FACIES INTERPRETATION AND DIAGENESIS OF THE COSSIGNY MEMBER, BEAGLE SUB-BASIN NORTH WEST SHELF, WESTERN AUSTRALIA

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STATEMENT OF AUTHENTICITY

To the best of my knowledge and belief this thesis contains no material which has been accepted for the award of any other degree or diploma in any University, nor does it contain any material previously published or written by another person, except where due reference is made in text.

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ABSTRACT

The Triassic reef complexes of the North West Shelf represent a new exploration play involving reservoirs in the reefs themselves or within associated carbonate platforms. The Triassic carbonates are found in number of exploration wells on the North West Shelf, the most notable occurrences are shelf carbonates of the Outer Bonaparte Basin (Mory, 1988), the Outer Browse Basin (Willis, 1988), on the Exmouth Plateau (Barber, 1988) and Timor (Audly-Charles, 1968). In the Northern Carnarvon Basin a 100-140 meter thick carbonate unit of Ladinian age known as Cossigny Member was intersected by wells Phoenix-1, Phoenix-2 and Cossigny-1. The Cossigny Member represents the only significant carbonate deposition in the study area, and was deposited in shallow water conditions on a broad gently sloping shelf, similar to the modern day Persian Gulf.

The Cossigny Member represents a transgressive then a regressive sequence and was deposited as a result of a brief marine transgression during the Ladinian times (Blevin et al 1993, Bradshaw et al., 1988). Detailed sedimentological descriptions and thin section studies of the Cossigny Member reveal three characteristic lithofacies. Each carbonate lithofacies is distinguished by a dominant lithology or association of lithologies. XRD analysis and staining of the selected samples allowed the identification of mineralogy. At the base of the Member in Phoenix-2 well, which represents all of the lithofacies, is an oolitic grainstone facies. This facies is composed of well sorted, well rounded, medium to coarse grained oolites deposited within a moderate to high energy ooid shoal. The ooids show a radial-concentric fabric (Heller et al. 1980) that reflects a calcitic or Mg calcitic precursor. The absence of abundant oolites in the shoreward wells of Phoenix-1 and Cossigny-1 indicates that this facies did not extend shoreward. Oolitic grainstone facies is overlain by a mixed-ooid-peloid grainstone facies; in Phoenix-1 and Phoenix-2 this represents a transitional zone between the ooid grainstone facies and the overlying low-energy lagoonal facies. This facies consist of peloids, pellets, ooids and bioclasts. Ooids generally constitute a smaller percentage of the framework grains and show a heterogeneous fabric. The mixed-ooid-peloid grainstone facies grades upwards into a muddy peloidal wackestone facies. This facies dominantly consist of faecal pellets and peloids. The petrographic characteristics and the presence of miliolid foraminifera indicate that this facies was probably deposited in a quite water lagoonal environment.

The Cossigny Member carbonates show several phases of diagenesis. Micritization is dominant in the muddy peloidal wackestone facies, most of the grains in the mixed facies are also micritized. An early marine cementation of the sediments created a rigid frame work and thus, prevented grain to grain compaction. The marine cement is seen as bladed crystals growing perpendicular to the substrate. In most cases it envelops the early micritic cement. The last generation of cement is equant spar that fills the rest of the pore spaces. The crystal size of the spar increases towards the centre and was probably deposited in meteoric phreatic environment. The upper part of the lagoonal facies is dominantly dolomitized. Dolomite crystals have replaced constituent grains as well as the cement. Dolomites were probably formed by the subsurface mixing of sea water and meteoric water Hanshaw et at al., (1971).

The Cossigny Member carbonates represent an excellent seismic horizon. Due to the wide spacing of the wells in the Beagle Sub-basin the seismic correlation of the Member was necessary. To assist in the stratigraphic interpretation and correlation, two other horizons Main Unconformity (Seismic Green Horizon) and top Bedout Formation (Seismic Blue Horizon) were tentatively carried (where present) throughout most of the selected seismic data.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

(List of figures and tables continued)

CHAPTER 1

INTRODUCTION

1.1. REGIONAL SETTING

The Beagle Sub-basin lies entirely off-shore, to the north of the Precambrian Pilbara Block (Fig. 1.2). The sub-basin trends northeast over a distance of 150 to 200 km., with maximum basin width exceeding 150 km (Halse, 1973). The total area of the sub-basin, including basin margins is more than 34 000 sq. km. Sediments encountered in drilling to date have ranged in age from Triassic to Pleistocene. Palaeozoic sediments are also considered to be present but as yet have not been intersected (Halse, 1973).

To the north-east the Beagle Sub-basin trends away into deeper water towards the present day shelf edge, eventually merging with the Rowley Sub-basin of the off-shore Canning Basin.

The Bedout Sub-basin lies to the northeast of the Beagle Sub-basin and is separated from the Beagle Sub-basin by the North Turtle Hinge (Fig. 1.1). The Bedout Sub-basin covers an area of approximately 25 000 sq. km.

The Beagle Sub-basin is regarded as the northern part of the Carnarvon Basin (Halse, 1973; Powell, 1976; Crostella and Barter, 1980). However, Playford et al., (1974) preferred to consider it as part of the Canning Basin, and some workers still adhere to this view. The Beagle Sub-basin may be considered as forming a "bridge" between the Northern Carnarvon Basin and the off-shore Canning Basin.

In the interest of clarity, the geology of the two basins has been unified in this thesis. The Beagle Sub-basin is a transitional area between the Northern Carnarvon Basin and the off-shore Canning Basin, containing the structural elements common to both.

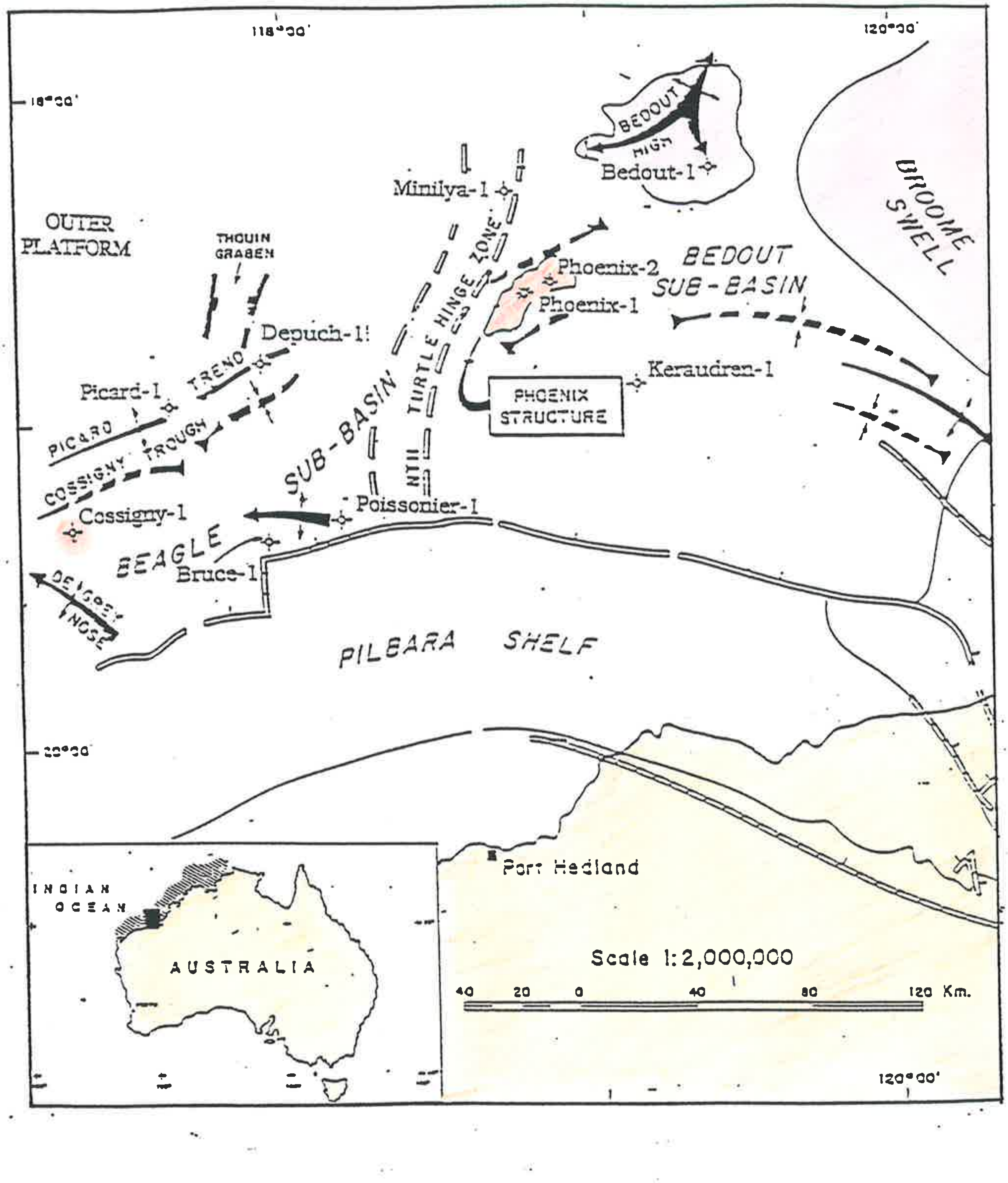


Figure 1.1- Location map of the Beagle and Bedout Sub-basins, map also shows well locations and structural elements. Hachured pattern shows approximate limits of the North WestShelf.

1.2. AIMS AND OBJECTIVES

A carbonate unit of Middle Triassic (Ingram, 1990; Halse 1973) referred to as the Cossigny Member was intersected by wells Cossigny-1 in the Beagle Sub-basin, and in Phoenix-1 and Phoenix-2 in Bedout Sub-basin. In view of the widespread distribution of the member in the off-shore Canning Basin and Northern Carnarvon Basin, this study was undertaken to establish the nature and possible origin of this unit. Carbonate petrography of the samples from the above three wells was sought to identify or discount reef affinities of the Cossigny Member.

The Triassic carbonates were encountered in number of exploration wells on the North West Shelf. The most notable occurrences of shelf carbonates occur in the outer Bonaparte Basin (Mory, 1988), the outer Browse Basin (Willis, 1988), the Exmouth Plateau (Barber, 1988) and Timor (Audly-Charles, 1968), together with those in the Northern Carnarvon Basin (Crostella and Barter, 1980, Halse, 1973). The Triassic reef complexes of the North West Shelf represent a new exploration play involving reservoirs in the reefs themselves or within associated carbonate platforms. At this stage reef complexes are known only from the Wombat Plateau on the North Exmouth Plateau (Fig. 1.2).

1.3. PREVIOUS LITERATURE

The Beagle and Bedout Sub-basins have not been described in detail. The first individual paper on the regional geology of the Beagle Sub-basin was written by Halse (1973).

The regional reports on the sub-basin which also include the Northern Carnarvon basin were first published by Condit (1935), Condit at al., (1936) and Raggatt (1936), and resulted from an initial phase of hydrocarbon exploration in the onshore portion of the basin. The stratigraphy of the basin was set out by Condon (1954), McWhae et al.,(1958) and Playford et al., (1974), and was later published by the BMR (Bureau of Mineral Resources) in a three part bulletin. In 1987 Hocking et al., (of Geological Survey of Western Australia) published a bulletin on the Carnarvon Basin. In 1988 a symposium in

