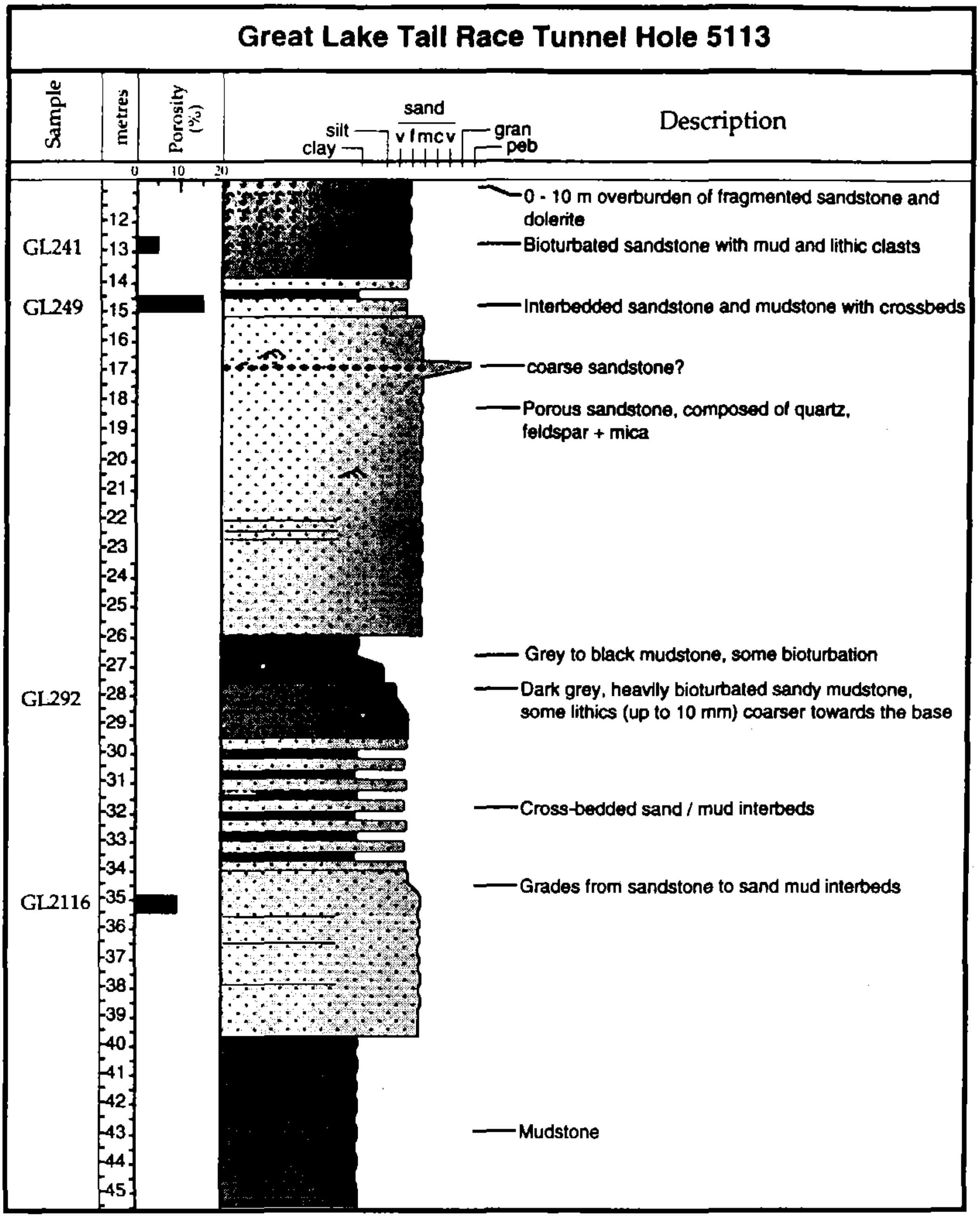

Figure 3.2 : Great Lake Tail Race Tunnel Hole 5113

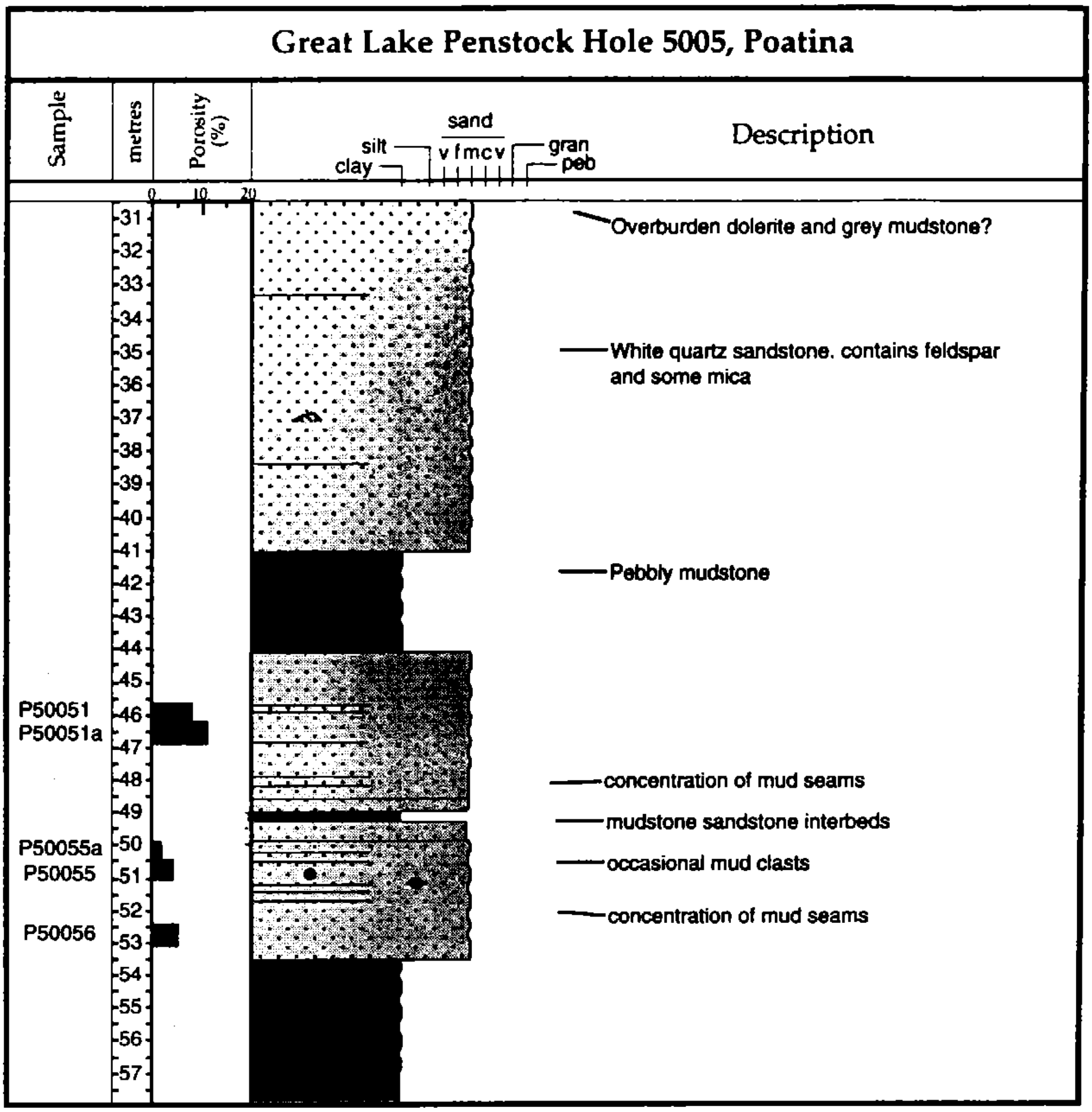

Figure 3.3 : Great Lake Penstock Hole 5005 at Poatina

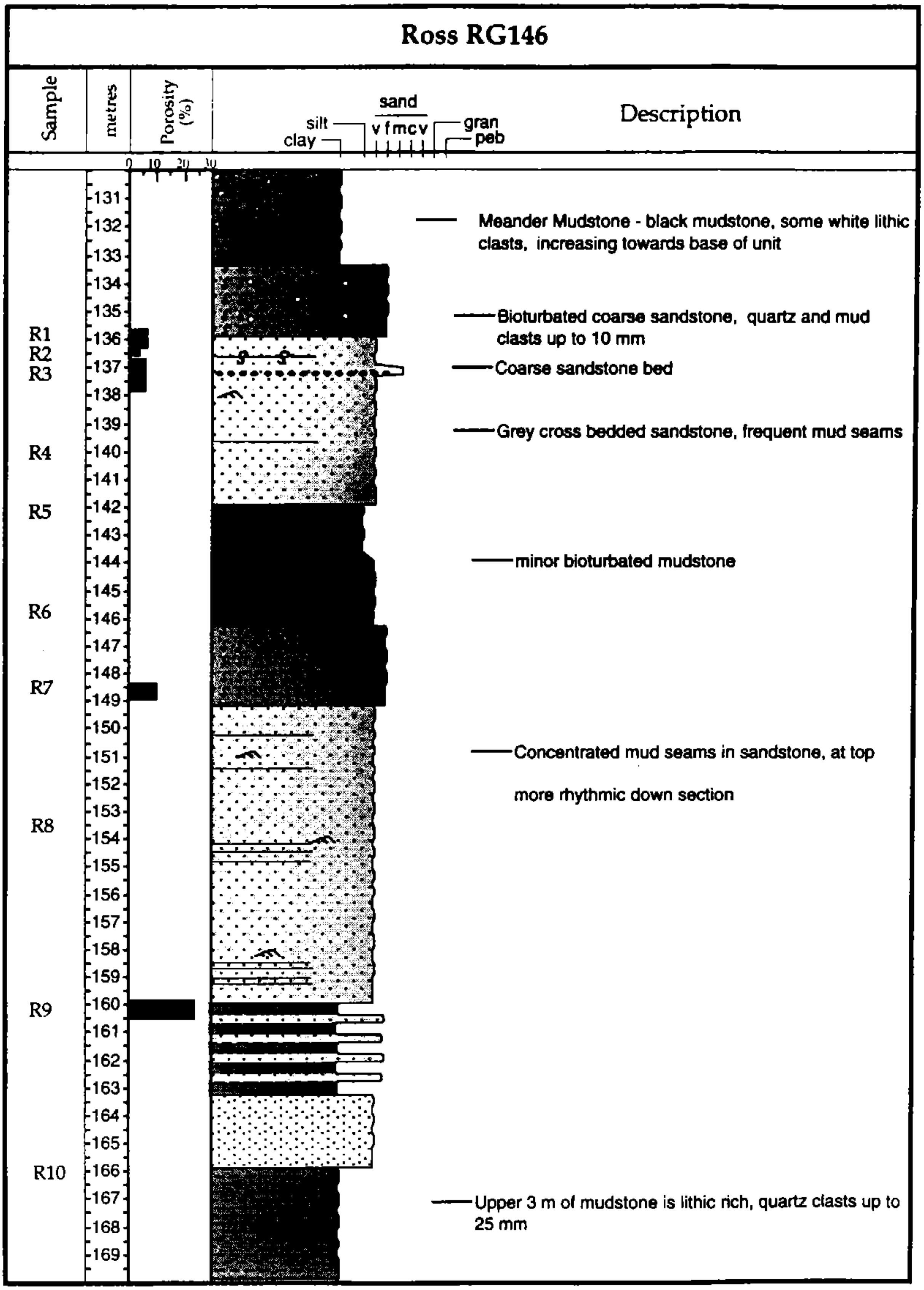

Figure 3.4 : Ross RG146 Hole

343050

Tunbridge Tier RG145

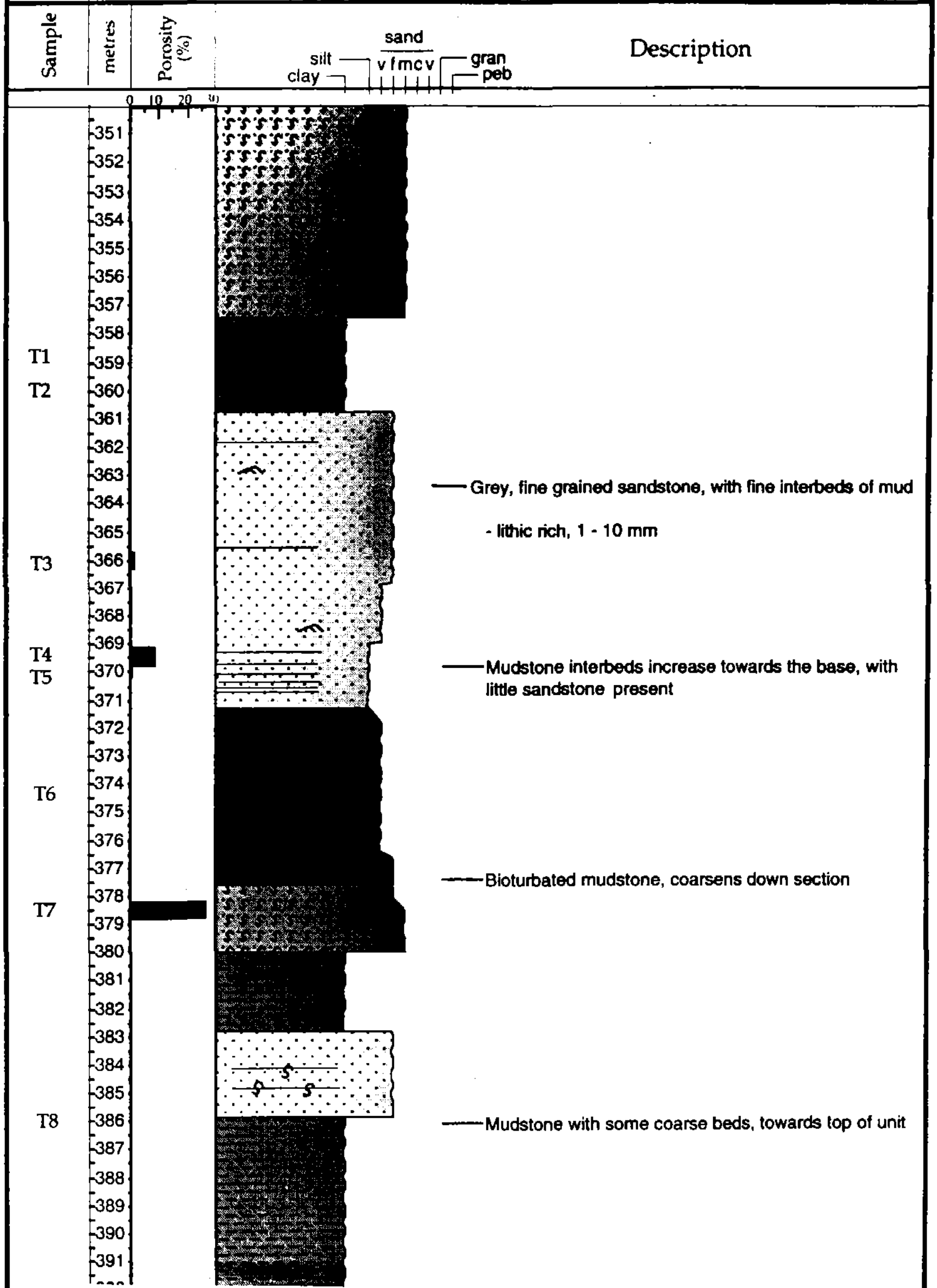

Figure 3.5 : Tunbridge Tier Hole RG145

343051

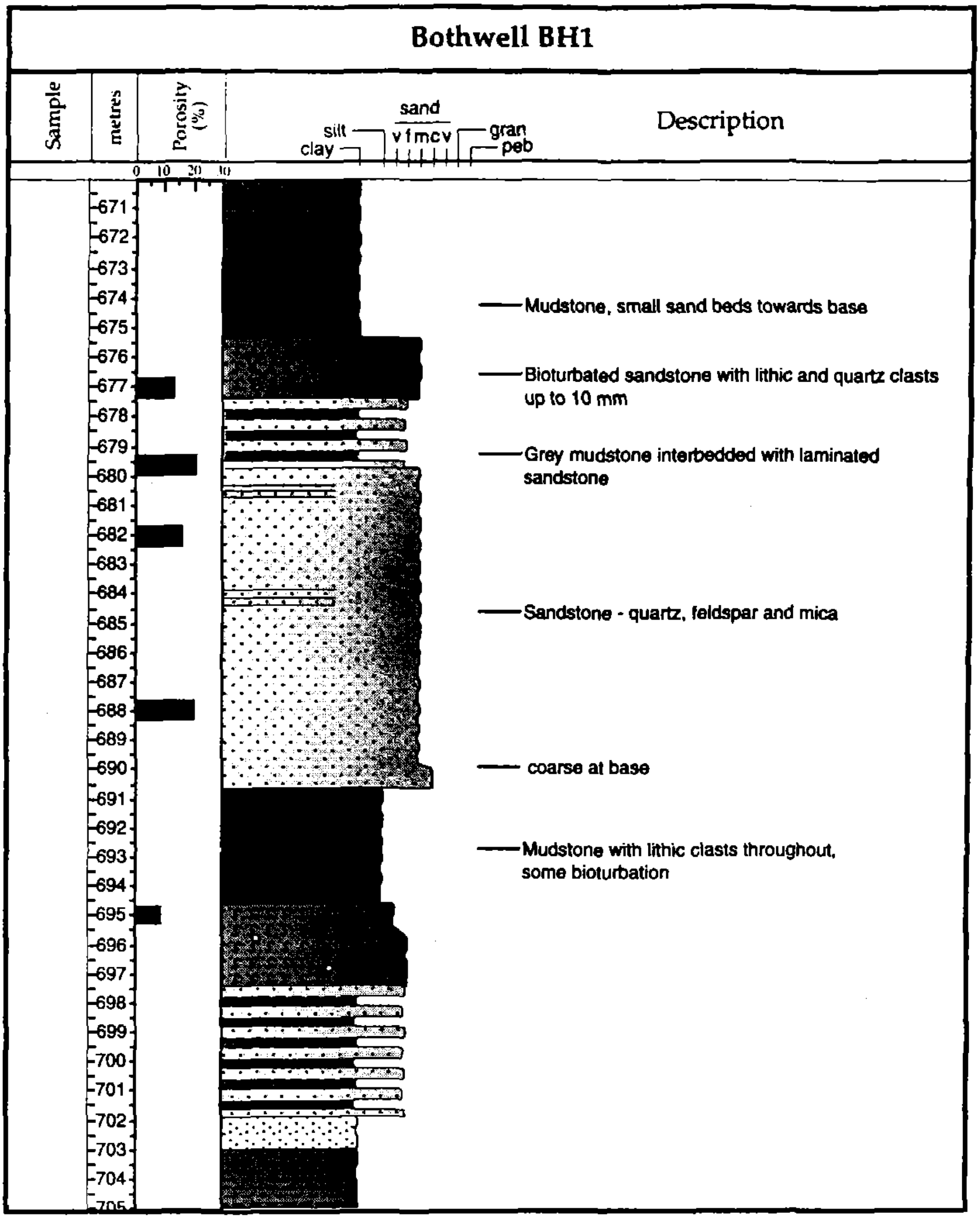

Figure 3.6 : Bothwell BH1

343052

Plate 3.1 : white-grey, well-sorted, fine grained, sandstone, with black silt laminae. Deformation of the laminae is as a result of bioturbation.

Plate 3.2 : white-grey, very-fine grained sandstone with cross-beds and deformation of silt layers deformed by bioturbation

Plate 3.3 : well sorted, medium-coarse grained quartz rich sandstone, weathered to a buff brown-orange colour.

Plate 3.4 : white to grey, well sorted, medium grained, quartz rich sandstone.

343053

Golden Valley (GV8 - 15.77 m) porosity = 14 %

Ross (R10 - 166 m)

Golden Valley (GV3 - 4.27 m) porosity = 31 %

Great Lake (GL249 - 14.95 m) porosity = 15.3 %

Diagenesis 4

4.1 Introduction

Porosity and permeability define the reservoir potential of particular sedimentary units. This discussion focusses solely on porosity, as this can be quantified for the Liffey/Faulkner Group. Porosity is affected by diagenetic processes, as they can greatly modify the composition and texture of sediments (Tucker, 1981). The results of processes such as compaction, quartz growth, cementation, dissolution and authigenic mineral growth, have been examined and recognised in respective units of the Liffey/Faulkner Group.

4.2 Porosity

Porosity is defined as the percentage of total volume of the rock that is pore space (North, 1985). A qualitative evaluation (North, 1989) of porosity considers:

0 - 5 %	negligible
5 - 10 %	poor
10 - 15 %	fair
15 - 20 %	good
20 % +	very good.

Porosity may be primary or secondary. Primary pores are formed during the deposition of the sediment. These can be either interparticle or intraparticle pores. Interparticle pores are initially present in all sandstones, but are often lost rapidly in clays and carbonate sands because of compaction and cementation. Much of the porosity in sandstone reservoirs is preserved primary, intergranular porosity (Selley, 1985). Secondary porosity occurs after deposition, and is generated by dissolution of minerals as pore water undersaturated in particular mineral phases passes through the rock. This pore water can either be meteoric water, or connate water. Meteoric water flows into the basin, driven by the head of an elevated water table. Connate water is pore water buried in sediments which is forced upwards, due to the compaction of the sediments (Bjorlykke, 1984; Fig. 4.1).

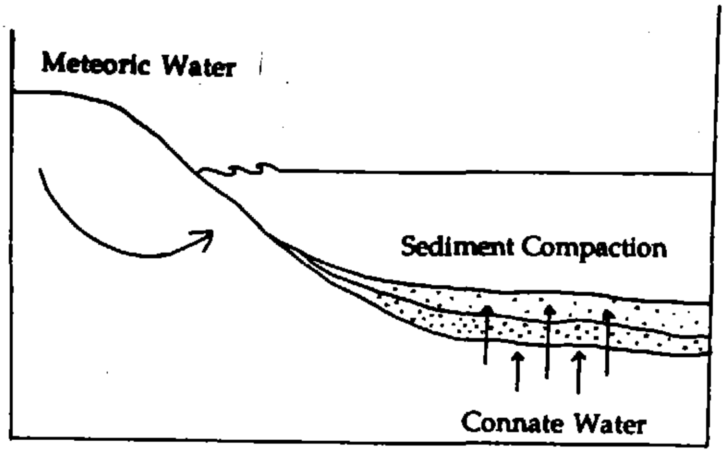

Fig. 4.1 : Connate water and meteoric water passing through sediment.

4.3 Diagenesis

Porosity loss or occlusion in sandstones occurs from diagenetic processes; for example, grain compaction, pressure solution, growth of authigenic minerals and cements (Hutcheon, 1990). As these processes affect porosity and permeability, they control the reservoir potential of the sediment. Effects on porosity vary between basins, and units within basins, as many interacting processes contribute to diagenetic processes (Hutcheon, 1990).