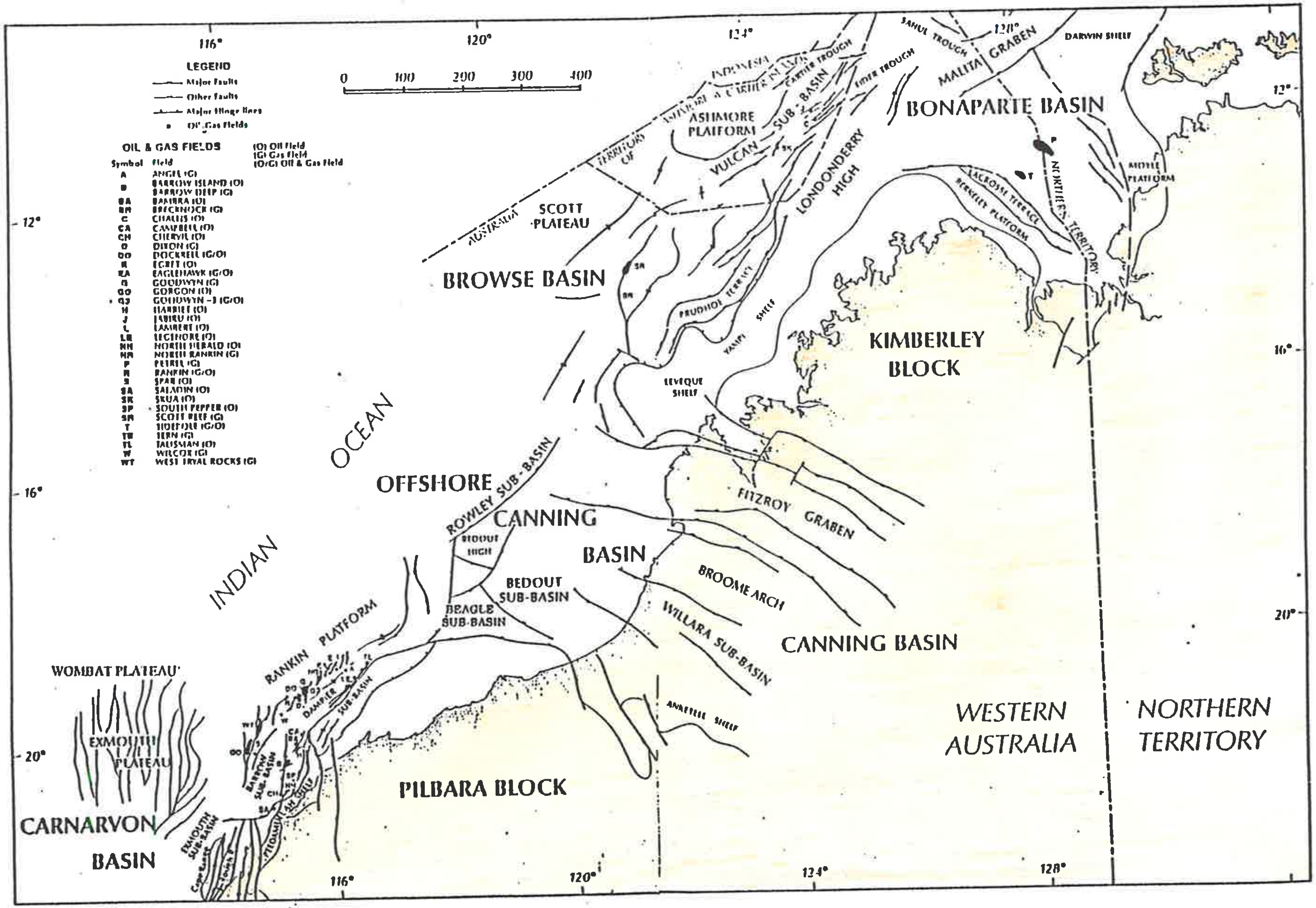


Figure 1.2- Map showing various sub-basins of the North West Shelf and their tectonic elements.

Perth was held by the Petroleum Society of Australia on the North West Shelf. The aim of the symposium was to develop a current and comprehensive summary of the geology and petroleum potential of the North West Shelf. The proceedings of this symposium culminated in a publication edited by P.G. Purcell and R.R. Purcell.

1.4. EXPLORATION HISTORY OF THE NORTHERN CARNARVON BASIN

The first off-shore seismic work on the North West Shelf was carried out by West Australian Petroleum (WAPET) in 1961.

In 1965 the Burmah Oil Company of Australia Ltd.(BOCAL) carried out the first seismic survey in the Beagle Sub-basin. In addition the Bureau of Mineral Resources conducted a regional survey in 1968. Drilling for hydrocarbons in the study area commenced in 1969. In 1971 Burmah Oil Company of Australia (now Woodside Off-shore Petroleum Pty Ltd) drilled the North Rankin-1 discovering the North Rankin Gas field. Since then, several smaller fields, including South Pepper, Harriet, Tubridgi, Saladin, Talisman, and Rosette have been discovered. Broad geological reviews which were based on the results from wells drilled for petroleum exploration were made by Thomas and Smith (1974), Powell (1976), Parry and Smith (1988) and Woodside Off-shore Petroleum (1988).

Phoenix-1 was drilled on 22nd March, 1980 on Phoenix Structure (Fig. 1.1). The Phoenix structure is a large northeast trending, elongate anticline which is transacted by a series of north northeast trending normal faults, downthrown to the west. Middle to Late Triassic sandstones formed the primary objectives. A secondary objective was sandstones of late Middle Jurassic age directly below the Main Unconformity (Jc). The Cossigny Member in this well extends from 3650 to 3786 meters. No core was taken for that interval. Phoenix-1 was suspended without testing when it was considered unsafe to continue operations with the available pressure-control equipment. The sandstones were found to be dry.

Phoenix-2 was drilled as an exploration well on 10th March, 1982. The well was drilled on a fault-block forming part of the Phoenix structure (Fig. 1.1) to test presence of hydrocarbons, within Triassic sandstones of the Lower Keraudren Formation. The objective sandstones were found to be of significantly lower permeability than where penetrated in Phoenix-1, with hydrocarbon saturation correspondingly very low. The sandstones had no commercial hydrocarbon flows. No production testing was therefore carried out. The well was plugged and abandoned on 15th June, 1982. The Cossigny Member was penetrated between 3575 and 3700 meters.

Cossigny-1 was an exploratory well located on a large east-west oriented faulted-induced structure situated on the southern margin of the Beagle Sub-basin (Fig. 1.1), adjacent to the northeast flank of the De grey Nose. The well reached total depth at 3203 meters. No significant hydrocarbon shows were recorded. The Cossigny Member in this well extends between 2855 and 2935 meters.

1.5. METHODS OF STUDY AND SAMPLE PREPARATION

1.5.1. Thin Sections

Ditch cutting samples from three wells Cossigny-1, Phoenix-1 and Phoenix-2 were prepared as thin sections for microscopic studies (see Appendix I for sample list). All samples were tagged for depth. Thin sections were made by first placing the grain samples in a mould filled with an embedding resin (Araldite). The mould was then placed in a pressurised oven to eliminate air bubbles and allow the samples to set in the resin. Thin sections 0.03 mm thick were cut from the each mould. Half of each section was stained in a solution of Alizarin Red S and potassium ferricyanide, the staining method is described in Appendix II (Dickson, 1966) to differentiate the mineralogy of the various carbonate grains.

1.5.2. X-Ray Diffraction

To determine bulk mineralogy by X-ray diffraction (XRD), samples were hand ground in acetone and fluorite (used as standard) and made into a slurry. This slurry was smeared on a glass slide and run from 3 to 75 degrees 2 theta at 4 degrees per minute, using Co k radiation, 50 KV and 35 m A on a Philips PW 1050 diffractometer.

The resulting traces were studied to determine the bulk mineralogy by using CSIRO "X-PLOT" program. The results of these analyses are shown in figures 4.3 to 4.6. in chapter 4.

1.5.3. Wireline Logs

Wireline logs from Cossigny-1, Phoenix-1 and Phoenix-2 were tied to the rock data from ditch cuttings and lithology descriptions from well completion reports to interpret the depositional environment for different rock facies of the Triassic in the Beagle and Bedout Sub-basins. Wireline logs are extensively used in subsurface facies analysis (Selley, 1978; Pirson 1977). Log responses are a function of lithology, porosity, fluid content and textural variations within formations. Specific depositional environments frequently exhibit a characteristic sequence of depositional energies which result in characteristic profiles of lithology and sorting, thus giving characteristic log motifs. Figure 3.3 in chapter 3 shows different curve shapes with their likely depositional environment.

1.5.4. Geophysics

A large volume of seismic data has been shot over the Northern Carnarvon Basin. These surveys date from 1967 and are essentially of random orientation.

The overall quality of the data is generally good on the recent surveys and poor to fair on the older surveys. Reprocessing of some of the older data greatly enhances seismic quality. Correlation of seismic events was made difficult by misties between different vintages of data. In this case, bulk shifts of up to 30 ms were necessary to tie horizons. In a few instances, it was impossible to correlate some reflectors due to the poor quality of the data, but this was more the expectation than the rule. Despite misties and profile data quality, it was still possible to correlate a high amplitude reflector which is representative of the Cossigny Member across the Beagle and Bedout Sub-basins.

CHAPTER 2

REGIONAL GEOLOGY

2.1. BASIN DEVELOPMENT

The North West Shelf of Australia was formed by a series of major tectonic episodes that began in the late Paleozoic and continued into the Cretaceous. These episodes were also responsible for the breakup of Gondwanaland and the formation of the Indian Ocean (Hocking, 1988; Butcher, 1987; Bradshaw, 1988).

Geologically, the Carnarvon Basin was formed as one of the several epicontinental basins and sub-basins created by predominantly extensional tectonism in the North West Shelf region.

The structural development of the basin can be divided into three stages (Hocking, 1988) Fig. 2.1. The first stage extends from the Silurian to the Late Permian; the second from Late Permian to the Cretaceous; and the third from Late Cretaceous to the present day.

2.1.1. Stage 1

The first stage is preserved only in the Palaeozoic sub-basins. Palaeozoic sediments have not been penetrated in the Beagle Sub-basin but are believed to be present (Halse, 1973) and so stage 1 is discussed briefly.

The Carnarvon Basin initially developed as an interior fracture basin during an episode of rifting in the Late Ordovician or earliest Silurian (Hocking, 1987). In the Early Devonian, it evolved to an interior sag-basin, and remained so until the Late Permian (Fig. 2.1). The first stage of the development is referred to as the "failed arms" stage by Veevers et al. (1984) and Veevers (1988).

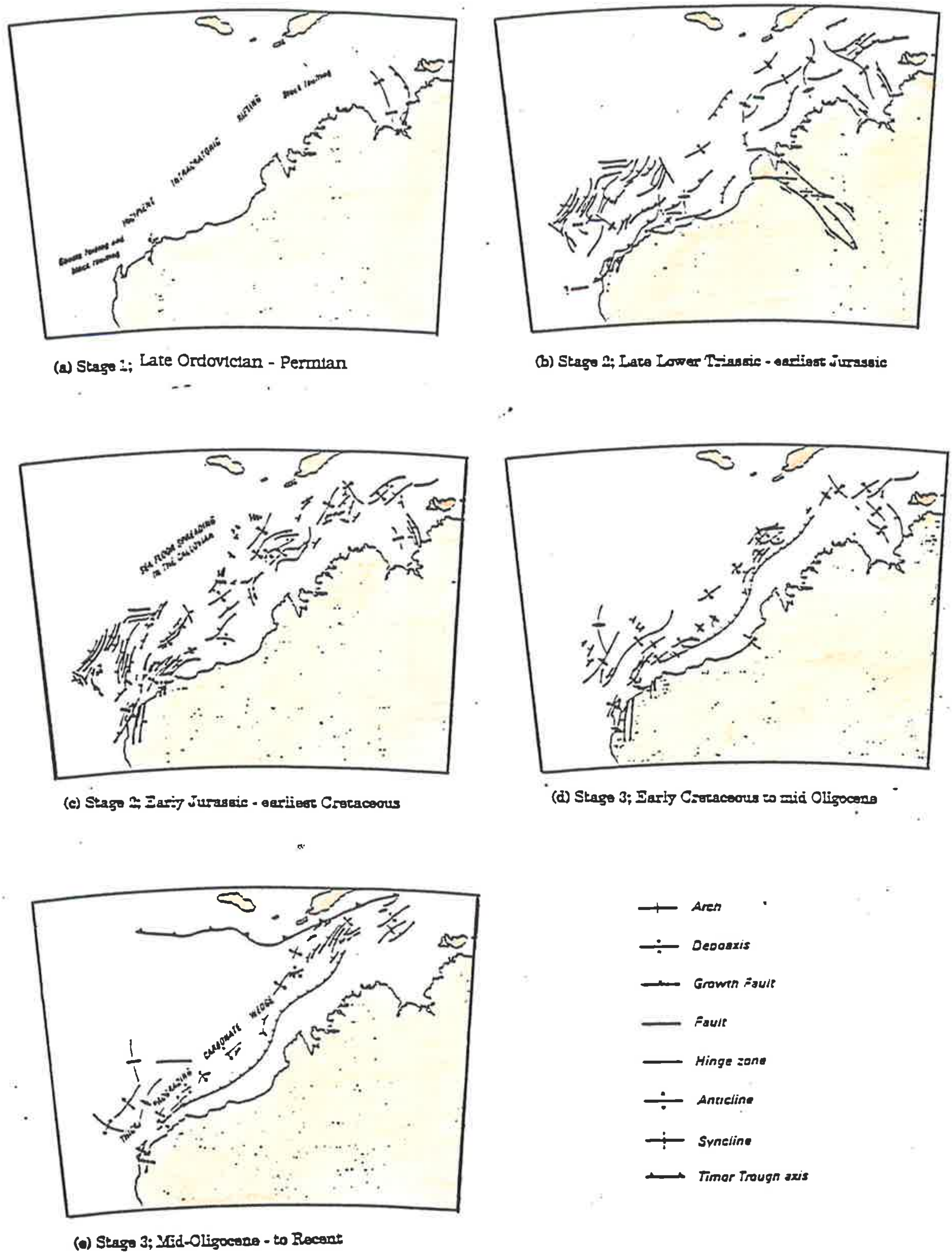


Figure 2.1- Structural history beneath the North West Shelf region: a) incipientGondwana rifting and block faulting in the permian; b) Mid Triassic to Early Jurassic growth faulting and hinge zone development, and Late Triassic to Early Jurassic block fauling (Exmouth Plateau Arch) and wrench movements (Canning Basin); c) Jurassic to earliest Cretaceous growth faulting nd subsidence, block faulting (Exmouth Plateau Arch) and the beginning of seafloor spreading; d) continued subsidence controlled by a hinge zone as the Indian Ocean continued to deepen in the Cretaceous, and e) the development of progradational carbonate wedges with further deepening of the Indian Ocean in the Cainozoic (after Bradshawet al. 1988).

2.1.2. Stage 2

During the Triassic a reorientation of the basin occurred and a series of northeasterly Mesozoic sub-basins developed along the northwestern margin of Australia (Butcher, 1987) (Fig. 2.1). The post-Palaeozoic evolution of the North West Shelf has been dominated by the Callovian episode of continental breakup which resulted in the formation of the Indian Ocean and breakup of Gondwanaland. The Mesozoic sub-basins underwent subsidence and downwarping in the Triassic, followed by growth faulting and further subsidence during the Jurassic (Fig. 2.1). The subsidence and faulting continued after breakup. Palaeozoic depocentres to the south underwent tectonic uplift and subsequent erosion. Further north, the Rankin Platform was exposed but, elsewhere, there was marine shale deposition (Kopsen and McGann, 1985).

In the final part of the second stage, sea level rose from the north and drowned the Carnarvon Basin. This was the first time that the Carnarvon Basin could be regarded as a trailing edge basin, although deposition was still dominated by siliciclastic sediments (Hocking, 1987).

2.1.3. Stage 3

The Third stage of the basin started from Cretaceous and continues till Recent. This stage is taken as starting when oceanic circulation-patterns changed in the Late Cretaceous, and calcareous pelagic deposition began. The basin was then a "trailing edge" marginal-sag basin which was opened to the north into unrestricted ocean (Hocking, 1988). In the Cainozoic there was a development of progradational wedges with further deepening of the Indian Ocean (Bradshaw et al., 1988)

2.2. PALAEOGEOGRAPHIC EVOLUTION OF THE NORTHERN CARNARVON BASIN

The palaeographical evolution of the Northern Carnarvon Basin reflects a history of changing tectonic regime, climate, and sea level. Since the late Palaeozoic there has been a progression from intracratonic rift to passive margin with a late phase of collision, paralleled by a shift in climatic regime from glacial conditions in the Permian to the tropical seas of today (Bradshaw et al., 1988).

The Carnarvon Basin was the site of shallow marine deposition from the mid-Silurian to the Late Carboniferous, with hiatuses during the Early Devonian and mid Carboniferous. However, pre-Permian sediments have only been intersected onshore and close inshore.

2.2.1. PRE-MESOZOIC

The oldest rocks yet penetrated in the Northern Carnarvon Basin are of Permian and possibly Late Carboniferous age. The Late Carboniferous-Permian interval contains two subsequences (Hocking, 1988). The first subsequence encompasses the glaciogenic Lyons Group which contains a wide range of siliciclastic lithofacies with minor calcareous sediments (Fig. 2.2).

The second subsequence is made-up of Wooramel, Byro and Kennedy Groups. These are dominantly sandy or shaly sequences containing only minor carbonate intercalations (Fig. 2.3).

The Wooramel Group is sandstone-dominated, locally thick siltstone and limestone sequences are also present. This Group formed in fluvio-deltaic and shallow marine environments. The overlying Byro Group is dominated by interbedded siltstone and shale with some sandstones. The Byro Group was deposited on a periodically subsiding, storm influenced marine shelf. The Kennedy Group is similar to, but sandier than, the Byro Group.

ROCK TYPES

- Limestone
- Dolomite
- Marl
- Salt
- Shale, Siltstone
- Sandstone
- Conglomerate
- Tillite (glacigene)
- Coal

ENVIRONMENTS

- Not interpreted
- ND- Non-deposition / erosion

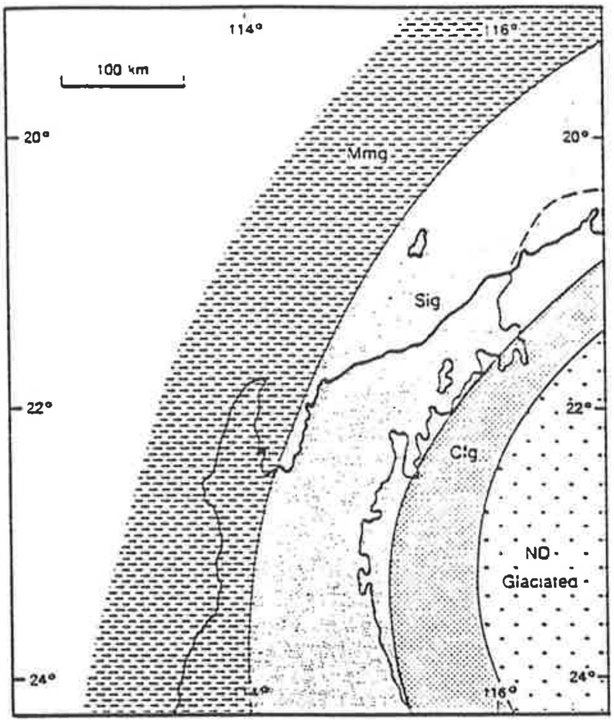
CONTINENTAL
- Ca alluvial fan
- Cf fluvial

SHORELINE
- Sd deltaic
- Si paralic; intercalated, continental and marine

SHALLOW MARINE
- Ml fine clastic shelf
- Ms course clastic shelf
- Mc carbonate shelf
- Mm mixed shelf

DEEP MARINE
- Dm Outer shelf and slope, clastic and carbonate

Key to Palaeogegraphy Diagrams



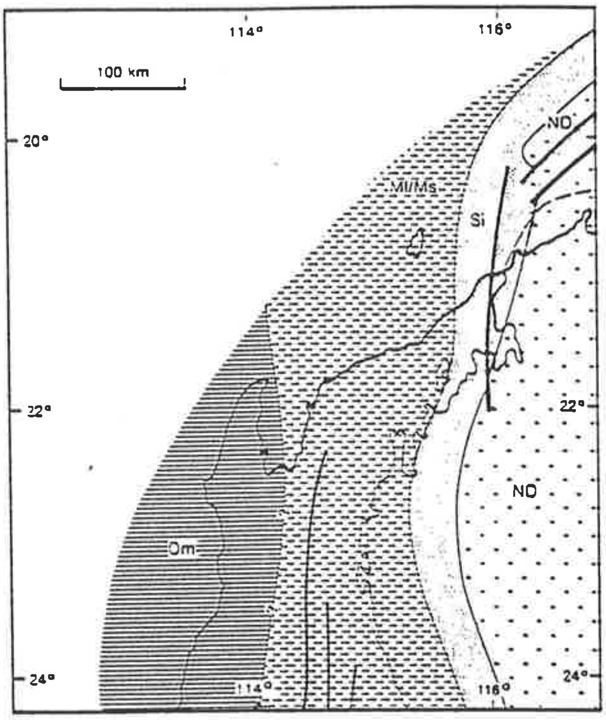
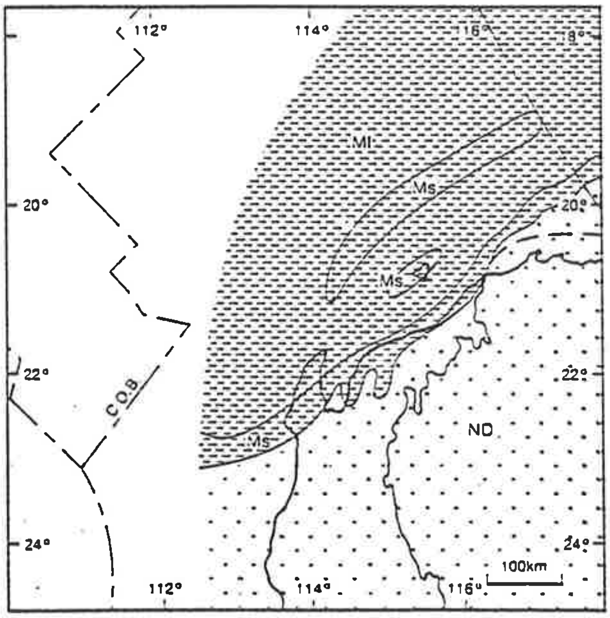


Figure 2.2.-- Palaeogeography and intersections, Early Permian - Lyons Group (after Hocking, 1988).

Figure 2.3.-- Palaeogeography and intersections, late Early Permian - Byro Group, lower Kennedy Group, Wooramel Group and equivalents (after Hocking, 1988).



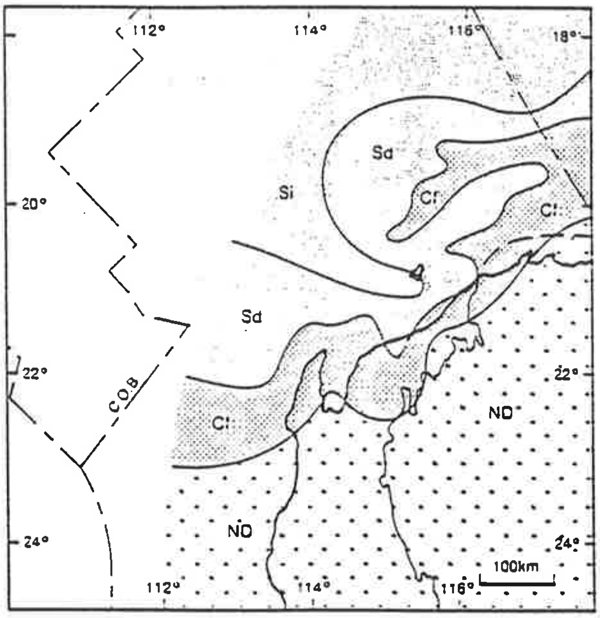


Figure 2.4.-- Palaeogeography, Early Triassic - Locker Shale (after Hocking, 1988).

Figure 2.5.- Palaeogeography, Late Triassic - Mungarro Formation(After Hocking, 1988).

2.2.2. TRIASSIC

2.2.2.1. Early and Middle Triassic

Triassic strata are distributed across the entire North West Shelf region, and extend onshore into the Fitzroy Graben and Wallal Embayment of the Canning Basin, the eastern edge of the Bonaparte Basin and northeastern Carnarvon Basin (Fig. 1.2). Triassic depocentres are controlled by major faults and hinge zones, and are arranged along a northeast trend. The facies show a complete cycle from marine transgression in the early Triassic, through regression in the Middle Triassic, to a period of coastal onlap in the Late Triassic. Early Triassic was a time of maximum marine inundation. The basal marine shale is overlain by prograding fluvio-deltaic sediments. Limestones form very minor intercalations in early part but are more significant in the Late Triassic sequence in the far northwest of the region.

The reconstructed environments (Fig. 2.6) show almost the entire North West Shelf region covered by a shallow sea. The absence of widespread Lower Triassic paralic deposits, and the local occurrence of basal sandstones and carbonates suggests that the transgression occurred rapidly. It drowned coastal environments as it lapped on to the palaeoshelf, and created estuaries inshore along northwest-trending embayments of the Canning and Bonaparte Basins.

The remarkably uniform shaly facies deposited over the entire region comprises: the Mount Goodwin Formation of the Bonaparte Basin (Hughes, 1978); a postulated equivalent in the Browse Basin; the Blina Shale in the Canning Basin (Yeates et al., 1984), and its equivalent in the adjoining "unnamed basinal elements" (Gorter, 1978);- These shale units are of the order of 200-(?)1000m thick throughout the region. The known units all share the same fauna (Dickins et al., 1972) and the same impoverished microflora (Dolby and Balme, 1976).

In the Northern Carnarvon Basin, the Locker Shale (Fig. 2.4) was deposited unconformably over Permian and older rocks (Crostella and Barter, 1980). Table 2.10 shows a generalised stratigraphic column for the Beagle and Bedout Sub-basins. The Locker Shale consists of a thick, entirely marine section of interbedded claystone and minor siltstone. In most cases a thin basal limestone is present, which in rare cases changes facies into a sandstone. The climax of the transgression apparently was reached late in the Scythian. The Locker Shale is organic rich and considered to be a source rock for hydrocarbons in the basin (Thomas, 1979).

A regression commenced in the late Early Triassic, and culminated in Middle Triassic (Bradshaw et. al, 1988), when land may have been present above the Ashmore and Sahul platforms and Seringapatam Rise. Inshore, dominantly paralic environments included deltaic and fluvial facies except where substantial growth faulting (eg., along the Flinders and Sholl Islands fault system) caused sufficient subsidence to exceed sediment input. The regression has been well documented in the region of the Canning Basin by Gorter(1978).

Following the regression, there was a time of relative coastal onlap in the region during the latest Middle and Late Triassic. The ensuing transgression was not nearly as extensive as that in the Early Triassic. In the Beagle and Bedout Sub-basins Cossigny Member was deposited as the result of this minor marine incursion. This incursion was more gradual too, allowing substantial fluvio-deltaic systems, up to several kilometres in thickness, to form over the southern half of the North West Shelf region. These sediments became important reservoirs for gas and condensate particularly on the Rankin Platform (Campbell and Smith, 1982).