Sandstones may have a very open framework on deposition, with initial porosities ranging from 40 - 50%. The sediment is compacted during burial, resulting in reduction of porosity (Selley, 1985). Porosity can be reduced to 15% depending on depth of burial and the presence of smaller grains to occupy interstitial positions between larger grains (Greensmith, 1989). Cementation often occurs at the same time as compaction. This is a two-way process involving episodes of cementation, which reduces porosity and episodes of cement dissolution which increases porosity (Greensmith, 1989).

Pressure solution and quartz overgrowths may often be the most significant porosity-affecting diagenetic feature in quartz-rich sandstones. Pressure solution is a process in which grains or authigenic minerals dissolve at intergranular, or intercrystalline contacts (Bjorkum, 1996). This leads to diffusion of silica which can fill pores (Hutcheon, 1990). Quartz overgrowths, which occur as silica derived from the reaction of clay minerals and also by replacement of silica bearing minerals, nucleate on existing quartz grains (Hutcheon, 1990). These processes can be affected by the presence of clay during deposition, authigenic clay, or by the infiltration of clay minerals into sediments. Clay coatings on quartz grains can inhibit the nucleation of quartz overgrowths by physically blocking sites for nucleation on the host quartz grains (Pittman et al., 1992).

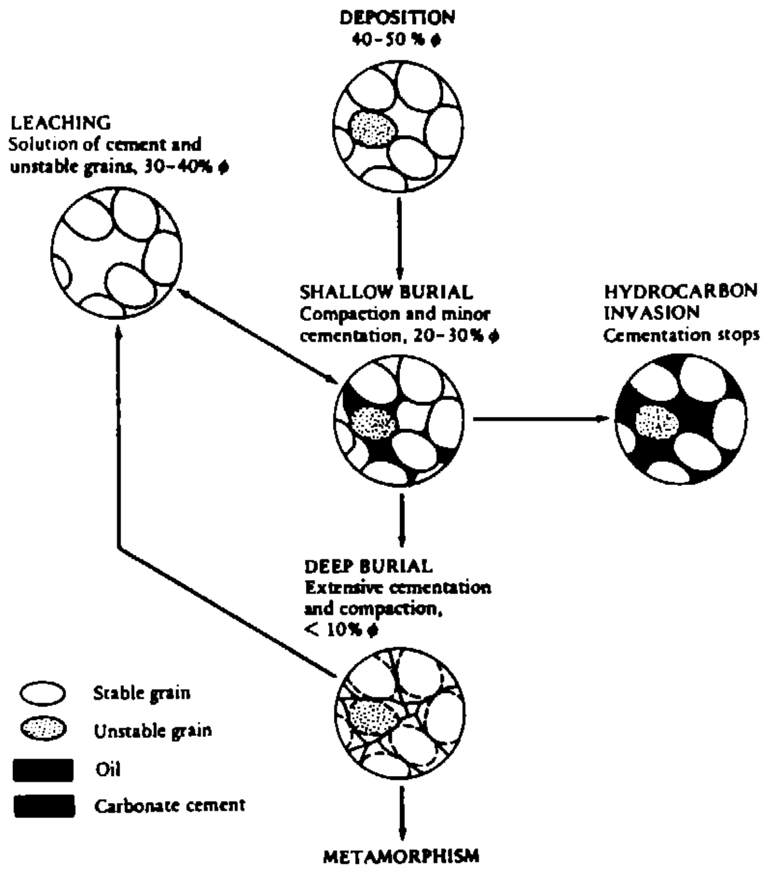

Figure 4.2 : Simplified flowchart of diagenetic pathways of sandstones (Selley, 1985).

4.4 Liffey/Faulkner Group

Diagenetic features and subsequent effects on porosity within selected units were examined in thin section and using an environmental scanning electron microscope (ESEM). Variation of these characteristics can be seen between the units and within units in different areas.

4.4.1 Unit 1

This unit has a porosity of 14 % at Golden Valley, 9.6 % at Great Lake and 3-5% at Poatina. This is made up of intergranular porosity, and secondary intragranular porosity resulting from feldspar dissolution. Grain compaction is evident with sutured quartz-grain boundaries from quartz growth, associated silica cementation, and the presence of mica bent around quartz grains. Pressure solution of mica into quartz may also be present. Authigenic clay occludes porosity. Early diagenetic clay is also evident, as coating of quartz grains in some areas has prevented quartz overgrowth preserving primary intergranular porosity. There is minor diagenetic pyrite (Table 4.1; Plate 4.1, 4.2).

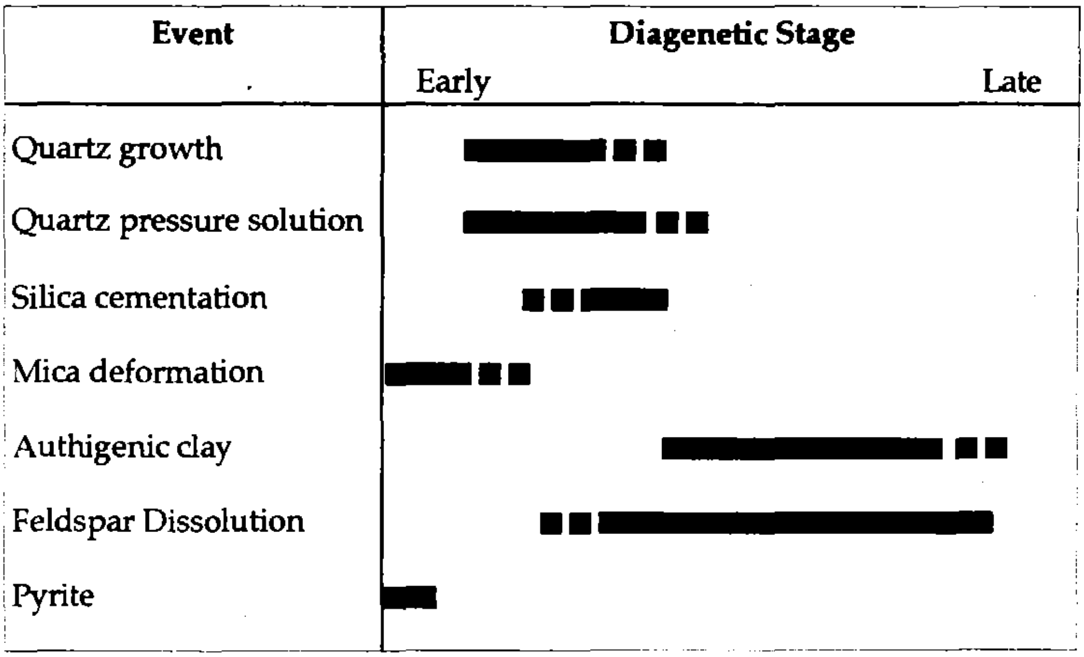

Table 4.1: Sequence of diagenetic events for unit 1 at Golden Valley and Great Lake.

The lower porosity of unit 1 at Poatina is due to carbonate cement occluding porosity. Compaction features are still evident present (for example quartz growth and sutured grain boundaries), however, the carbonate cement surrounds isolated quartz grains, and infills partially dissolved feldspar grains. This indicates carbonate cementation was relatively early as it prevented more quartz growth. The porosity lower in the section is marginally higher (2 %), and there is no evidence of carbonate cement. Authigenic clay fills pores and it appears that carbonate has dissolved and been replaced by some clay(?). Minor diagenetic pyrite is also present (Table 4.2; Plate 4.3, 4.4, 4.9).