This interbedded sequence of quartz sandstones, siltstone-shale and coal units is known as the Mungaroo Formation (Fig. 2.5) in the Carnarvon Basin. In Bedout Sub-basin Keraudren Formation corresponds to the Mungaroo Formation (Hocking et al., 1987). In the Bonaparte Basin the equivalent unit is the Sahul Formation of Helby (1987). On the Ashmore and Sahul platforms this unit includes carbonates, indicating that progressively more marine conditions prevailed to the northwest. Here, the Sahul Formation is thinner (Yeates and Mulholland, in prep.) and contains labile-mineral detritus (Cook, 1985) suggesting that land areas were nearby.

LEGEND

- *Highlands*
- *Land*
- *Fluvial deposition*
- *Fluvio-lacustrine deposition*
- *Glacial deposition*
- *Paralic deposition*
- *Intertidal-supratidal deposition*
- *Deltaic deposition*
- *Very shallow (0-20m) marine deposition*
- *Shallow (0-200m) marine deposition*
- *Bathyal-abyssal (>200m) marine deposition*
- *Palaeocurrents*

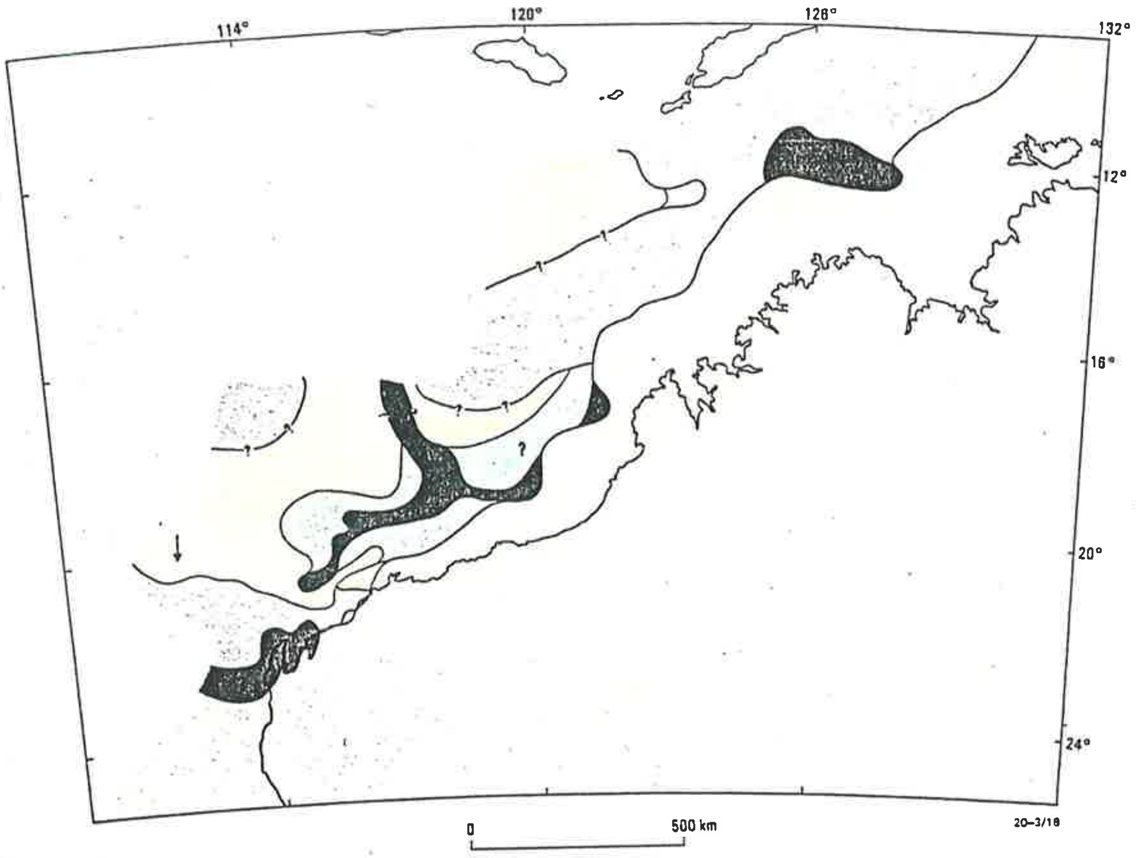


Figure 2.6.- Early Triassic environments (after Bradshaw et al., 1988).

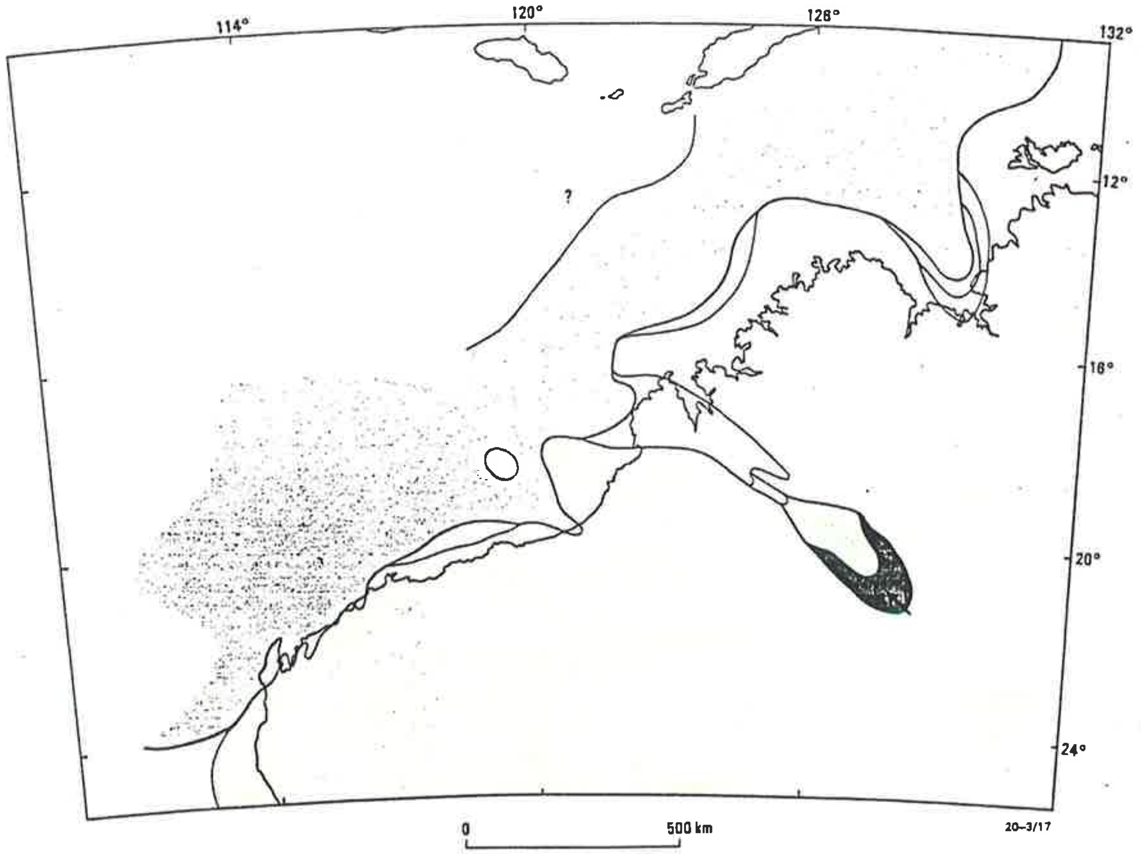


Figure 2.7.- Early Late Triassic environments (after Bradshaw et al., 1988).

2.2.2.2. Late Triassic

During Late Triassic to Early Jurassic time, there was wrench movement and concomitant uplift along the bounding faults of the Fitzroy Graben(Yeates et al., 1984). This was a period when fine grained sediments (which include redbeds) were deposited in low-energy, fluvial flood plains as the sea retreated from the regions northern portion. The redbed - bearing units of this interval are not continuous over the entire region; in places there are unconformities between the upper Triassic and Jurassic. The deposits constitute the Malita Formation in the Bonaparte Basin (Bhatia et al., 1984), In other parts of the basin, and in the Exmouth Plateau Arch, their equivalent is the Brigadier Formation (Hocking et al., 1987).

During the late Triassic the northern Carnarvon Basin became the site of extensive and apparently continuous continental sedimentation (Crostella and Barter, 1980), although several thin marine intervals are recognised.

Crostella and Barter (1980) recognised cycles within the Upper Triassic section, each consisting of a unit of coarse sand representing braided-river deposits, paired with a unit of mainly claystone with minor coal and fine-grained sandstone representing flood-plain deposits. Overlying this is a marginal marine unit of thinly bedded sandstones and claystones with a fully marine claystone at the top. This unit is identified as Brigadier Beds. Previously this unit was considered a totally different lithostratigraphic unit from the underlying, entirely continental, Mungaroo Formation. However, recent studies indicate at least some marine influence for the whole of the Mungaroo Formation (Butcher, 1987).

In the Bedout Sub-basin a redbed sequence called the Bedout Formation was deposited in latest Triassic to early Jurassic time. The upper boundary of this sequence is sharp suggesting an unconformity at the top of the Bedout Formation prior to marine transgression in early Jurassic times. Red bed facies in the Lower Jurassic suggest low water-tables and a climate that was seasonally arid, but still humid enough to support large river systems and limited coal deposition. The climate may have been monsoonal (Hocking, 1988).

2.2.3. JURASSIC

A return to more marginal marine conditions during Early to Middle Jurassic time resulted in the deposition of the Depuch Formation. This formation consists predominantly of medium to coarse grained sandstones, with minor amounts of clay matrix and carbonates (see stratigraphic column in table 2.1). The Depuch Formation is interbedded with carbonaceous and micaceous siltstones and mudstones. Landward in the Beagle Sub-basin this formation shows fluvial to deltaic sedimentation with a strong deltaic affinity (Butcher, 1987).

Sedimentation in the Jurassic was strongly influenced by a shift in the tectonic regime from a rift environment to actual breakup and sea floor spreading. This change in sedimentation is marked on seismic records by a regional intra-Jurassic unconformity that has been termed the "break-up unconformity" (Falvey, 1974) or the "drift-onset unconformity" (Veenstra, 1985).

Upper Jurassic post-Main Unconformity sediments are thin or absent in the study area. They consist of a variety of lithologies but in all cases reflect a marine transgression which commenced in the Oxfordian and continued into the early Cretaceous. Two formations were deposited during the Upper Jurassic; Egret Formation (Oxfordian to Tithonian) and the Rosemary Formation (Callovian to Kimmeridgian). The sediments of these formations are dominated by sandstones which are glauconitic and often contain shelly hash.

2.2.4. CRETACEOUS

2.2.4.1. Lower Cretaceous

Marine mudstones of the Mermaid and Nelson Rock Formations were deposited during the early Cretaceous. These two formations are well developed in the Beagle Sub-basin except in the Cossigny-1 and Sable-1 areas which appear to have remained structurally elevated whilst the pre-Main unconformity surface was inundated.

2.2.4.2. Upper Cretaceous

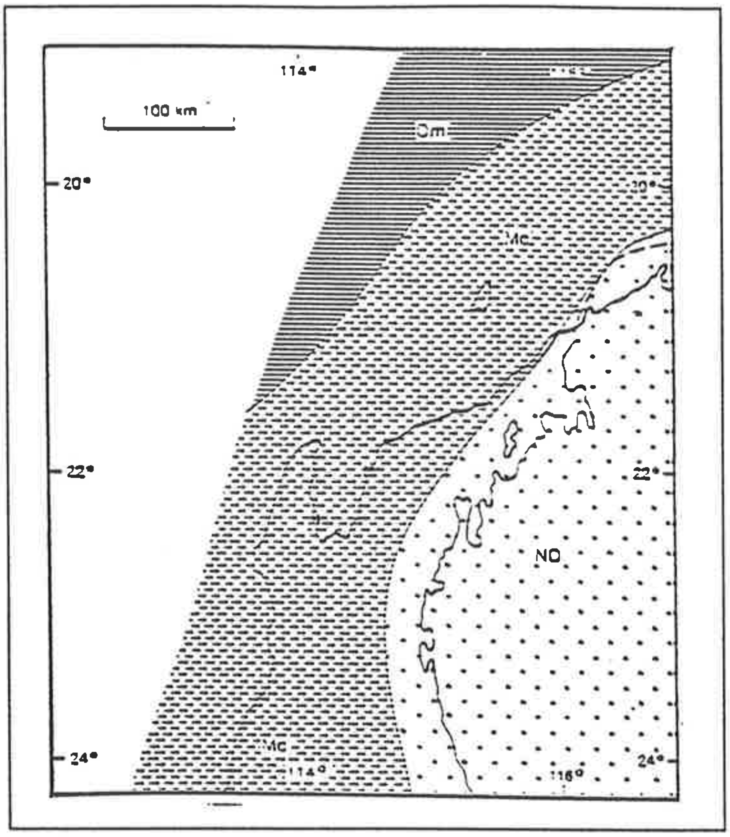


Figure 2.8.- Palaeogegraphy, Late Cretaceous - Toolonga calcilutite (after Hocking, 1988).

Upper Cretaceous deposits mainly consist of "marls", calcareous mudstones and calcilutites which were laid down under outer shelf to slope conditions. Formations present include the Toolonga Calcilutite (fig. 2.8), (Coniacian to Campanian) and the Miria Marl (Campanian to Maastrichtian). The Toolonga Calcilutite is a very distinctive lithological unit of regional extent which is conformably overlain by the Miria Marl.

2.3. STRUCTURAL ELEMENTS OF THE BEAGLE AND BEDOUT SUB-BASINS

The main structural elements of the Beagle and Bedout Sub-basins are shown in figure 2.9. Structurally stable conditions prevailed in the area during the late Permian and the greater part of the Triassic. However, extensive block faulting took place in late-Triassic - early Jurassic and resulted in the formation of the major structural elements of the basin which are described below.

2.3.1. Outer Platform Area

Outer Platform has a strong affinity to the major Rankin Trend structure of the Dampier Sub-basin. Both sets of structures are essentially the result of Jurassic tilting and tensional block faulting. This was followed by extensive erosion, and subsequent deposition in the

Cretaceous (Halse, 1973). The Outer Platform appears to swing in a more north-easterly direction and trends away into deep water.

2.3.2. The Picard Trend

This trend comprises a major line of structures situated immediately north of the structurally negative Beagle Trough (Fig 2.9). The major unconformity as shown by the Picard-1 well is Early Cretaceous in age, with Neocomian overlying Middle Jurassic sediments, reflecting the different structural history of this trend compared to that of the Outer Platform Area.

2.3.3. The Cossigny Trough

The Beagle Trough consists of two prominent downwarps, separated by a positive zone of structural interference referred to as the Samson Nose (Halse, 1973). The pronounced thickening seen on the seismic records (Line 69-379) towards the depocentres of both components of the trough indicates that subsidence was most active during the Mesozoic. Cossigny - 1 was drilled on a large fault-induced structure immediately adjacent to the southern flank of the Beagle Trough (Line 69-379). Cossigny-1 well represents the type section for the Cossigny Member and extends between 2855 and 2935m.

2.3.4. The North Turtle Arch

The North Turtle Arch is a structurally positive zone of block faulting (Fig. 2.9). This arch separates the Beagle Sub-basin from the Bedout Sub-basin in the east. The arch, as indicated by the seismic mapping, had most effect on sedimentation in pre-Cretaceous times (Halse, 1973)

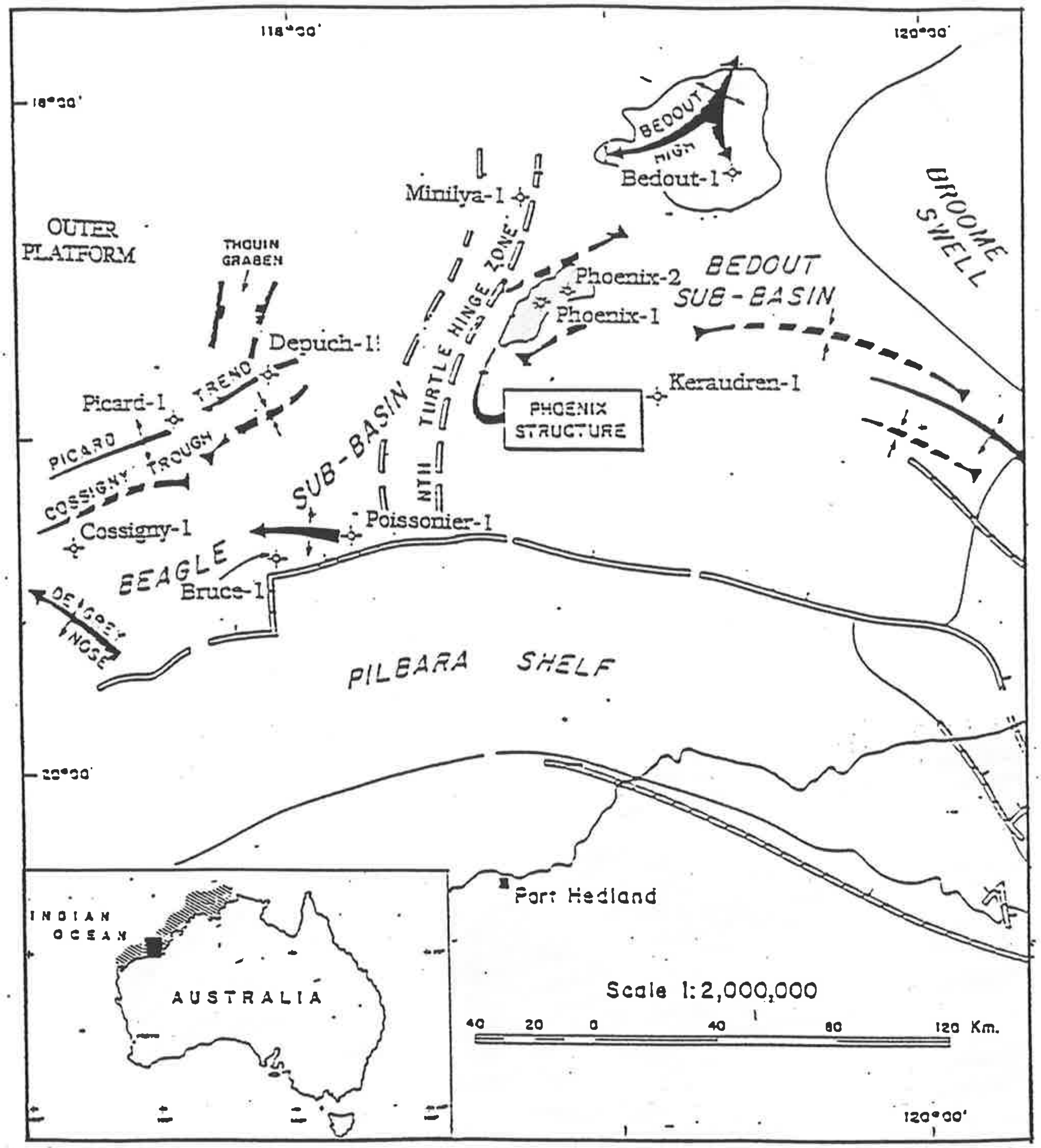


Figure 2.9.- Structural elements of the Beagle and Bedout Subbasins. map also shows well locations.

2.3.5 Phoenix Structure

The Phoenix structure is a large northeast trending, elongate anticline (Fig. 1.1 and 1.2) which is transected by a series of north northeast trending normal faults, downthrown to the west. Phoenix-1 was drilled on 22nd March, 1980 on this structure. Middle to Late Triassic sandstone reservoirs formed the primary objectives. Phoenix-2 was drilled in 1982 on a fault-block forming part of the Phoenix structure (Line R79-01). No significant hydrocarbons were found and the well was plugged and abandoned on 15th June, 1982. The Cossigny Member was found at depth 3575-3700m.

2.3.6. Pilbara Shelf

The Pilbara Shelf forms the southern margin of the Bedout Sub-basin. The Pilbara Shelf forms a wide zone of relatively thin sedimentary cover immediately adjoining the Precambrian Pilbara Block, and is characterise by the presence of multiple unconformities.

2.3.7. Bedout High

The Bedout High is a largely unfaulted anticline of early Palaeozoic age. It forms the northern boundary of the Bedout Sub-basin, and Permo-Triassic strata exhibit onlap on this feature. The Bedout High represents a westerly, down-faulted, extension of the Broome Swell (Fig. 1.9). The Broome Swell defines the easterly margin of the sub-basin and is an elevated platform that is capped by a condensed Upper Mesozoic to Tertiary section .
During most of Triassic time, the Bedout High was a distinct feature as shown by stratigraphic onlap. However, some sedimentation did occur over the high as 12.5m of Smithian-Anisian (Lower-Middle Triassic) shales were penetrated in Bedout-1 directly above the volcanics. These thin shales are probably preserved in a depression on an irregular erosion surface. A hiatus over the crestal areas of the high is due to onlap of carbonate strata (Cossigny Member) on to the flanks of this feature. The first significant

deposition over the Bedout High occurred during the late Triassic with the sandy, fluvial deposits of the Upper Keraudren Formation.

2.3.8. De Grey Nose

A seaward plunging positive extension of the Pilbara Shelf, the De Grey Nose separates the Beagle Sub-basin from the Dampier Sub-basin. De Grey-1 was drilled to test the hydrocarbon potential of possible stratigraphic wedgeouts and deeper fault controlled structures on the De Grey Nose. De Grey -1 was drilled to a total depth of 2088 meters and penetrated a section ranging in age from Quaternary to Triassic. The actual boundary between Jurassic and Triassic cannot be determined as samples were not recovered due to lost circulation between 2012 and 2082 meters. Definite Triassic was encountered from 2082 to 2088 meters at T.D. No significant indications of hydrocarbon were encountered and the well was abandoned without testing. Core taken from 2080 to 2088 meters (T.D.) show the top 4 inches composed of recrystallised limestone. The remainder of the core is dominantly sandstone, with interbeds of clay stone, siltstone, coal and shale of indeterminate age.

2.3.9. Thouin Graben

This Early-Mid Jurassic feature was most active in the Callovian. Although the Pre-Callovian structural growth rates are small, they may have influenced the pattern of sedimentation sufficiently to give rise to improved source rock quality within the graben.

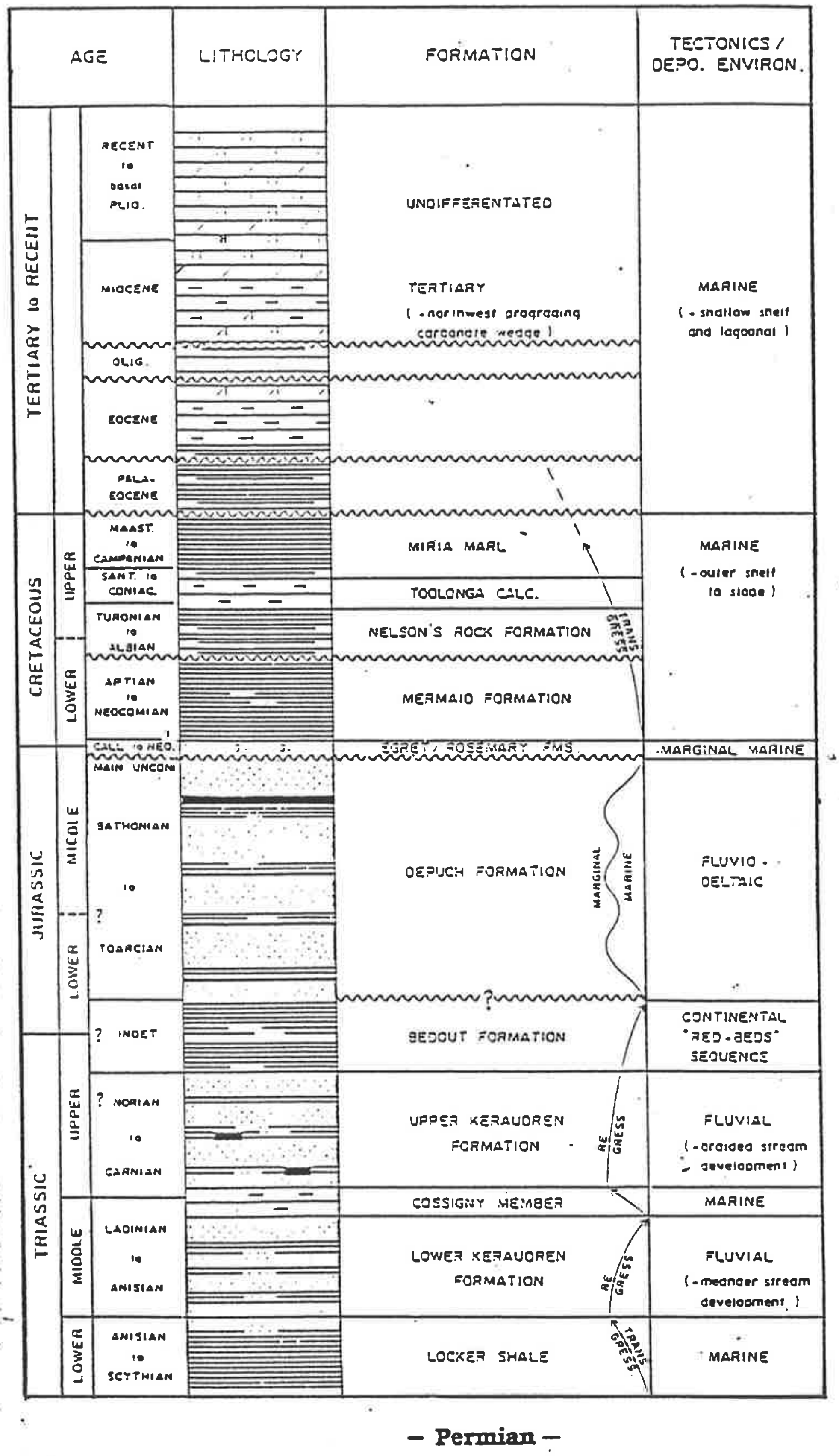


Figure 2.10.- Generalized stratigraphic column for the Beagle and Bedout Sub-basins

CHAPTER 3

TRIASSIC LITHOFACIES IN THE BEAGLE AND BEDOUT SUB-BASINS

3.1. Seismic Correlation Of the Cossigny Member

A set of seismic lines of various vintage was used for interpretation (Fig. 3.1; Base Map, the selected lines are included as appendix VI). The data is of varying fold, energy source and quality. The main objective was to correlate the Cossigny Member across the study area. Due to the small number of wells drilled in the area the well ties were limited.