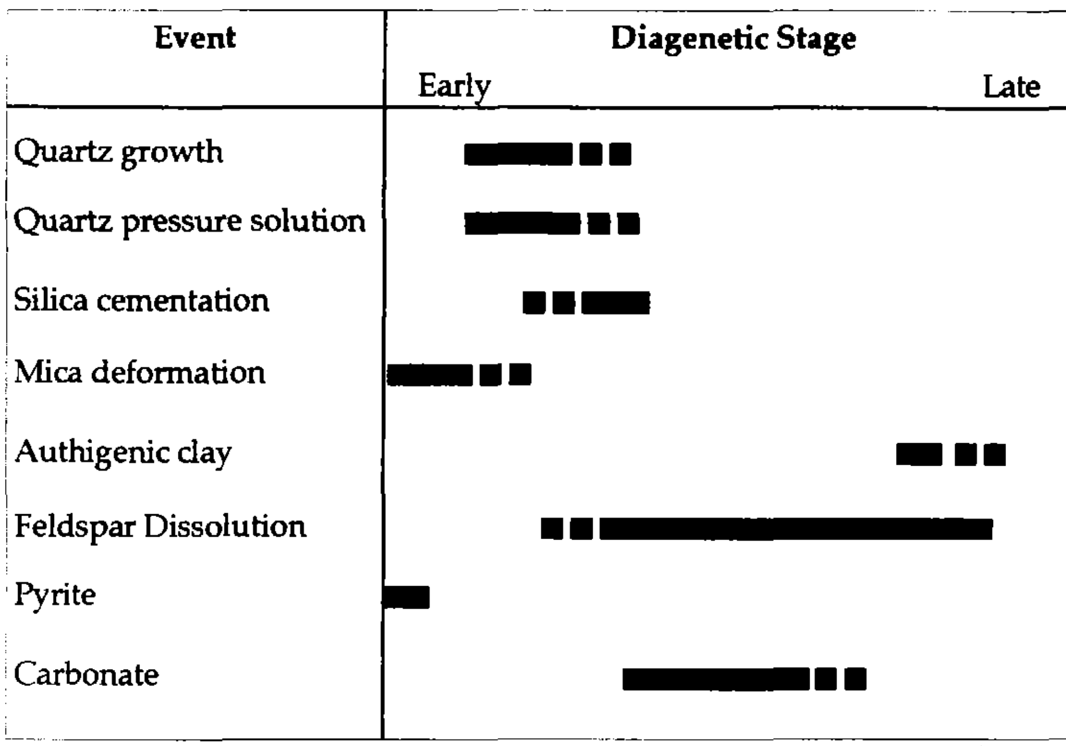

Table 4.2: Sequence of diagenetic events for unit 1 at Poatina, where carbonate cement occludes porosity

4.4.2 Unit 3

Porosity in this unit ranges from approximately 10% at Poatina, up to 25% at Ross. This consists of both intergranular porosity and intragranular porosity (e.g. dissolution of feldspar). Compaction has resulted in bent mica grains, suture boundaries in quartz due to pressure solution, and also limited silica cementation. Clay coating on grains has prevented quartz growth, in some instances, preserving primary intergranular porosity. Clay occludes porosity as mainly mixed layer mica-smectite and chlorite (2 - 5%); (Table 4.3).

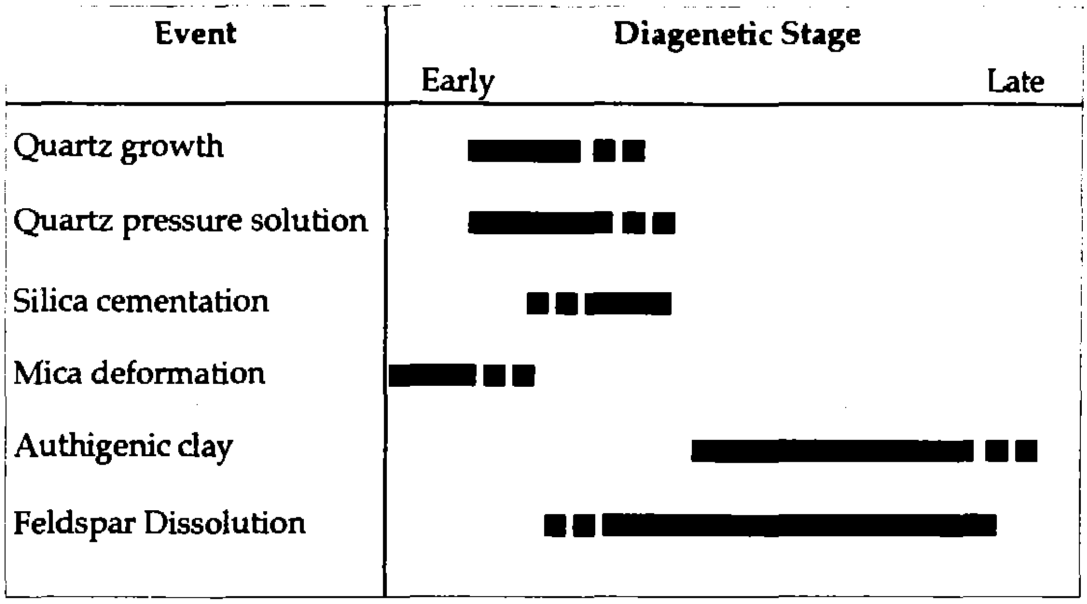

Table 4.3: Sequence of diagenetic events for unit 3 at Poatina and Ross.

4.4.3 Unit 4

Porosity for unit 4 ranges from 10% at Ross, up to 25% at Tunbridge, and approximately 9% at Bothwell. Porosity is mainly intergranular with some fractures. Primary porosity is preserved due to clay coating of grains preventing cementation and pressure solution of quartz. This is probably due to the presence of clay during deposition which is common in this heavily bioturbated unit. Mixed layer mica-smectite occludes porosity in unit 4 at Ross with minor pressure solution of quartz and SiO_2 cementation.

Porosity is much higher at Tunbridge, with clay coatings preserving intergranular porosity, and only limited authigenic clay precluding pore infilling (Table 4.4; Plate 4.5, 4.10).

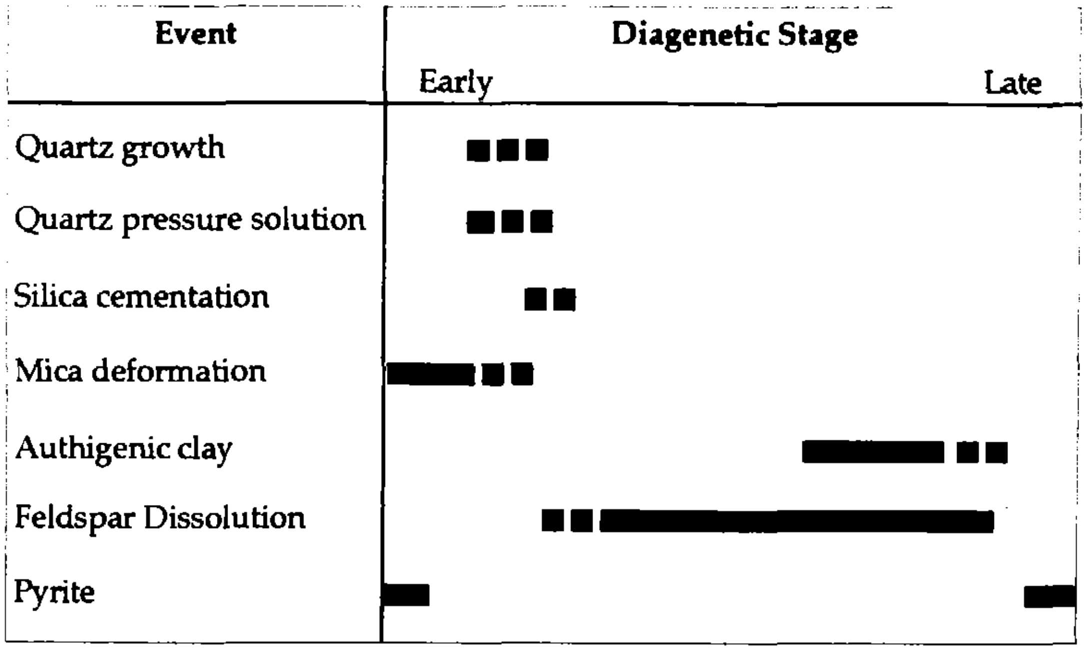

Table 4.4: Sequence of diagenetic events for unit 4 at Ross and Tunbridge, where quartz growth has been inhibited by clay coatings.

Porosity at Bothwell is reduced due to porosity occlusion by carbonate cement. This comprises siderite and minor calcite cementation. Fracture related porosity has been filled with calcite and minor dissolution has created some secondary pore space. There is some diagenetic pyrite, and late stage pyrite veins (Table 4.5).

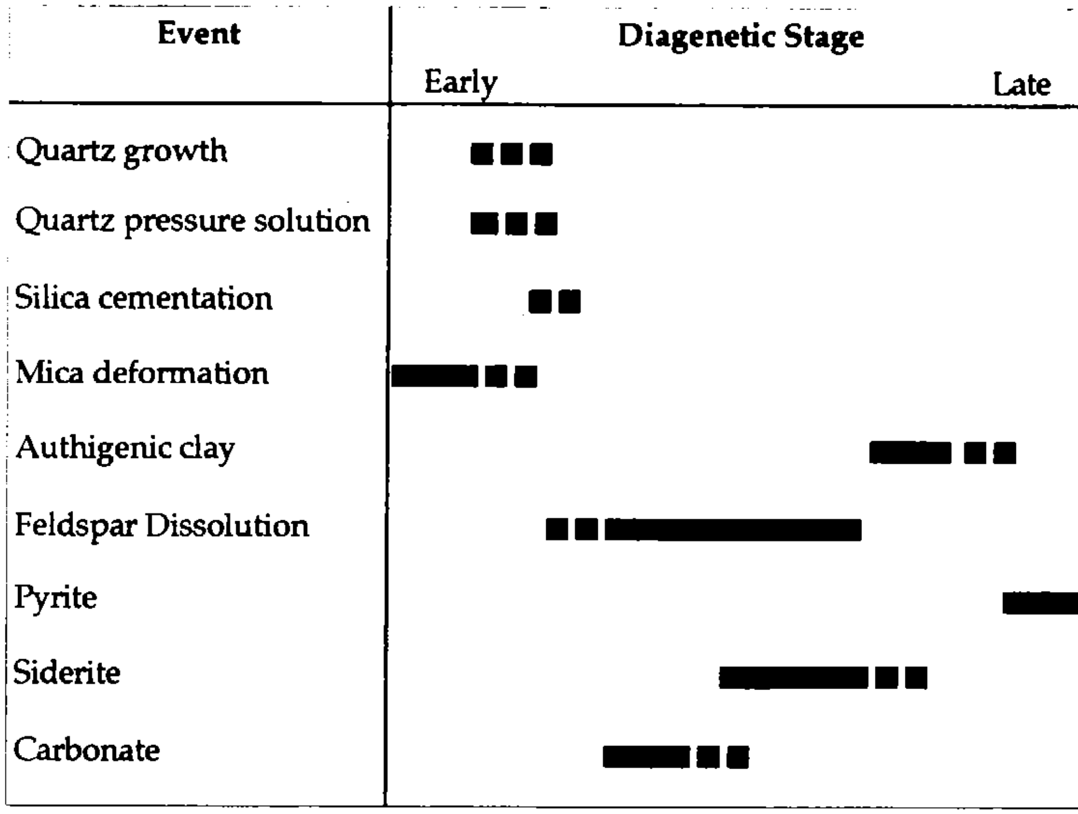

Table 4.5: Sequence of diagenetic events for unit 4 at Bothwell, where porosity is reduced due to carbonate cement.

4.4.4 Unit 5

Porosity in unit 5 ranges from 10-30% at Golden Valley, 15% at Great Lake, 15-20% at Bothwell, and less than 10% at Ross and Tunbridge. The upper part of the Golden Valley section has compaction textures indicative of quartz pressure solution, and also some silica cementation (Plate 4.11). Near surface weathering of the at Golden Valley has caused prevention of occlusion of intergranular porosity.

Intergranular pores and secondary porosity caused by dissolution of feldspars are the main elements of porosity at Great Lake. Porosity has been occluded by quartz overgrowths, due to compaction and pressure solution. There is also minor clay present (Plate 4.12).

Intergranular and intragranular porosity is present in unit 5 as sampled at

Bothwell. Compaction has resulted in sutured boundaries around quartz grains, silica cementation, and deformed mica grains. Some of the quartz grains present are indicative of glacial origin, with step and arc, textures and striations (Rao, 1981). Dissolution occurred after compaction and this is evident from the presence of deformed mica around pore space. This indicates the mica was bent around a grain which was later dissolved. Some authigenic clay (kaolinite) also fills intergranular pores (Table 4.6; Plate 4.6).

Event	Diagenetic Stage Early Late
Quartz growth	
Quartz pressure solution	
Silica cementation	
Mica deformation	
Authigenic clay	
Feldspar Dissolution	

Table 4.6: Sequence of diagenetic events for unit 5 at Golden Valley, Great Lake and Bothwell.

Unit 5 is very fine grained at Ross and Tunbridge, and the sections consist of much fine-grained silt. Kaolinite, and chlorite clay minerals are present. Compaction and the abundance of silt sized material has resulted in poor porosity (Plate 4.7).

4.4.5 Unit 7

Porosity in this unit ranges between 5 and 10% at Great Lake and Ross.

Porosity types include both intergranular and intragranular porosity. Clay coating around grains prevents major quartz overgrowth and silica cementation. Occlusion of porosity is due mainly to clay infilling pore spaces (Plate 4.8).

This is similar at Ross, with some added porous microfractures. Minor carbonate cement is present infilling some areas of dissolution and intergranular pores. Minor diagenetic pyrite is also present (Table 4.7).

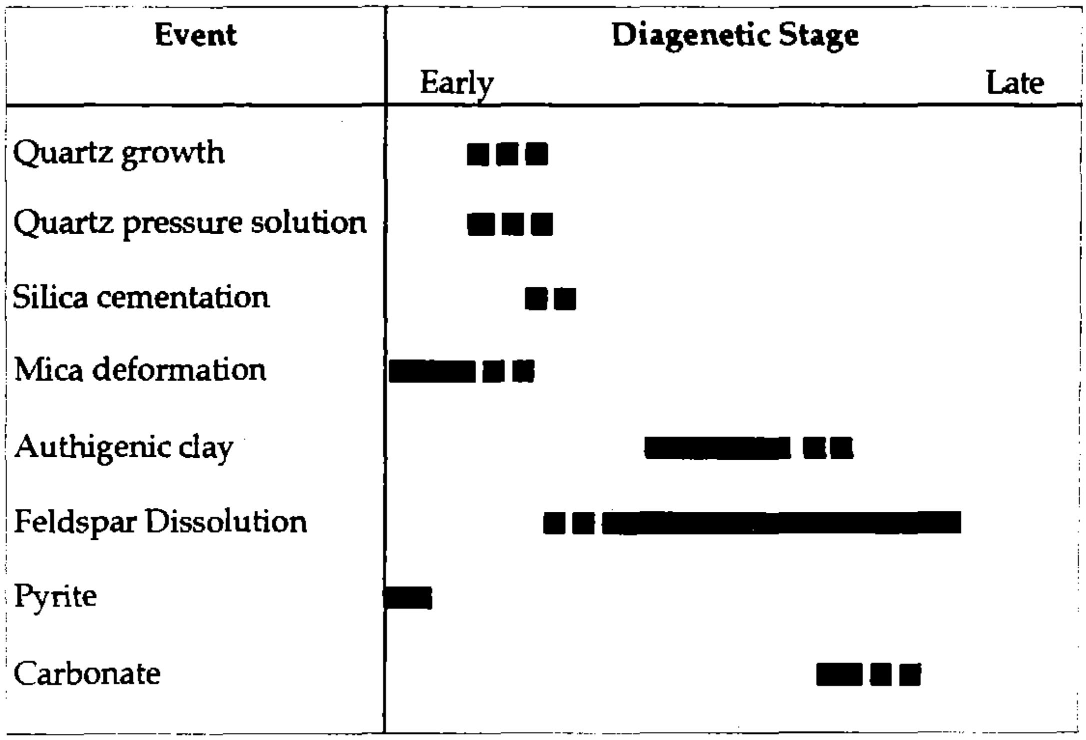

Table 4.7: Sequence of diagenetic events for unit 7 at Great Lake and Ross.