The Cossigny reflection (Seismic Orange Horizon) is a complex seismic event produced by high velocity carbonates within a siliciclastic section of Lower and Upper Mungaroo Formation. To assist in the stratigraphic interpretation and correlation, two additional horizons were tentatively carried (where present) throughout most of the seismic lines. These were the Green Horizon, corresponding to the Main Unconformity, and the Purple Horizon which correlate with the top of the Bedout Formation.

3.1.1 Seismic Orange Horizon

This event is generated by the moderate to high amplitude carbonate unit of the Cossigny Member which is encased within a package of sandstones and shales. It is an excellent seismic marker, and allows the extent of the unit to be correlated. Away from the Phoenix 1 and 2 , the character of the reflection changes and the amplitude decreases dramatically (Fig 3.2). The amplitude variations are caused in part by changes in the thickness of the carbonate member, which alters the degree of interference of reflections from the top and base of the carbonate. Although the picked extent of this event is interpretative and a facies

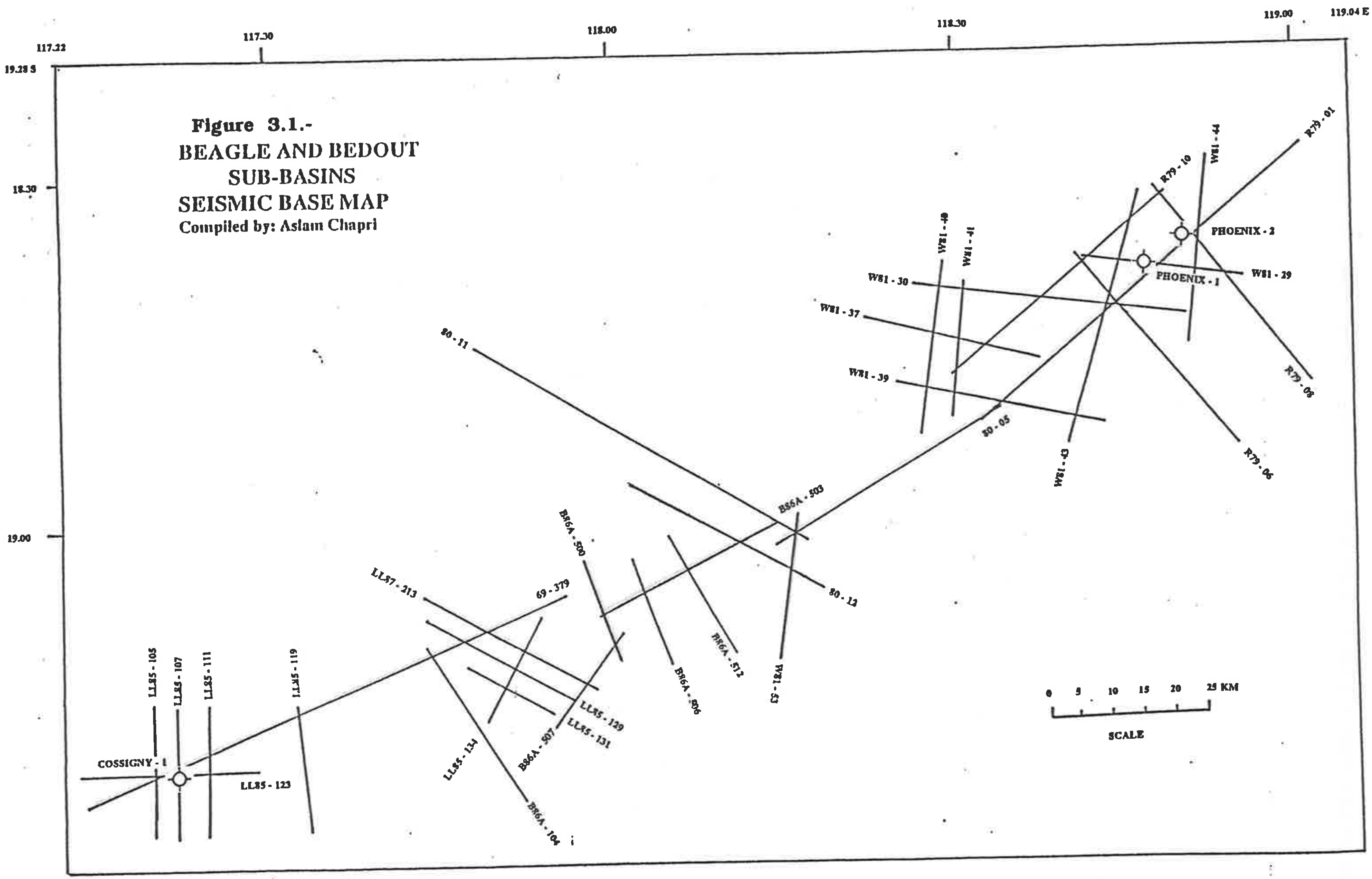


Figure 3.1.-
BEAGLE AND BEDOUT
SUB-BASINS
SEISMIC BASE MAP
Compiled by: Aslam Chapri
117.22
117.30
118.00
118.30
119.00
119.04 E
19.28 S
18.30
19.00
PHOENIX - 2
PHOENIX - 1
COSSIGNY - 1
R79 - 01
R79 - 10
R79 - 08
R79 - 06
W81 - 44
W81 - 40
W81 - 41
W81 - 30
W81 - 29
W81 - 37
W81 - 39
W81 - 43
80 - 11
80 - 05
80 - 12
B86A - 503
B86A - 500
B86A - 512
B86A - 506
B86A - 507
B86A - 104
W81 - 53
LL87 - 213
69 - 379
LL85 - 129
LL85 - 131
LL85 - 134
LL85 - 105
LL85 - 107
LL85 - 111
LL85 - 119
LL85 - 123
0 5 10 15 20 25 KM
SCALE

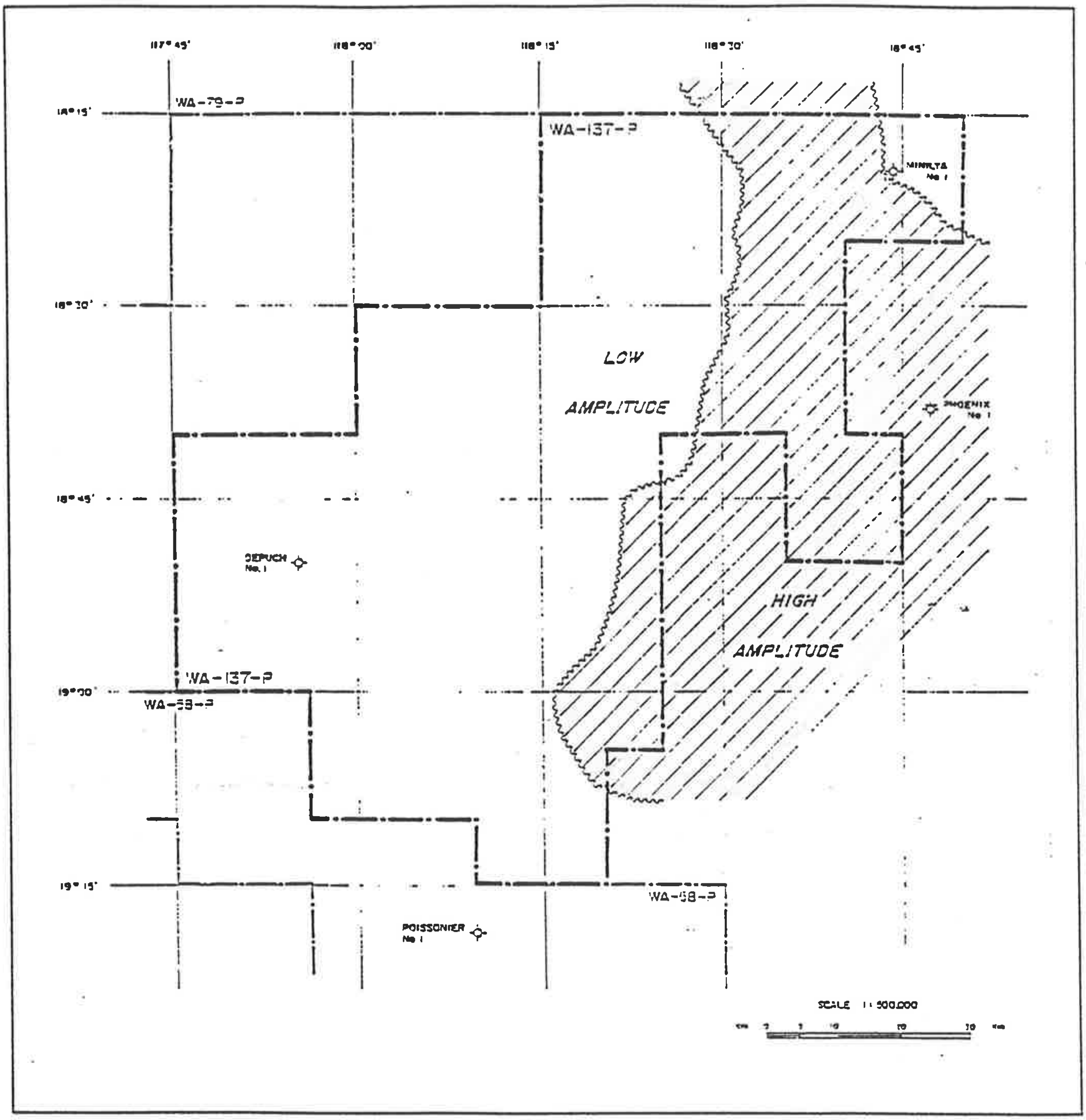


Figure 3.2.- Limit of high amplitude seismic Orange horizon (from well completion report Phoenix No.1).

change is not necessarily implied. However, well control indicates that there is a change from carbonates to calcareous claystones both capable of sealing a reservoir.

3.1.2. Seismic Purple Horizon

The seismic purple horizon is a weak reflection associated with the top of the Lower Jurassic Bedout Formation. Although this event is not conformable with the Orange horizon, no unconformity is apparent between the orange and green reflectors. This horizon provides support for the correlation of the Cossigny Member from well to well. The confidence in the picking of this horizon decreases markedly away from the well control.

3.1.3. Seismic Green Horizon

The seismic green horizon is associated with the Middle Jurassic Main Unconformity. The dominant fault dip direction is westwards and down to the basin, but minor down to the east faulting is also observed.

3.2. WIRELINE LOG INTERPRETATION

Wireline logs from Cossigny-1, Phoenix-1 and Phoenix-2 were used to describe the different Triassic rock facies in the Beagle Sub-basin (see Appendix-V for wireline logs). Log curve shapes were tied to the rock data from cuttings and core to understand the gross depositional environment for the different rock facies of the Triassic. The objective was to determine whether processes operating within these environments were favourable for deposition of carbonate sediments.

A great deal has been written about the interpretation of log curve shapes in terms of depositional environment (Selley 1978, Pirson, 1977, among others). Much of the log data is used to develop sedimentary depositional models. A log curve shape, by itself, however, has no predictive capability until it is linked by a genetic interpretation to a facies model. The most typical pattern seen on these logs are shown in figure 3.3 with some depositional setting indicated in which each curve can be generated.

3.3. Definition of a Facies

A facies is defined as " sum total of features that reflect the specific environmental conditions under which a given rock was formed or deposited." Moore (1979) used the term to signify any particular type of sedimentary rock or distinguishable rock record formed under common environmental conditions of deposition.

A lithofacies is a lateral, mappable subdivision of a designated stratigraphic unit, distinguished from adjacent subdivisions on the basis of lithology, including all mineralogical and petrographic characters and those palaeontologic characters that influence the appearance, composition, or texture of the rock. Laterally equivalent lithofacies may be separated by vertical arbitrary cut-off planes, by intertonguing, or by gradational changes.