4.5 Discussion

The pore types of the sandstone units 1, 3 and 5 are mainly intragranular pores after the dissolution of feldspar, with some intergranular pores. Porosity ranges from generally fair to very good, with the exception of unit 1 at Poatina where carbonate cement has occluded most of the pores, and unit 5 at Ross and Tunbridge where the unit is very fine-grained.

Porosity in units 1,3 and 5 is generally occluded by quartz overgrowths, pressure solution and silica cementation.

The pore types of units 4 and 7 are mainly primary intergranular pores, preserved due to clay coatings around quartz grains preventing overgrowth. This porosity is particularly well developed in unit 4 at Tunbridge (up to 25%). These pores are filled with clay at Ross, and are occluded by carbonate cement at Bothwell. This may be attributed to variable movement of a carbonate saturated fluid. Unit 7 is less porous than unit 4 (porosity range 5-10%), with pores occluded by clay.

Areas proximal to Poatina to and Bothwell may have also been subjected to similar episodes cementation, but this is difficult to constrain due to the limited amount of data available and the distance between logged sections. Future research should be directed to the determination of the source and extent of these episodes, in order to establish their effect on reservoir character.

Plate 4.1 : unit 1 at Golden Valley, well-sorted quartz-rich sandstone. Pores are highlighted by green araldite, porosity = 14%. (plane polarised light, field of view ≈ 4mm)

Plate 4.2 : unit 1 at Golden Valley, containing quartz, clay, and mica. Compaction textures include mica deformation, sutured quartz-grain boundaries, overgrowths and silica cementation. (crossed polars, field of view ≈ 1mm)

Plate 4.3 : unit 1 at Poatina, carbonate cement infills pores. (Q - quartz, C - carbonate cement; crossed polars, field of view ≈ 2mm)

Plate 4.4 : unit 1 at Poatina, carbonate cement infills pores, sutured quartz boundaries, some feldspar reserved, (Q - quartz, C - carbonate cement, F- feldspar; crossed polars, field of view ≈ 1mm)

Plate 4.5 : unit 4 at Tunbridge, poorly-sorted sandstone, relatively open framework, high porosity (27%). (Q - quartz, P - porosity; plane polarised light, field of view ≈ 4mm)

Plate 4.6 : unit 5 at Bothwell, well-sorted sandstone, sutured quartz grain boundaries, deformed mica. (crossed polars, field of view ≈ 1mm)

Plate 4.7 :unit 5 at Ross, very fine grained, porosity <5%. (Q - quartz, M - Mica; crossed polars, field of view ≈ 4mm)

Plate 4.8 : unit 7 at Bothwell. Poorly sorted, pyrite rich. (Q - quartz, Py - pyrite; plane polarised light, field of view ≈ 2mm)

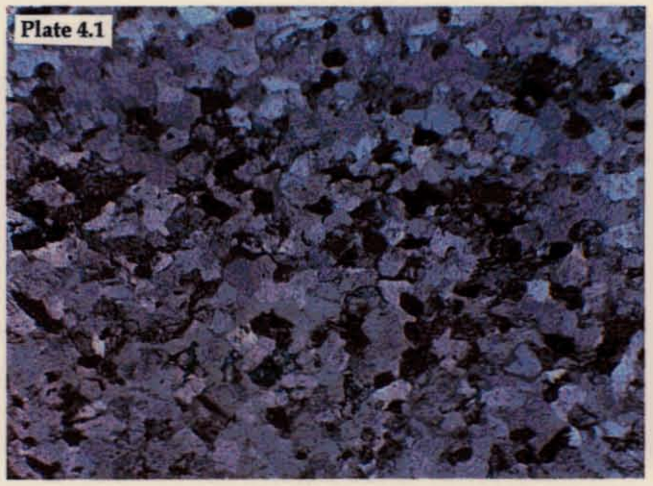
Plate 4.1


Plate 4.2

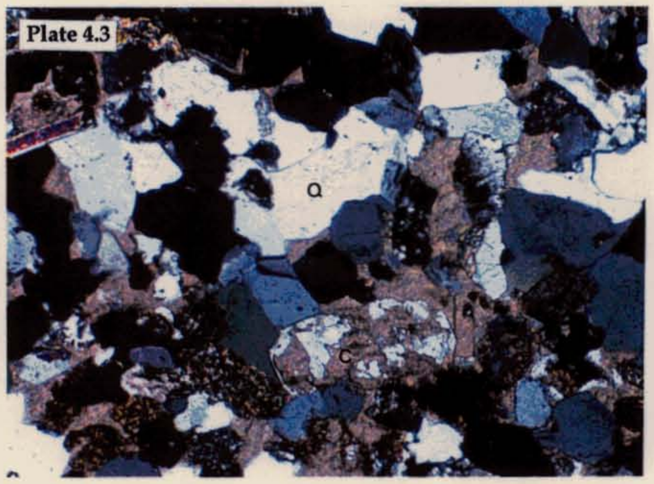

Plate 4.3

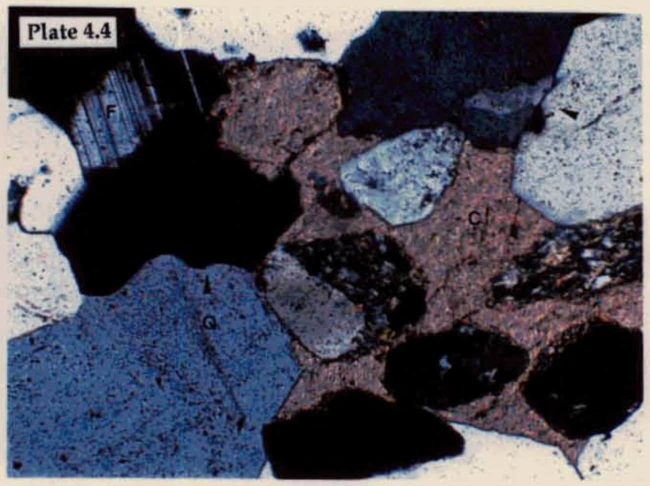

Plate 4.4

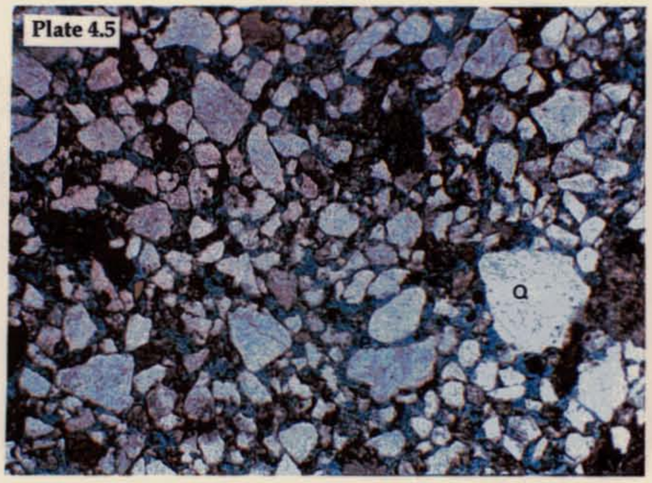

Plate 4.5

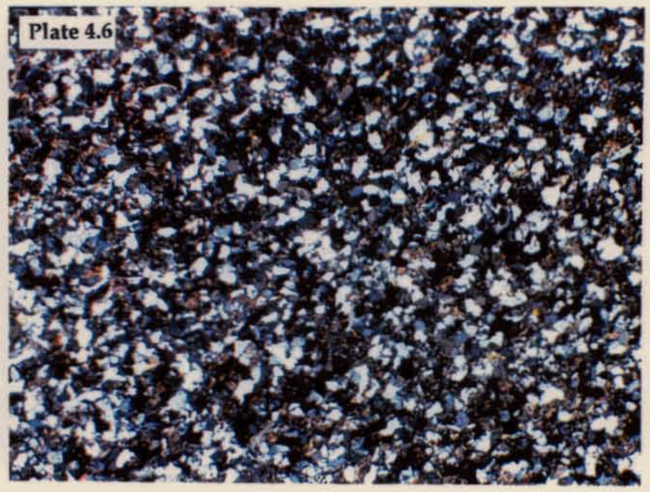
Plate 4.6

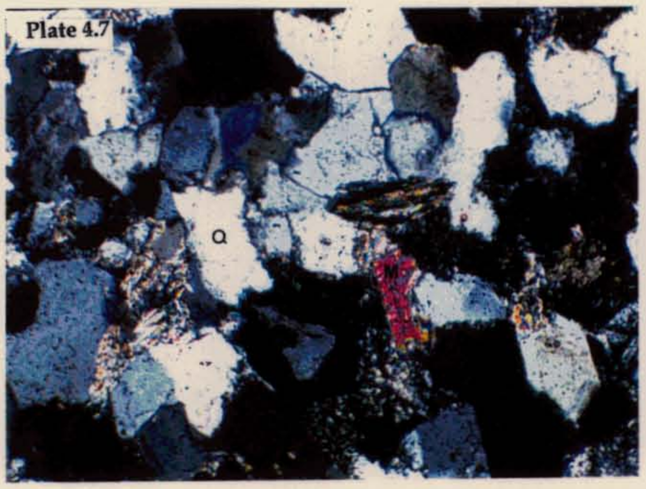

Plate 4.7

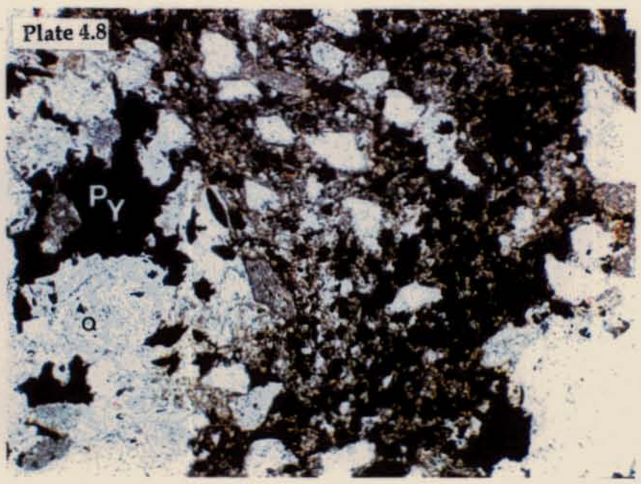

Plate 4.8

Plate 4.9 : unit 1 at Poatina. Calcite in pore between quartz grains. (Q - quartz, C - carbonate cement; SEM, scale as shown)

Plate 4.10 : unit 4 at Ross. Quartz grains with clay (mixed layer-Mica Smectite); (Q - quartz, M - Sm - mised layer mica smectite; SEM, scale as shown)

Plate 4.11 : unit 5 Golden Valley. Well developed pore space, minor silica cement around quartz. (Q - quartz, P - porosity; SEM, scale as shown)

Plate 4.12 : unit 5 at Great Lake silica cement infilling pore between quartz grains. (Q - quartz, S - silica cement; SEM, scale as shown)

Plate 4.13 : unit 5 at Bothwell. Large pore. (P - porosity; SEM, scale as shown)

Plate 4.14 : unit 5 at Bothwell. Quartz grain indicative of glacial origin, showing steps and arcs. (SEM, scale as shown)

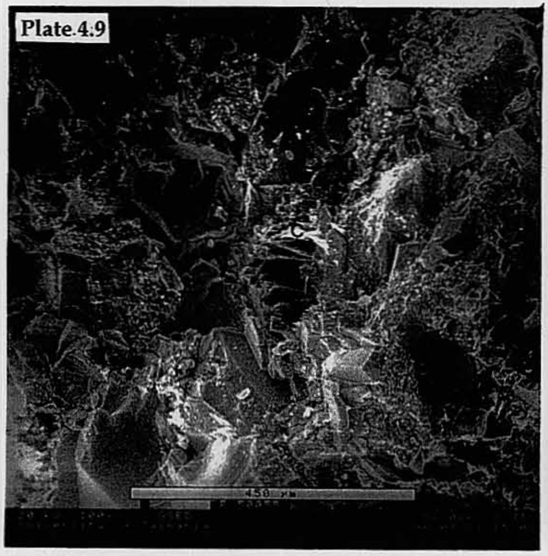

Plate 4.9

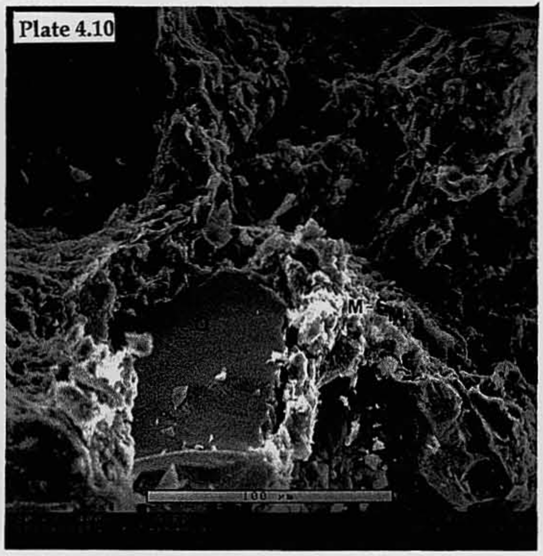

Plate 4.10

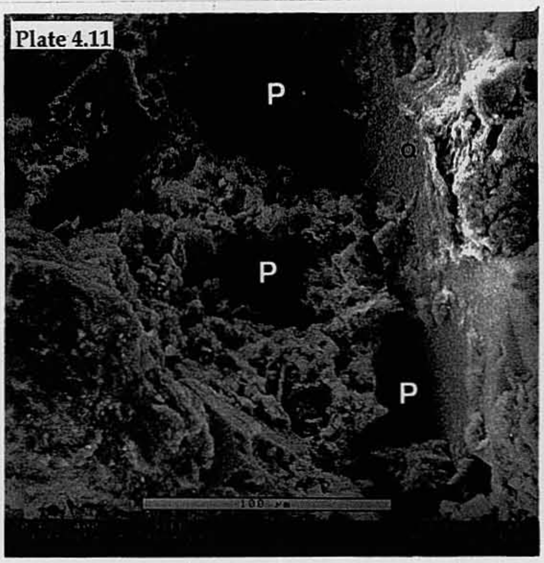

Plate 4.11

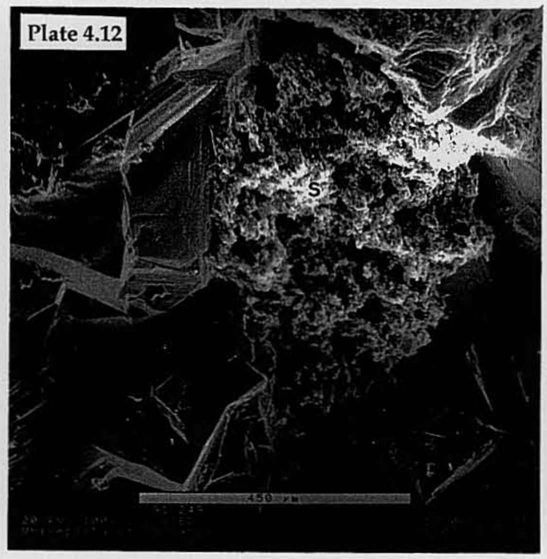

Plate 4.12

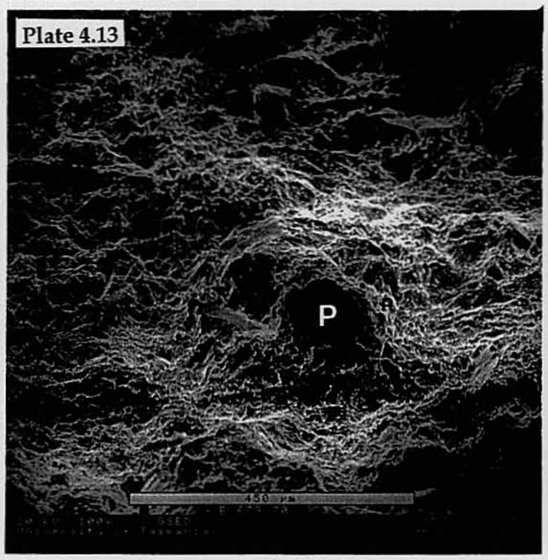

Plate 4.13

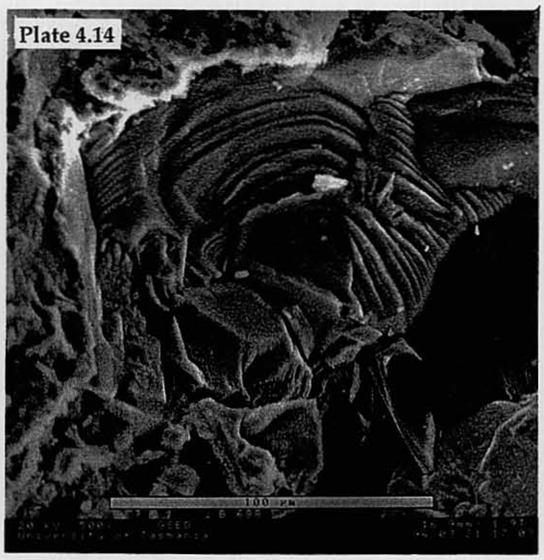

Plate 4.14

Reservoir Potential Summary 5

5.1 Introduction

The results of chapters 3 and 4 can be combined to define the overall reservoir potential of each unit, and the Liffey/Faulkner Group *as a whole*. The spacing of drill core does not allow complete assessment of the continuity of the units, and comment must be made on the structures affecting the group.

5.2 Unit Variation

From this study it can be seen that variation occurs between, and within units. Local flushing of sediment with fluids rich in carbonate has caused reduction of porosity (and reservoir potential) due to cementation in areas such as Poatina and Bothwell. Data available is insufficient to constrain the extent of these events, and the effect on the reservoir. Structures and reservoir characteristics between current drill holes need to be determined. More closely spaced sampling within units, with accurate porosity and permeability tests are required to constrain variation within units.

A preliminary assessment of the reservoir potential has been made from this study. Ratings have been given to each of the units, and this has been represented in Figure 5.1 to show the horizons of good, fair and poor potential. These ratings are based on porosity, thickness, and to a lesser extent sorting, consistency, and area.

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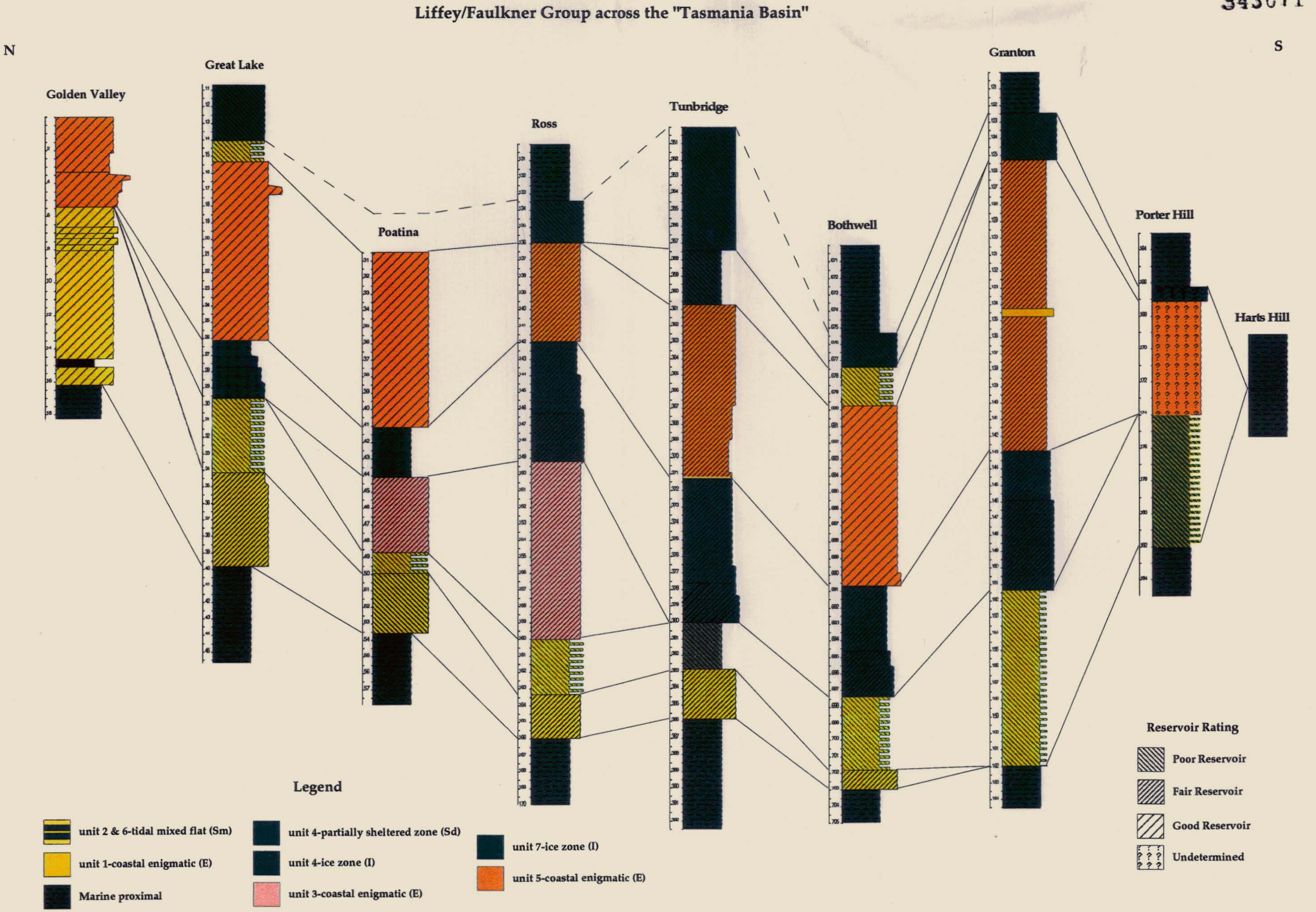

Figure 5.1 : Reservoir rating of the Liffey/Faulkner Group

Unit 1 is classed as a good reservoir at Golden Valley, where it is relatively thick(10 m) and porous. It is thinner (5 m) in the Great Lake area, but still has good porosity. The unit has low porosity due to carbonate cement and clay at Poatina, so the reservoir potential is poor here. This unit thins to the south and in general is a fair to poor reservoir.

Unit 3 is not extensive, occurring at Poatina and Ross. It is considered a fair reservoir.

Unit 5 is rated as a fair to good reservoir. Variation within the unit appears to be minimal, although more closely spaced sampling at each locality is required. Porosity is poor and grainsize is very fine at Ross and Tunbridge. At Granton variation within the unit is not defined, but porosity values (Woods, 1995) indicate reservoir potential may be fair.

Unit 4 has areas which have a porosity range from good to poor. This unit is poorly sorted and porosity, where well developed, is due to the preservation of primary porosity. This unit is classed as a fair reservoir, as character can vary on the metre scale. More close spaced analysis is required. Unit 7 has a similar lithology but porosity is much lower and it is considered a poor reservoir.

Unit 2 and unit 6 are considered to have a poor reservoir potential throughout the basin due to interbeds of mud. The interbedding is dominated by mud in the south, but less pronounced in the north. These beds may be marginally more permeable in the Golden Valley, Great Lake areas.

The reservoir character for the Liffey/Faulkner Group as a whole could be considered to be defined by the units occurring between units 2 and 6. Units 3, 4 and 5 have a range of fair to good reservoir potential, and have a total thickness ranging from 15-20m. The sections at Ross and Tunbridge appear to lie on either side of the Tiers Fault and have poor reservoir potential. This area may represent deposition in the deeper parts of the basin and localities around this area are likely to have poor reservoir potential.

5.3 Structure

The reservoir potential of the Liffey/Faulkner Group may be greatly affected by lateral continuity. Syndepositional faults (Banks, 1979) may disrupt the group, dividing it into separate packages. The nature and placement of these, and post-depositional faults, are not fully understood, and this makes it difficult to properly constrain the reservoir potential of the Liffey/Faulkner Group throughout the "Tasmania Basin".

The stratigraphic sections do suggest that the units may have been deposited broadly and in significant continuous volumes. The units are lithologically consistent and can be correlated from Great Lake in the north of the state, to Bothwell and Granton in the south, a distance of least 150 kms. The Liffey/Faulkner Group can also be correlated with the Mt. Elephant Sandstone in the northeast of Tasmania. The section is also up to 30 m thick in this area (McNeil, 1960).

Fracture porosity enhances the permeability of reservoirs, e.g. the Paraná Basin (Potter et al., 1995) and the Spraberry Reservoir, Texas (Wilkinson, 1953). Fracture porosity may have been developed in the Liffey/Faulkner Group during syndepositional faulting or dolerite intrusion. Work is required to establish the existence of fractures and their importance with respect to the reservoir potential of the Liffey/Faulkner Group.

Other structural issues, such as dolerite intrusions or spatial separation of post-depositional faults are important to the reservoir potential of the group. Zones of Tertiary volcanic activity are known in Tasmania, in areas such as Derwent Valley, Melton Mowbray and Storm Bay. This activity may have provided positive and negative effects on the Liffey/Faulkner Group. These volcanic events may have resulted in break up of blocks within the group, making it discontinuous and reducing the reservoir potential.

5.4 Play Models

The Liffey/Faulkner Group has now been established as a potential reservoir but effective source rocks and suitable seal rocks are required to create a petroleum play in the "Tasmania Basin".

A play requires three components: source rocks , reservoir rocks and a seal, to allow the generation and storage of petroleum (Fig. 5.2). A number of plays should be considered to put the reservoir characterisation of the Liffey/Faulkner Group into context. Potential source, reservoir and seal rocks for the "Tasmania Basin" are summarised in Figure 2.5.

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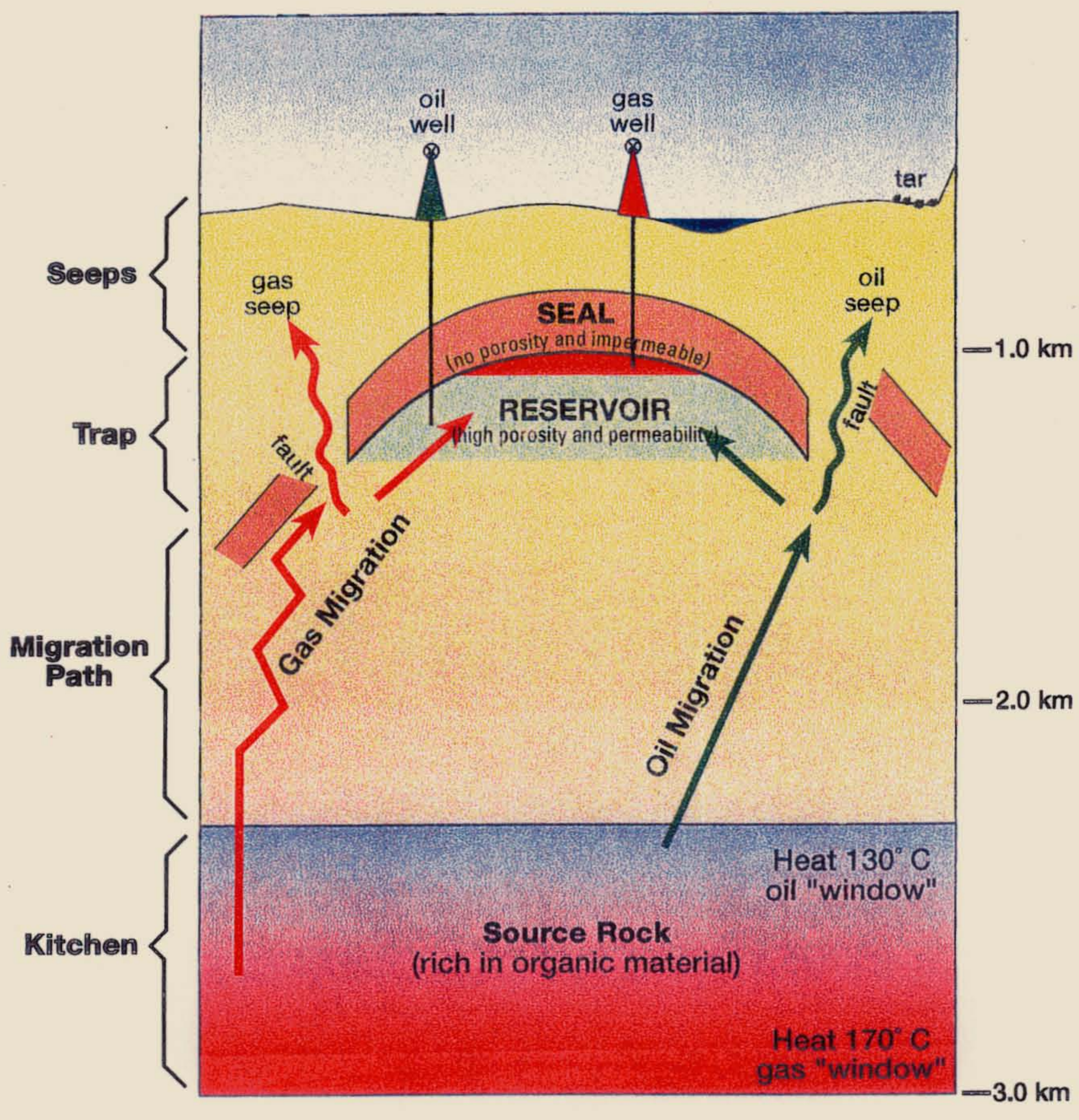

Figure 5.2 : Elements of a play

Different combinations of these potential source, reservoir and seal units, can represent plays in the "Tasmania Basin".