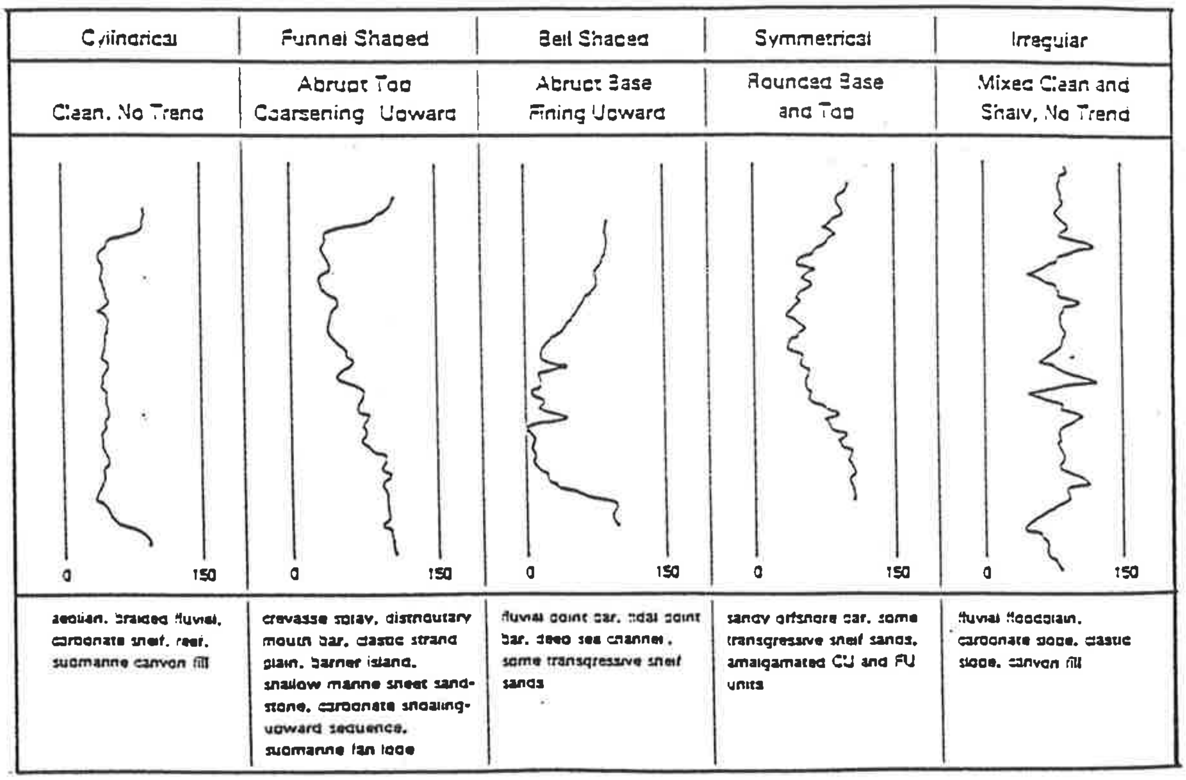


Figure 3.3.-- The most common idealised gamma-ray (SP) log curve shapes and at least some of the depositional settings in which they can originate. Several environments are listed under more than one curve, indicating they are somewhat variable (After Cant 1984).

3.4. TRIASSIC LITHOFACIES IN THE BEAGLE AND BEDOUT SUB-BASINS

Triassic sedimentation commenced in the area with a marine transgression early in Scythian time (Bradshaw, et al., 1988; Crostella and Barter, 1980). This transgression was truly regional in extent, having been documented as influencing sedimentation in the Perth, Canning and Bonaparte Gulf Basins as well as the Northern Carnarvon Basin. The Triassic sediments are largely clastic, coarsening-up from fine grained marine shales at the base to fluvio-deltaic sands at the top. Carbonates are a significant part of the Late Triassic sequence in the far northwest of the region

In the Beagle and Bedout Sub-basins Cossigny Member represents a significant carbonate deposition and varies in thickness from 100-120 meter. This unit was deposited as a result of a short lived marine transgression during the Ladinian times (Blevin et al 1993; Bradshaw et al., 1988)

3.4.1. Deposition of The Locker Shale

The Locker Shale was deposited unconformably over Permian and older rocks as a result of marine transgression in early Scythian, (Crostella and Barter, 1980). On the wireline logs the top of the formation corresponds with a downhole increase in gamma ray response, and transition to a more blocky gamma character compared to the more erratic response within the overlying Lower Keraudren Formation (see Appendix-V). Formation resistivities show an increase in the Beagle area but decreases in the Bedout Sub-basin (Phoenix area). The sonic log character changes downhole to a rather more erratic response. Thin beds of fine to very fine grained sandstone are occasionally found within the dominantly mudstones of this formation. The reconstructed environments (Fig. 2.6) show almost the entire North West Shelf region covered by a shallow sea (Bradshaw, et al., 1988). The absence of widespread lower Triassic paralic deposits, and the local occurrence of basal sandstones and carbonates suggest that the transgression occurred rapidly (Bradshaw, et al., 1988).

3.4.2. Deposition of the Keraudren and Mungaroo Formations

In the Bedout Sub-basin, the Locker Shale grades upwards to the Keraudren Formation which consists mainly of fluviatile sandstones. Figure 3.4 shows a stratigraphic column for the area. The facies equivalent of the Keraudren Formation is known as Mungaroo Formation in the Beagle Sub-Basin (Hocking 1988). The Cossigny Member was deposited within these fluviatile sediments, indicating a marine transgression during that time.

3.4.2.1. Lower Keraudren Formation

The top of this formation is picked at the base of Cossigny Member. On wireline logs this corresponds with a downhole reduction in sonic velocities and a sharp increase in gamma ray signatures.

The Lower Keraudren Formation consists dominantly of a thick sequence of grey brown mudstones, with interbeds of generally fine-grained argillaceous sandstones. The mudstones are silty and appear as units of varying thickness some up to 100m thick. Thickness of the sandstone bodies generally vary between 2 and 30m, although one sandstone unit at base of the formation is 99m thick. The sandstones are generally very fine to fine grained, occasionally ranging up to medium grained (table 3.1). Argillaceous material and lithic fragments are subordinate to quartz. Additionally, interbedded with these mudstones is a 20-25 meter thick carbonate unit, consisting of a light grey, fine grained limestone containing marine fauna (Well completion reports), indicating a slight marine incursion on the coastal area.

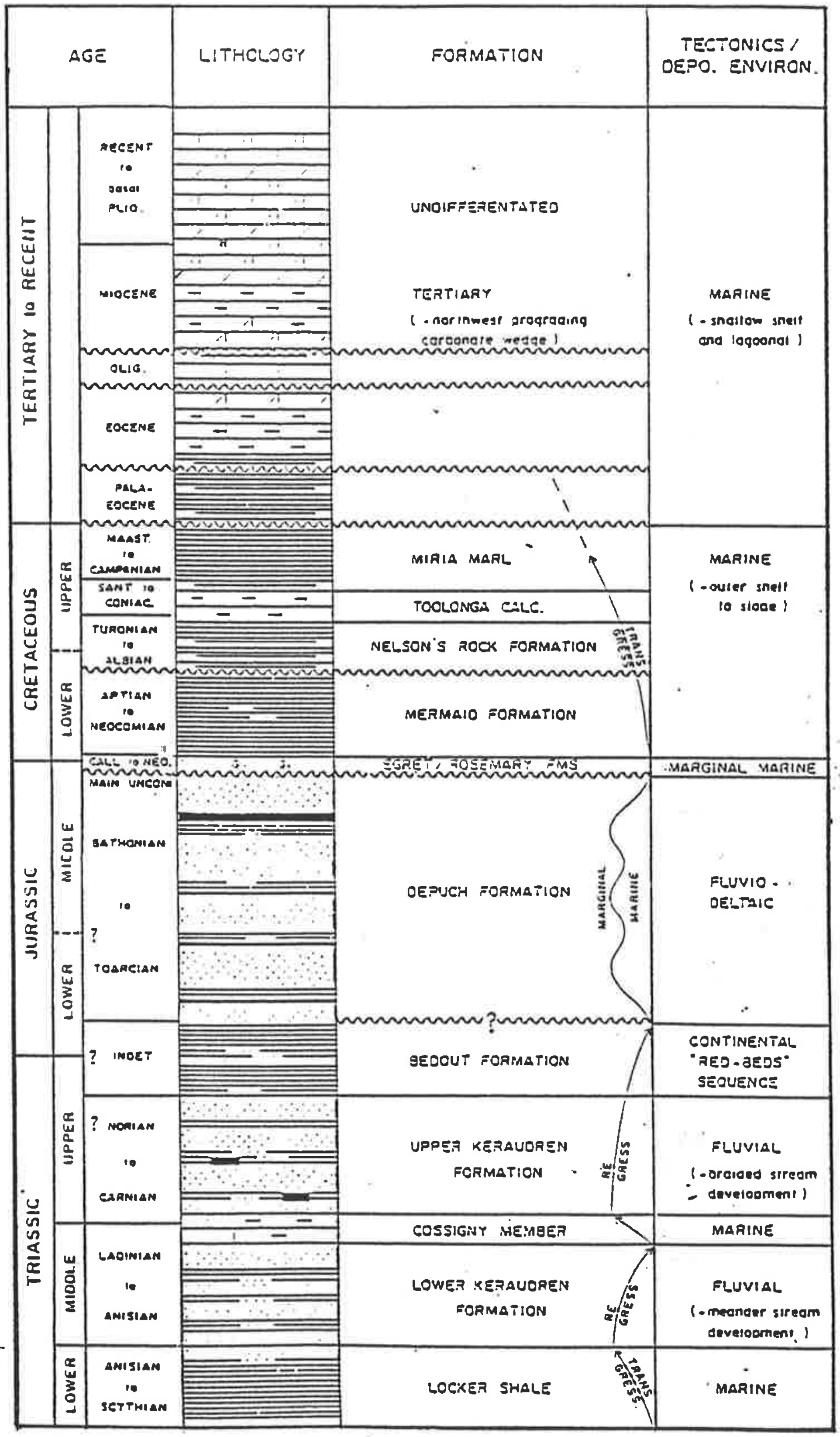
The high maturity of the Lower Keraudren sandstones and the high content of the shale imply a low energy deposition probably in the meandering rivers (well completion reports). Figure 3.5 shows characteristic meandering river log motif. The thick sandstone development between 4429.5m and 4506m could be the result of a period of high aggradation or amalgamation channel bars with resultant brief transition to a braided stream

Sand Body Characteristics	Observations from the Lower Keraudren Formation - Phoenix No. 1
COMPOSITION/ MINERALOGY	Dominantly quartzos, rock fragments and feldspars rare rock fragments pyrite, mica and carbonaceous relatively common. Secondary calcite/dolomite cementation common.
FOSSIL CONTENT	Predominantly miospores with rare acritarchs
TEXTURE (i) Grainsize (ii) Shape (iii) Sorting	 Fine to medium-grained Subangular to subrounded Moderately well sorted.
SEDIMENTARY STRUCTURES (-based on Core No. 2)	Tabular X-beds, fining upwards units, asymmetric ripple development basal granule bands, sedimentary deformation structure.
BEDDING CHARACTERISTICS	X-beds range in thickness from 0.2 m to 1.0 m, dip angle 0 top 40 degrees decreasing upwards, beds occasionally thinning upwards
VERTICAL SEQUENCE OF BEDDING AND STRUCTURE	Sandstone units exhibit sharp basal contact with underlying silty mudstones. Silty mudstones are interlaminated with silt and very fine-grained sandstone, show asymmetric ripple structure, and deformation structure due to loading. Granule bands at base of sandstone units and development of ripple structure at the top of X-bed units.
SIZE, SHAPE AND ORIENTATION	Little data. Lower Keraudren characterised by sandstone units which do not exceed 15 to 20 m thickness. the sand/shale ratio is 26%.
ASSOCIATED LITHOLOGIES	Mudstone grading to siltstone (carbonaceous/pyritic), thin coals, thin dolomite stringers in upper interval.

Table 3.1. Sand body characteristics of Lower Keraudren Formation from Phoenix-1 well, (from Phoenix-1 well completion report).

Sand Body Characteristics	Observations from the Upper Keraudren Formation - Phoenix No. 1
COMPOSITION/ MINERALOGY	Dominantly quartzose, rock fragments and feldspars common, micas and pyrite common, carbonaceous material occasionally present
FOSSIL CONTENT	Predominantly miospores with rare acritarchs and algal cysts.
TEXTURE (i) Grainsize (ii) Shape (iii) Sorting	 Very fine-grained to granule (av. medium to coarse-grained). subangular grain-shape. moderate to poor sorting.
SEDIMENTARY STRUCTURES (Based on Core No. 1)	Tabular X-bedding, asymmetric ripple development sedimentary deformation, fining upwards units.
BEDDING CHARACTERISTICS	Sandstone beds are very thick (up to 75 m), X-beds up to 3.55 m in thickness (Core No. 1), X-bed dip angle is 0 to 20 degrees, decreasing upwards (Core No. 1), sharp basal contact to sandstone beds.
VERTICAL SEQUENCE OF BEDDING AND STRUCTURES	Sandstones exhibit sharp basal contact with underlying silty mudstones. Silty mudstones are ripple laminated with silt and very fine-grained sandstone and show load deformation structure
SIZE, SHAPE AND ORIENTATION	Little data available. Upper Keraudren comprises 230 m sandstone (75%) and units range in thickness up to 75 m.
ASSOCIATED LITHOLOGIES	Silty mudstone (pyritic/carbonaceous), siltstone, very thin coals and oil shales.

Table 3.2 Sand body characteristics of upper Keraudren Formation from Phoenix-1 well, (from Phoenix-1 well completion report).



– Permian –

Figure 3.4.- Generalized stratigraphic column for the Beagle and Bedout Sub-basins

system. The formation has been dated as Anisian in its upper part. It is nevertheless likely that the whole of the lower Keraudren Formation is Anisian (Well Completion reports).

3.4.2.2. Upper Keraudren Formation

On the wire line logs, the top of this formation is picked at an increase in sonic velocity to approximately 70-80 microseconds per foot. The dipmeter log shows the presence of an unconformity at the top of the formation (Well Completion Report, Phoenix-1).