A play to be considered is

Source = Tasmanite Oil Shale, or older source rocks (Gordon Group Carbonates)

Migration Paths = "Tasmania Basin" rift faults, Jurassic and Tertiary faults.

Reservoir = Liffey/Faulkner Group (in particular units: 1,3,4,5)

Seal = Jurassic Dolerite, Poatina/Cascade Group

Although this play is possible and the necessary conditions exist, the core of the Liffey Faulkner Group examined showed no evidence of ever having been a reservoir for petroleum. The core was examined under UV light with no response. There are a number of scenarios that may account for the absence of hydrocarbons. There may be some structural control which has restricted petroleum flow to specific areas of the reservoir. All the petroleum may have seeped out (unlikely since residuals would be retained) or perhaps no migration has reached either this horizon or the areas sampled. Perhaps the amount of hydrocarbon produced is not sufficient to fill a reservoir, but this is unlikely given the number of known producing source rocks, and the volumes of potential petroleum from the sources calculated from thermal modelling of the Tasmanite Oil Shale and the Gordon Group Carbonates. More research of is required to confirm or deny these options.

The characteristics of the Liffey/Faulkner Group compare favourably with the Cooper Basin rocks. It would be interesting to know whether Cooper Basin reservoir rocks carry residual hydrocarbons in areas removed from productive areas.

Gondwana Basins 6

6.1 Introduction

The Gondwana Supercontinent was characterised by widespread sedimentation in large intracratonic basins during the Carboniferous and Permian. Sedimentation initially consisted of diamictites with glacial-fluvial and glacio-marine deposits. These were followed by dark fossiliferous shales, which were overlain by sandstones and thin coal seams (Potter et al., 1995). There has been little interest in ancient glacial deposits as potential reservoirs in the past but more recently there has been some study on the hydrocarbon potential of some of these basins and their associated glacially related sequences. Basins that are comparable with the "Tasmania Basin" include the Cooper Basin in east-central Australia, the Paraná Basin in Brazil, and the South Salt Basin of Oman (Fig. 6.1).

It is constructive to consider and compare conditions in productive or better known basins in order to assess the potential of parts of the Parmeener Supergroup.

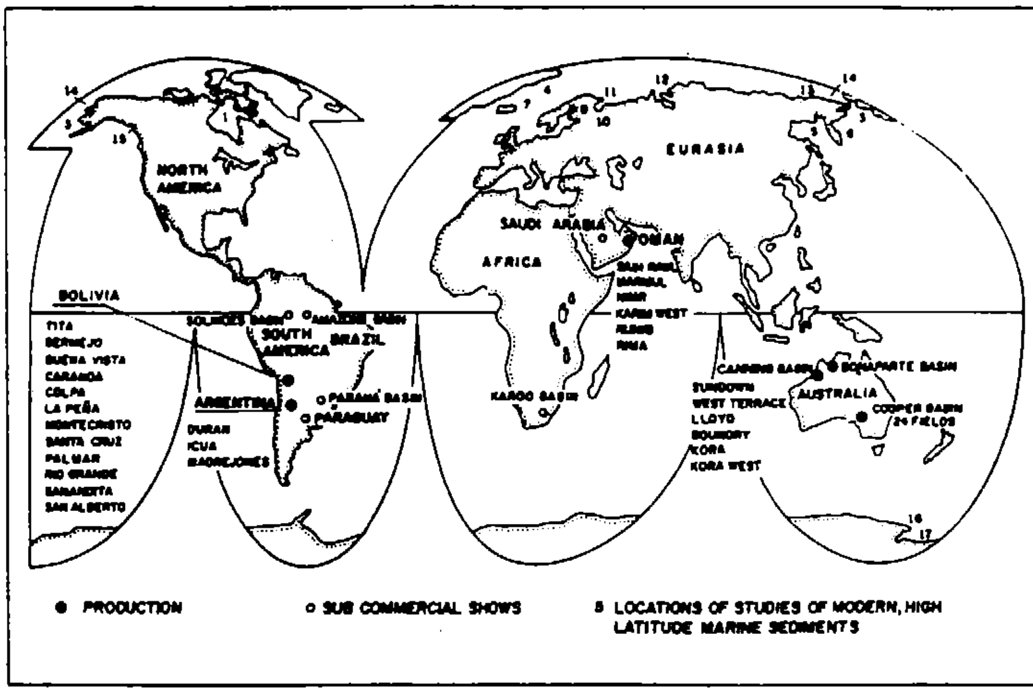

Fig. 6.1 : World map of productive basins including the Paraná Basin, Cooper Basin, and Oman.

6.2 "Tasmania Basin"

6.2.1 Source Rocks

Potential source rocks in the "Tasmania Basin" include the Gordon Limestone, and possibly others (such as the Eldon Group) from the Ordovician, and the Tasmanite Oil Shale, Quamby Mudstone and the Preolenna Coal Measures from the Permian.

6.2.1.1 Gordon Group Carbonates

The Gordon Group consists of a sequence of carbonate rocks, with a minor component of siliciclastics (Banks, 1989). The Gordon Group carbonates are a succession of tropical marine carbonates, which are up to 1.5 km thick in central Tasmania. Organic geochemistry of presumed seeps from Johnson's Well on Bruny Island and from Tasmania's coast shows a similar geochemical signature to the hydrocarbons from the Gordon Group limestone (Bendall et al., 1991). Burrett (1992) constructed isotherms across the "Tasmania Basin" using the colour alteration indices (CAI) of conodonts. Woods (1995) modelled the thermal history of the Gordon Group limestone, indicating that if the Gordon Group carbonates are present under the Parmeener Supergroup in south-east Tasmania, then they would fall within the oil and gas windows.

6.2.1.2 Quamby Mudstone, Tasmanite Oil Shale

The Tasmanite Oil Shale occurs as distinct bands towards the base of the Quamby Mudstone Formation and contains abundant algal cyst material of *Tasmanites punctatus* (Revill et al., 1994). The average thickness of the shale is 1.2 m and reaches a maximum of 2.2 m. The Tasmanite Oil Shale has a TOC of up to 25% in the north of Tasmania.

6.2.1.3 Preolenna Coal Seams

The Preolenna coalfield is located 20 km south-west of Wynyard. The coal measures at Preolenna overlie a marine siltstone (Inglis Siltstone and correlates), and are equivalents of the Mersey Coal Measures which are found further east. The Preolenna Coal Measures range in thickness from 220 - 600 mm, dip at 14° - 25°, and are discontinuous (Bacon, 1991). The seams are overlain by the Flowerdale Sandstone, which is a marine sandstone sequence (Bacon, 1991). The coal has kerogens of types II and III, but TOC analyses are not available (Bendall, 1992). The nature of these thin, irregular seams limits their potential as a source. They can be up to 40 m thick in the north of the state, but the area and volume of the seams is uncertain.

Table 6.1 summarises the potential sources in the "Tasmania Basin" relevant to this study. For the development of play models, these sources need to have passed through the oil or gas window in an area where a suitable reservoir exists.

Age	Unit/Formation	Kerogen	TOC Range	Reference
Ordovician	Gordon Limestone	II	0.07-0.23%	O'Leary (1987), Summons (1981)
Permian	Quamby / Woody Island Fm	III	0-3%	Campbell (1992), Denwer (1986)
Permian	Tasmanite Oil Shale	I	15-35%	Denwer (1986), Revill et al.,(1994)
Permian	Liffey / Faulkner Gp	?II, III	?	Bendall (1992)

Table 6.1: characteristics of potential sources in the "Tasmania Basin" (after Woods, 1995).

6.2.3 Reservoir Rocks

6.2.3.1 Gordon Group Carbonates

Reservoir conditions may occur in coral reef sections of the Gordon Limestone, and in areas of secondary (granular) dolomite (Summons, 1981). A palaeokarst topography may also provide areas of high porosity in the limestone (Bendall et al., 1991).

6.2.3.2 Eldon Group

The Eldon Group (Ordovician) overlies the Gordon Group and consists of alternating sequences of shallow marine sandstone and siltstone with minor limestone. The thickness of the sequence ranges from 1800-2300m. The sequence has a high sand to shale ratio, and may be considered a potential reservoir.

6.2.3.3 Liffey/Faulkner Group

The Liffey/Faulkner Group consists of fluvial and coastal sandstone, siltstones and mudstones and can be considered a useful reservoir. The group is about 30 m thick throughout the basin, but units within the sequence have variable thickness, and as a whole there is variation in reservoir character. The reservoir potential of the whole group is higher on the western side away from the axis of the Tiers Fault, away from the . Units 3, 4 and 5 within the group maintain good reservoir potential as far as Bothwell and Granton in the South, although somewhat reduced at Ross and Tunbridge.

6.2.4 Seal Rocks

6.2.4.1 Poatina Group

The Poatina Group is a marine mudstone unit, with minor sandstone units. The Meander Mudstone, at the base, of the Group is 60 m thick in central Tasmania. Mudstone sequences may be a useful seal, as clay and mud occlude porosity and the unit may be relatively impermeable.

6.2.4.2 Jurassic Dolerite

Dolerite intrusions in the Jurassic, provide useful seals for a petroleum play, as in the Paraná Basin, in Brazil (Potter et al., 1995). The dolerite rose through basement rocks into the Parmeener Supergroup, through faults acting as conduits beneath the supergroup (Hergt et al.,1989). Dykes and sills may also provide seals to prevent lateral migration of petroleum. Faults used by or affecting the Jurassic Dolerite may be links in migration paths for source rocks to the Liffey/Faulkner Group. Dolerite is not known to form sills in the group, but does cut across it.

6.3 Paraná Basin

The Paraná Basin is an oval shaped basin which covers 1,600,000 km^2 of southeastern South America, including Brazil, Argentina, Paraguay and Uruguay. The basin covers 600,000 km^2 in southern Brazil. It is a poly history basin, with a continental interior fracture during early deposition from the Silurian to Early Permian, and an interior sag basin from Early Permian to the Cretaceous (França and Potter, 1991). The Permo-Carboniferous Itararé Group and equivalents are the major glacial deposits, and are the most prospective petroleum targets in the basin.

6.3.1 Itararé Group

The Itararé Group is generally subdivided into three depositional cycles. Each cycle is composed of a basal sandy layer covered by a diamictite or silt-to-shale layer (Potter et al., 1995). França and Potter (1991) suggested three major ice advances into the basin in the Carboniferous - Permian. During the first advance terrestrial tillites were deposited. The second, occurred during a minor marine transgression which resulted in interbedded terrestrial and marine deposits later in the second depositional cycle. The last ice advance occurred at the same time as the major Permian transgression. This resulted in turbidites and fossiliferous, varved, dark grey to black shales with dropstones being deposited in the deeper parts of the basin in the south. The glacier movement deposited tillites, and glacial debris flows, in a shallow sea environment, associated with deltaic sandstones, turbidites, and storm deposits (França and Potter, 1991).

Reservoirs are all sandstones, and seals include dolerites, diamictites, and shales (Potter et al.,1995).

6.3.2 Source

The source rocks for the field are black, marine shales of the underlying Devonian Ponta Grossa Formation (Potter et al.,1995).

6.3.3 Reservoirs

Reservoirs are sandstone members of the Itararé Group. There are two major types of sandstone in the group including sandstones deposited by strong currents, containing little or no detrital clay matrix (Rio Segredo and Tarabai Members); and sandstones deposited by weak currents containing abundant detrital clays (Campo Mauro Formation and Cuiabá Paulista Member). Porosity of sandstones in general averages 8% although some average 15%, and 20% near the surface (França and Potter, 1991). This is comparable to the Liffey/Faulkner Group which has an average porosity of 10%(±2%). The four major pore types include: intergranular pores, oversized pores, intraconstituent pores, open fracture pores. Most of the porosity in the sandstones is secondary, after the dissolution of carbonate cement (siderite) and framework grains (França and Potter, 1991). Fractures that develop near dolerite dykes and faults are also important for porosity (Potter et al.,1995). Similar structures may occur in the "Tasmania Basin" such as the Jurassic Dolerite which intrudes the Parmeener Supergroup. The effects on these rocks is uncertain as the thick dolerite sheets hides much of the section.

Tight gas reservoirs have been identified within the sandstone and siltstone sequences. These and other clastic units are considered to be potential producers of economic quantities of gas, where the permeability of the rocks has been significantly improved by fractures (Potter et al., 1995).

6.3.4 Seals

Seals include dolerites, diamictites and shales, which overlie the reservoirs (Potter et al., 1995; Fig. 6.2).

The Paraná Basin is a good analogy for the "Tasmania Basin as it contains similar elements of sources reservoir and seals, and has been subject to dolerite intrusion through the Permian section, thereby suggesting exploration potential for the "Tasmania Basin".

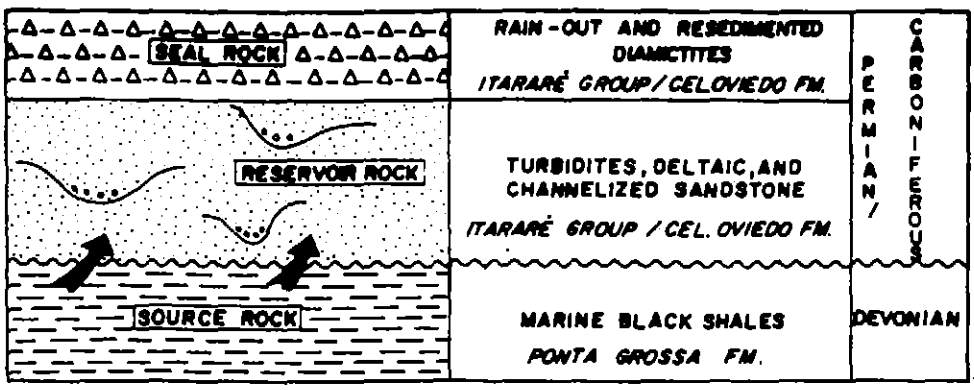

Fig 6.2 : Play summary in Brazil (after Potter et al., 1995)

6.4 Cooper Basin

The Cooper Basin is an intracratonic basin of Permian-Triassic age, which is situated in South-central Australia and covers 127,000 km^2. The sediments in the basin overlie pre-Carboniferous and granitic rocks. The 2 km thick package of sediments are overlain by 3 km of the Jurassic-Cretaceous sequence in the Eromanga Basin. The two main producing formations are the Merrimelia Formation and the overlying Tirrawarra Formation (Potter et al., 1995).

6.4.1 Source

Petroleum sources in the Cooper Basin consist of abundant coal measures with high pyrolysable carbon and total organic carbon content. Geothermal gradients are generally high in the area ranging from 30-60°C/km. Units in the Permian range from mature to over-mature, with some units currently mature for gas generation (Paton and Zwigulis, 1988). Coals in the Patchwarra Formation are considered to be sources for the underlying reservoirs (Potter et al., 1995). It is uncertain, however, if underlying source rocks can or do produce petroleum

6.4.2 Reservoirs

The Tirrawarra Sandstone is the primary reservoir for the field. This sandstone is fluvio-deltaic, averaging 50 m thickness over a large area of the northern part of the Cooper Basin (Paton and Zwigulis, 1988). The Tirrawarra Sandstone is divided into 4 facies associations. These include: siltstone, very fine sandstone and mudstone with marginal isolated porosity (3-5m thick); fine to coarse grained carbonaceous sandstone, mudstone and minor conglomerate with moderate porosity (3-9m thick);

fine to coarse grained sandstone, with minor mudstone, with good porosity and permeability (12-30m thick); fine to coarse sandstone, locally carbonaceous mudstone, conglomerate and coal, with moderate, variable porosity (9-18m thick); (Hamlin et al., 1996). Porosity averages 11.2%, and consists of primary intergranular pores and secondary pores resulting from dissolution (Hamlin et al., 1996). Other reservoirs in the basin include fluvio-deltaic sandstones from the Patchwarra and Toolachee Formation (Paton and Zwigulis, 1988; Fig 6.3).

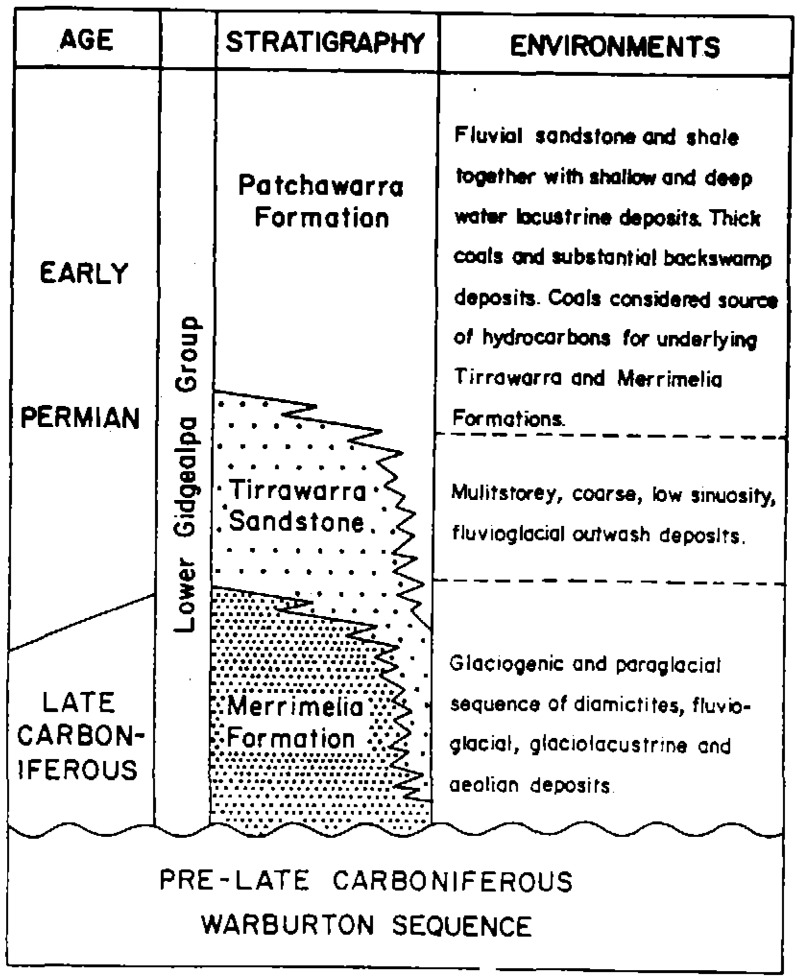

Fig. 6.3 : Stratigraphic section illustrating the relationships between the Merrimelia Formations and the Tirrawarra Sandstone (Potter et al., 1995)

The reservoir units are analogous to the Liffey/Faulkner reservoir of the "Tasmania Basin" with similar pore types and porosity values which are locally variable with similar thicknesses. Underlying rocks of the Tirrawarra Sandstone include up to 300m of diamictites, glaciogenic fluvial sandstones and conglomerates, and lacustrine mudstones (Hamlin et al., 1996). This is comparable to the 500+ m of diamictite and mudstones in the Lower Parmeener Supergroup.

6.4.3 Seals

The seal for the Tirrawarra Sandstone, in the Tirrawarra Field is provided by the basal shales in the Toolachee Formation (Paton and Zwigulis, 1988). This may be analogous to the Poatina Group, a marine unit overlying the Liffey/Faulkner Group in the "Tasmania Basin".

6.5 Oman

Oman is located in the Southern part of the Arabian Peninsula, and oil is produced from glaciogenic deposits. These oil fields have the largest oil reserves in Gondwana deposits worldwide (Potter et al., 1995).

6.5.1 Source

The source is considered to be Late Precambrian, marine algal-rich rocks in the Huqf Group, which is a mixed clastic, continental to marine, carbonate-evaporite sequence (Potter et al., 1995).

6.5.2 Reservoir

Reservoirs are mainly in the Al Khlata Formation and consist of glacial-fluvial, and glacial lacustrine-deltaic sandstones of the Carboniferous. The best reservoirs in this sequence are composed of sandstones, followed by pebbly sandstones. Poor reservoirs include conglomerates, sandstones with some siltstone, claystones and sandy and silty diamictites (Potter et al., 1995). The Al Khlata Formation is over 1,000 m thick and covers an area of at least 160,000 km^2. The formation is divided into 10 different facies, of which facies 2-5 are considered poor-good reservoirs. The consist of pebbly sandstones, sandstones and siltstones. Some of these units are up to 100 m thick.

6.5.3 Seal

Seals are mainly complex structural traps in the Oman oil fields. These include:

- turtle-back anticlines, from inversion of peripheral synclines.
- small anticlines, over Precambrian dolomite and shale masses
- truncated reservoirs along the flanks of anticlines

Although lithologies of reservoir are similar to the units in the Liffey/Faulkner Group these structural style traps in Oman have no "Tasmania Basin" analogue involving the Parmeener Supergroup.

6.6 Summary

Similarities exist between the "Tasmania Basin" and other Gondwana basins such as the Paraná and Cooper Basin. The oil fields in Oman are similar with respect to reservoir types. Table 6.2 summarises the main characteristics of these basins. The "Tasmania Basin" appears to be on a much smaller scale than these known producers, but it contains all the elements of a petroleum play. The "Tasmania Basin" is not completely constrained in the east of Tasmania, and could be considered an intracratonic sub-basin of a larger basin system, when considering the assembled Gondwana continent.

Potter et al., (1995) reviews many Gondwana Basins including the Paraná, Cooper Basins, and fields in Oman, and concludes that there are no, good source rocks associated with high-latitude marine sediments, nor ancient marine shales closely associated with ancient ice sheets. By contrast the Tasmanite Oil Shale in the "Tasmania Basin" occurs at the base of the Quamby Formation, and is a marine shale closely related with an ancient ice sheet. This is a good source rock as it has a high TOC value (25%), and has produced oil (Lonnavale seep; Amdel report, 1996).

The reservoir types are similar throughout the major basins, as are pore types and porosity values .

Seals for the Paraná and Cooper Basins, involve shales and siltstones, as well as dolerite seals (Paraná Basin), which have been suggested in plays for the "Tasmania Basin".

		"Tasmania Basin"	Paraná Basin	Cooper Basin	Oman
Area		40,500 sq. km	600,000 sq. km	127,000 sq. km	160,000 sq km
Basin		intracratonic / rift	intracratonic	intracratonic	intracratonic
Source					
	Lithology	Tasmanite Oil Shale	Devonian black, marine shales	Early Permian coal beds	Late Precambrian, marine algal-rich
	Thickness	2 m	-	-	600m+
	TOC	15-25%	-	-	
Reservoir					
	Lithology	Sandstones	Sandstones	Sandstones	Sandstones
	Environment	Coastal & fluvial (glacigene)	Coastal & fluvial (glacigene)	Coastal & fluvial	glacial-fluvial, and glacial lacustrine
	Thickness	up to 30 m	40 m (some 200 m) thick	averages 30 m	1,000 m
	Porosity	av 10%*	av 8-15%	av 11%	
	Pore Types	Secondary, some primary porosity (fracture?)	Secondary, & fracture porosity	Primary and Secondary	
Seals					
	Types	silts, mudstone, dolerite	dolerite, diamictite, shales	shales	shales, and complex structural traps

Table 6.2 : Summary and comparison of selected Gondwana Basins

Summary and Conclusions 7

7.1 "Tasmania Basin"

The "Tasmania Basin is taken to be the Permian-Triassic cover which extends over central and eastern Tasmania. The sediments of the Lower Parmeener Supergroup are sub-horizontal in the basin which now forms a broadly synclinal area plunging SSE. The Lower Parmeener Supergroup consists of glacio-fluvial and glacial-marine sediments. The "lower freshwater sequence" is of particular interest as it consists of relatively porous fluvial to coastal sandstones which can be considered a prospective reservoir. The Liffey and Faulkner Groups (and equivalents make up this package of dominantly freshwater rocks.

7.2 Liffey/Faulkner Group

The Liffey/Faulkner Group is a prospective reservoir for petroleum, in the lower Permian. The group can be broken up into 7 units from Golden Valley to Granton. These include:

- unit 1: white-grey massive bedded quartz rich sandstone, average thickness of 4.3m with an average porosity of 8.03%.

- unit 2: white-grey sandstone interbedded with dark grey mudstone, with an average thickness of 4.6m

- unit 3: white grey massive bedded sandstone, average thickness of 7.8m, average porosity of 14.3%.

- unit 4: heavily bioturbated, poorly sorted sandstone, that fines upwards to mudstone, averaging 6.2m thick and an average porosity of 15.2%

- unit 5: white-grey massively bedded quartz-rich sandstone, with an average thickness of 10m, an average porosity of 11.3%

- unit 6: white-grey sandstone interbedded with dark grey mudstone, with an average thickness of 2.2m

- unit 7: heavily bioturbated sandstone 3.6 m thick, with an average porosity of 8.1%

The depositional environment involves glacially influenced fluvial, coastal and marine elements. Mudstone was deposited in a proximal marine environment; sandstones, in a coastal setting, with some fluvial influence; and an area of tidal mixed flats where mudstone and sandstone are interbedded.

Porosity of the whole group averages 10.9 %. The main pore types include intergranular pores and intragranular pores. The intergranular pores may be occluded by quartz overgrowths, silica or carbonate cementation and authigenic clay. Intragranular pores are developed by dissolution by such minerals as feldspar and can be occluded by cementation or clay.

The Liffey/Faulkner Group is a prospective reservoir with units 1, 3, 4, 5, being good reservoir units.

7.3 Exploration for Petroleum in the "Tasmania Basin"

Comparison with other known producing fields especially the Paraná Basin offers hope for petroleum exploration in Tasmania. The Paraná Basin contains similar reservoir rocks of comparable thickness and variation, in a similar setting to the "Tasmania Basin", with dolerite intruding the sequence. More research into the nature of faults and fractures associated with the dolerite intrusions in Tasmania, would further constrain petroleum migration paths and seals, and define more prospective areas of hydrocarbon occurrences from those areas of which hydrocarbons are absent

More seismic sections across the basin are required to define the structural influences on the Liffey/Faulkner Group. The group is a reflective horizon as it is of sufficient thickness, and has different character to the marine sediments above and below (Leaman pers comm., 1996). Seismic work will determine if the group is structurally continuous as well as lithologically continuous. Further drilling of areas in around the Tiers Fault, (with seismic sections), would be useful in defining the reservoir potential in the deeper parts of the basin. The Liffey/Faulkner Group is constrained south of Hobart, and further study of this type of characterisation would help to define the bounds of this reservoir and of the "Tasmania Basin".

7.4 Conclusions

The Liffey/Faulkner Group is a prospective reservoir in the "Tasmania Basin". The group can be divided into 7 units, which are variable in their reservoir character, and are lithologically continuous. More research into the structure of the group, and migration pathways for petroleum is required to determine where petroleum may be stored in this reservoir.

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Appendix 1 *Porosity Permeability*

1. SAMPLE PREPARATION

A. The samples were cleaned by Soxhlet extraction using an azeotrope of Chloroform and Methanal. When the solvent in the Soxhlet chamber tested negative for salt (using $AgNo_3$) the samples were removed and dried in a humidity oven at 50°C/50% relative humidity.

B. The samples were then mounted in Epoxy Resin.

2. HELIUM INJECTION POROSITY

The helium injection porosity of both horizontal and vertical plugs was determined as follows. The sample was sealed in a matrix cup and a known volume of helium at 100 psi reference pressure introduced to the cup. From the resultant pressure the unknown volume i.e. the grain volume was calculated using Boyles Law where $P_1 V_1 = P_2 V_2$.

The bulk volume of the samples was determined by mercury immersion. The difference between the grain volume and the bulk volume is the pore volume and from this the porosity is calculated as the volume percentage of pore space with respect to the bulk volume. The porosity calculated using this technique is an effective porosity.

$$\text{Pore Volume} + \text{Grain Volume} = \text{Bulk Volume}$$

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Bulk Volume}}$$

3. AIR PERMEABILITY

Air permeability was determined on the resin-mounted plugs (horizontal and vertical). The plugs are placed in a Hassler cell at a confining pressure of 250 psig (1720 kPa). This pressure is used to prevent bypassing of air around the sample when the measurement is made.

During the measurement a known air pressure is applied to the upstream face of the sample, creating air flow through the sample. Permeability for each sample is then calculated using Darcy's Law through the knowledge of the upstream pressure and flow rate during the test, the viscosity of air and the plug dimensions.

ACS LABORATORIES PTY. LTD.
ACN: 008-273-005
Petroleum Reservoir Engineering Data

CORE ANALYSIS FINAL REPORT

Company	: University of Tasmania	Date	: 09/02/96
Well	:	File	: 2-234
Field		Location	:
Core Int.	:	ACS Lab	: 002-Brisbane
Core Int.		Analyst	: IJM
Core Int.			

Sample Number	Depth	Dir	Porosity % He Inj	Porosity % Roll Φ	Density ND	Density GD	Permeability (mD) Ka	Permeability (mD) Roll Ka	Remarks
1			3.7			2.65	< 0.01		
2			9.5			2.67	< 0.01		
3			6.1			2.65	< 0.01		
4			10.2			2.64	0.19		
5			5.7			2.64	< 0.01		

Appendix 2 *XRD*

TASMANIA DEVELOPMENT AND RESOURCES

Mineral Resources Tasmania

Client: B. Maynard
Sample Location: "Tasmania Basin"
Analysis: Approximate Mineralogy
Method: X-Ray Diffraction

Results (approx wt %)

Sample	*>80%*	*65%-80%*	*15%-65%*	*10%-15%*	*5%-10%*	*2%-5%*	*<2%*
T3		Quartz			Plagioclase, Mica	Chlorite, Kaolinite, Clay[1]	?Pyrite
T5		Quartz			Plagioclase	Mica, Chlorite, Kaolinite, Clay[1]	K-Feldspar
T7		Quartz			Plagioclase	Chlorite, Mica, Pyrite	K-Feldapar, Jarosite, ?Smectite
GV1		Quartz			Mica, Plagioclase, K-Feldspar	Clay[1]	
GV6	Quartz				K-Feldspar, Plagioclase	Mica	
GV7		Quartz			Plagioclase	Mica, K-Feldspar, Clay[1]	Chlorite, Jarosite, ?Pyrite, ?Zeolite
R7		Quartz		Plagioclase	Clay[1]	Mica, K-Feldspar	Gypsum, Chlorite, Jarosite, Pyrite
R9		Quartz			Plagioclase	Clay[1], Mica, Chlorite	Jarosite, Pyrite, K-Feldspar, Gypsum
B677		Quartz			Kaolinite[2]	Mica, Siderite, K-Feldspar	?Pyrite
B679.70		Quartz			Kaolinite[2]	Mica	K-Feldspar, Siderite
B688		Quartz			Mica, Kaolinite[2]		K-Feldspar, Siderite
B695		Quartz		Kaolinite[2]	Siderite	Mica	Calcite, K-Feldspar, ?Pyrite
GL249	Quartz				Plagioclase		Mica, K-Feldspar, Chlorite, Jarosite, ?Pyrite
GL3221	Quartz				*Plagioclase*	*Chlorite, Calcite, Mica*	*K-Feldspar, Kaolinite, ?Pyrite*
P50055		Quartz		Plagioclase	Calcite	Mica	Chlorite, K-Feldspar

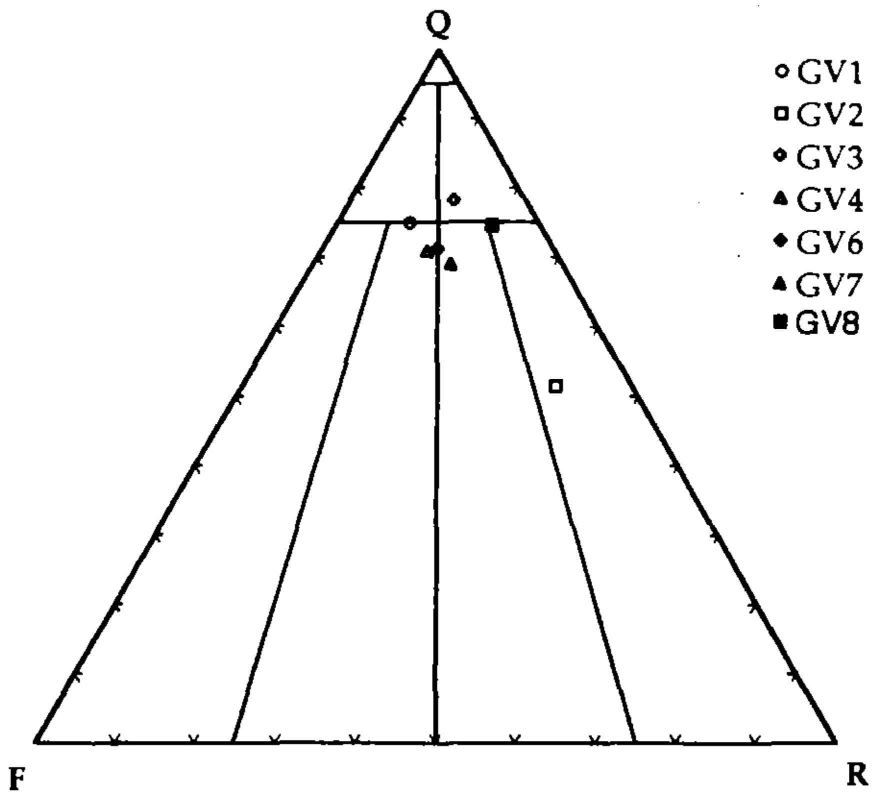
[1] probably mixed layer Mica-Smectite
[2] possibly Dickite

Peak overlap may interfere with identifications (e.g. in very low concentrations, Pyrite and Hematite can be difficult to distinguish).
Minerals present in trace amounts, or amorphous minerals, may not be detected.

R N Woolley

Analyst: R.N. Woolley

Appendix 3 Folk Classification



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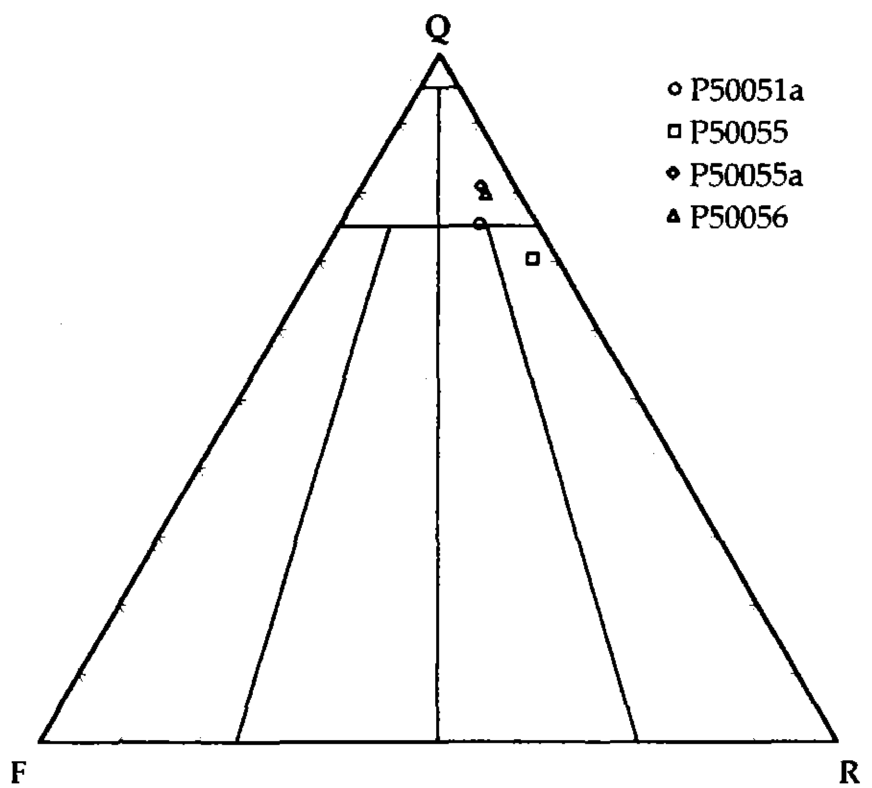
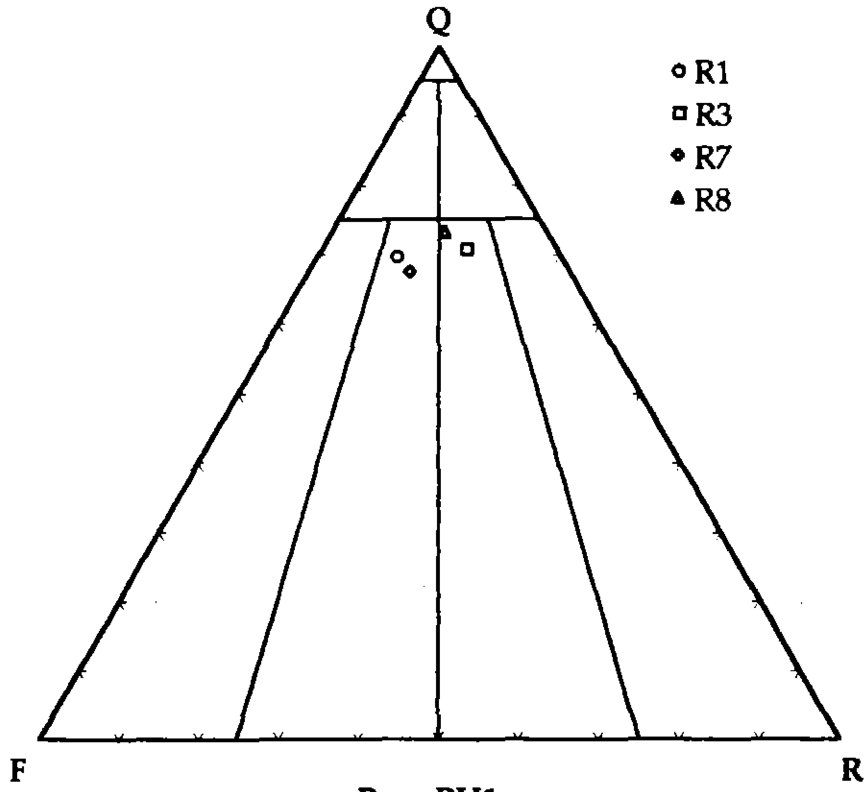
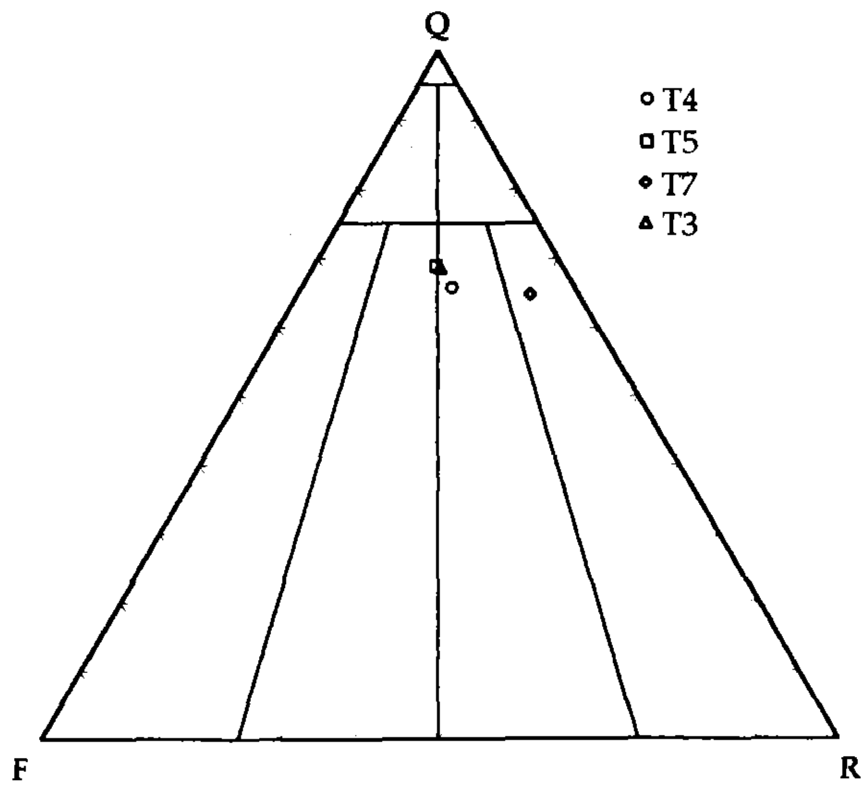


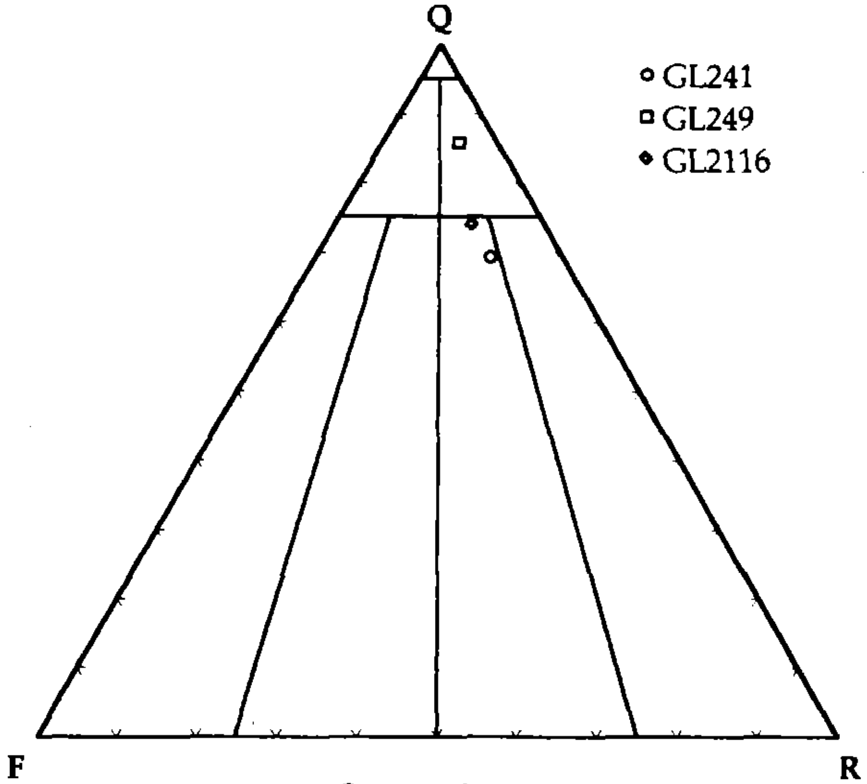
Poatina 5005



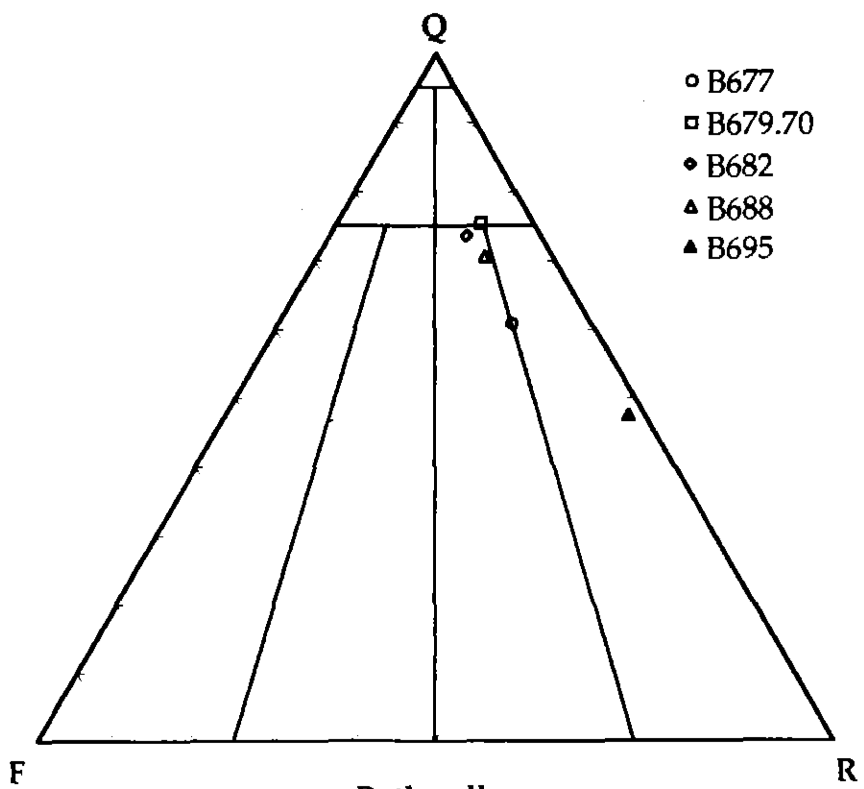
Ross BH1



Tunbridge Section



Great Lake 5113



Bothwell