In the upper part of the interval, the sandstones are light grey, fine to very coarse grained with abundant quartz granules. With depth, sandstones become coarse to very coarse grained, subangular and moderately to poorly sorted (table 3.2). In contrast to the Lower Keraudren Formation, the Upper Keraudren sandstones display a greater degree of disorganisation. The textural immaturity of these sands indicate a high energy deposition probably in a braided river. The log curves also show a characteristic braided motif in figure 3.6.

3.4.2.3. Mungaroo Formation

The Mungaroo Formation in the Beagle Sub-basin is dominantly sandy. Lithologically the sequence consists of sandstones with minor siltstone and claystone. Sandstones are light to dark grey in colour, very fine to coarse grained, poorly to moderately sorted. Claystones are silty and sometimes calcareous.

Due to the varied nature of this formation, the log response shows no typical pattern. The coarse grain size, angularity, poor sorting, indicate that the sediments of this formation were probably deposited by braided river systems (Vos and McHattie, 1981).

Fining-upwards gravel, sandstone and siltstone sequences are attributed to waning current velocities as a channel is gradually infilled (William and Rust, 1969). Coarsening-upward sequences are attributed to the infilling of braided channels at times of rising flood stages.

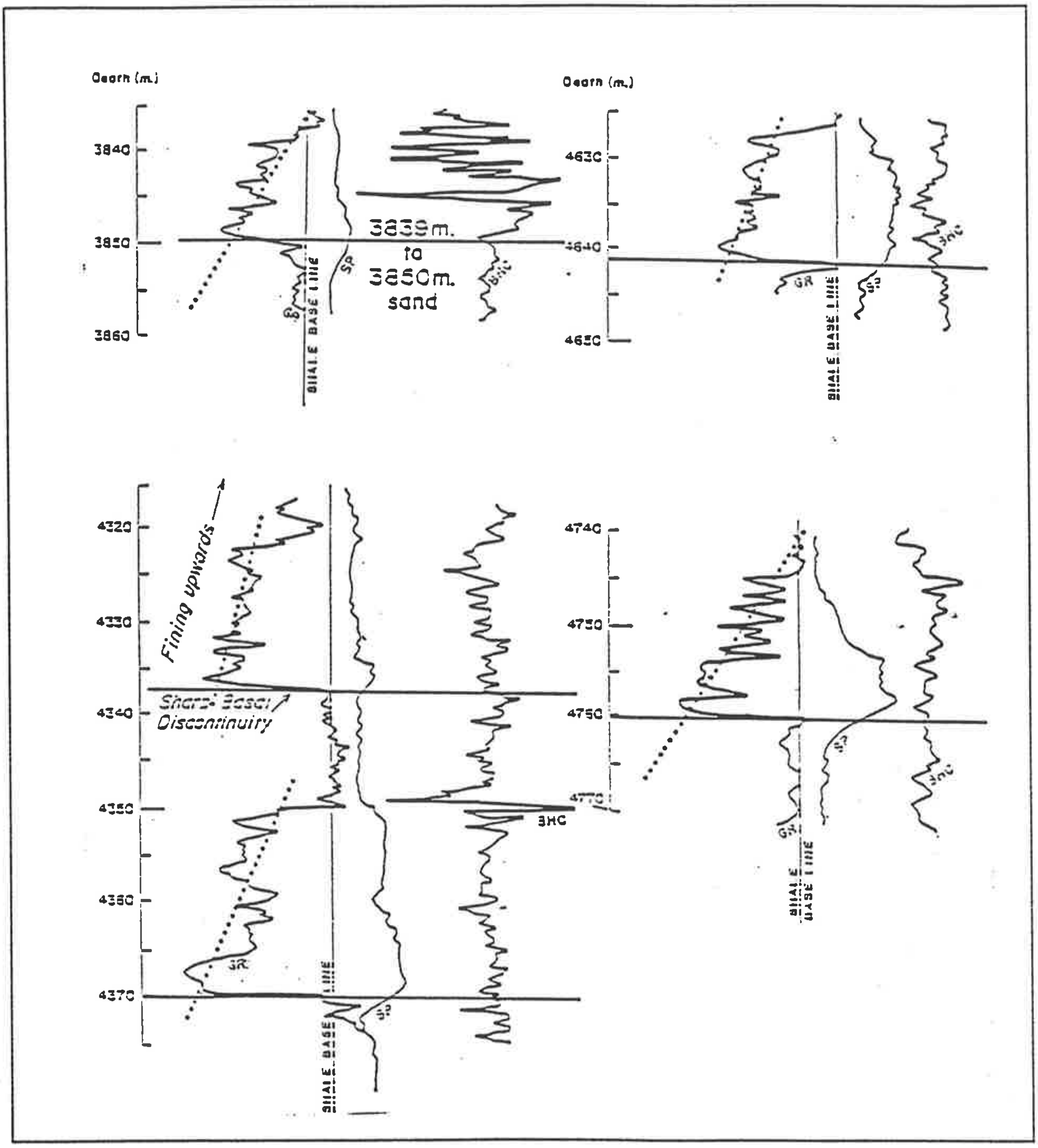


Figure 3.5.- Meandering stream electric log character - Lower Keraudren Formation (from well completion report Phoenix No. 2).

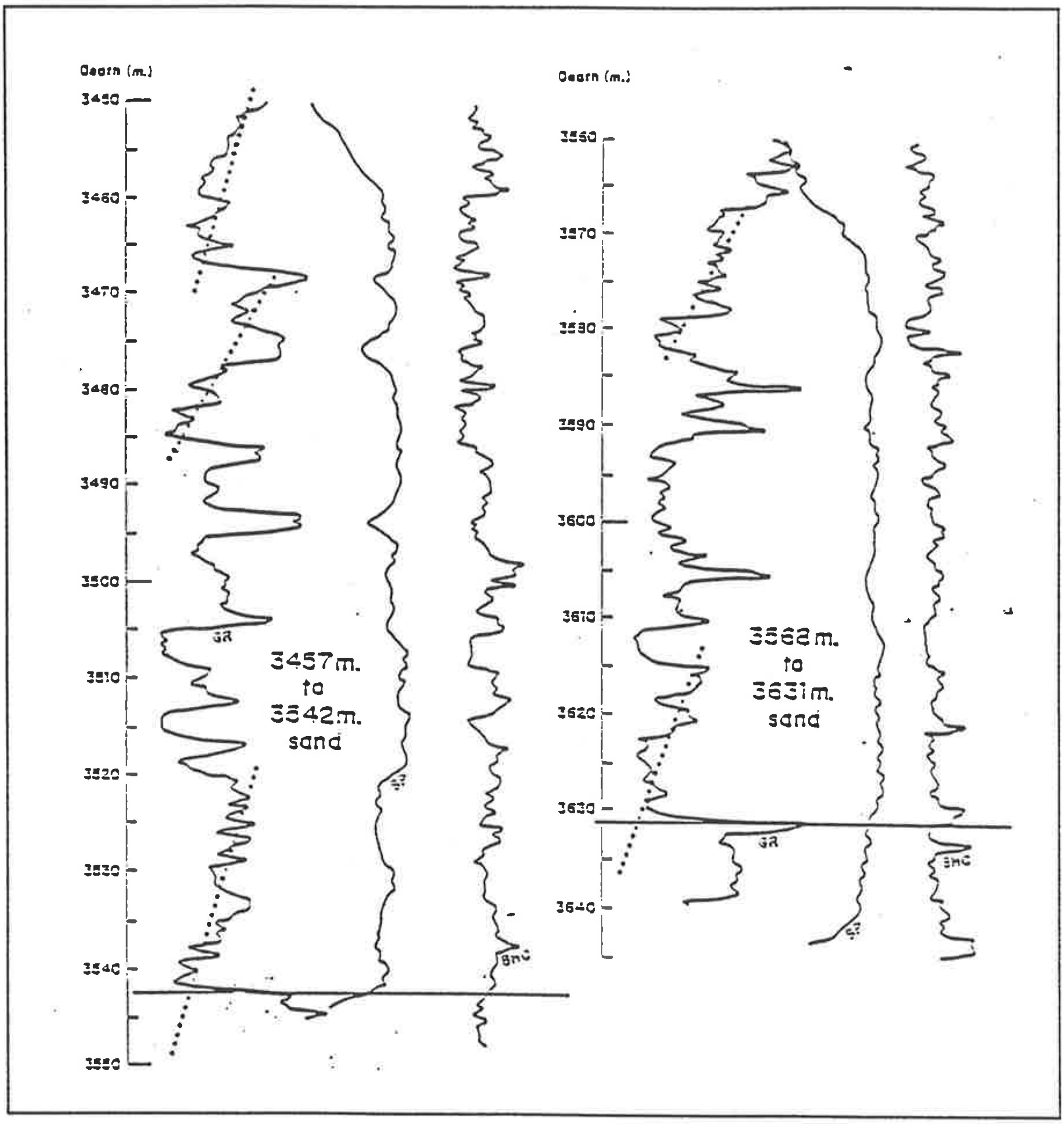


Figure 3.6.- Braided stream electric log character - Upper Keraudren Formation (from well completion report Phoenix No. 2).

The small amount of silt which is present in braided alluvium is generally deposited in abandoned channels. These form both by channel chocking and switching (Doeglas, 1962) and by river piracy due to rapid headward erosion of channels on the downslope part of a fan (Denny 1967).

3.5 TRIASSIC CARBONATES ELSEWHERE ON NORTH WEST SHELF

Shelf carbonates, ranging in age from Late Triassic to Middle Jurassic, were dredged from the northern margin of the Exmouth Plateau (which includes the Wombat Plateau) by RV Sonne (von Stackelberg et al., 1980) and RV Rig Seismic (Exon, et al. 1991). These represent the first discovery of Triassic reefal material near the Australian North West Shelf. Facies analysis suggests that they are likely to be found only on the outer shelf and slope.

Upper Triassic shelf carbonates are not known to be present in exploration wells in the off-shore Canning Basin (Horstman and Purcell, 1988) or in the Northern Carnarvon Basin (Hocking, 1988; Woodside Petroleum, 1988). The map 1.2 suggests that there is an excellent chance of Upper Triassic reef complexes being found along the present-day outermost shelf and upper slope of the entire North West Shelf.

At this stage, reef complexes are known only from the Wombat Plateau, and thick carbonate platforms from the Bonaparte Basin and the Wombat Plateau (Fig. 1.2). In the Bonaparte Basin (Timor Sea), the Sahul Group contains abundant Middle and Upper Triassic shelf carbonates on the Ashmore Platform, the Londonderry High and the Sahul Platform. The thickest shelf carbonates are on the Ashmore Platform, where the Carnian-Norain Benalla Formation is 1078 m thick in North Hibernia 1, and consists of interbedded fossiliferous and oolitic limestone, with lesser amounts of sandstone, siltstone and clay stone (Mory,1988).

On the Sahul Platform, shelf carbonates were drilled in Troubadour 1 and Sahul Shoals 1. In Troubadour 1 there is 239 m Ladinian - Carnian recrystallised limestone with minor interbeds of mudstone and sandstone. The limestone is skeletal and micritic.

In the Browse Basin, Upper Triassic carbonates are present in Mount Ashmore-1B, Scott Reef-1 and North Scott Reef-1 (Willis, 1988).

Late Triassic to Early Jurassic shelf carbonates are common in exploration wells on the Exmouth Plateau, and have been described by Barber (1982; 1988).

3.6. CONCLUSION

Facies analysis from wireline logs and cuttings and core (where available) indicate that the Triassic sediments in the Beagle and Bedout Sub-basins are dominantly sandy and shaly. Except for the Cossigny Member, no other significant carbonate deposits have been penetrated by the wells in the study area.

CHAPTER 4

LITHOFACIES OF THE COSSIGNY MEMBER

4.1. Introduction

The Cossigny Member represents a transgressive then a regressive sequence deposited as a result of a brief transgression during Middle Triassic time (Halse, 1973; Hocking et al., 1987; Bradshaw et al., 1988). In the Beagle Sub-basin, the Cossigny Member is represented by 100 meter thick shelf carbonate. The top of the Cossigny Member is picked from wireline logs at a downhole increase in resistivity, corresponding to a downhole reduction in gamma ray values. Dipmeter evidence suggests that a low angle unconformity is present at the top of the formation (unpublished company reports, Bridge Oil Ltd). The Cossigny Member is overlain and underlain by continental/paralic deposits of the Mungaroo Formation in the Beagle Sub-basin and its facies equivalent the Keraudren Formation in the Bedout Sub-basin.

Detailed sedimentological descriptions and thin section studies of the Cossigny Member by the author has distinguished three characteristic lithofacies. Each carbonate lithofacies is distinguished by a dominant lithology or association of lithologies. XRD analysis and staining of the selected samples allowed the identification of mineralogy.

4.2 LITHOLOGICAL DEFINITIONS

Cossigny Member lithologies are defined by variations in grain components and the nature of the associated matrix. The chief grains are ooids, pellets, peloids and comminuted fossils Figure 4.1 shows carbonate grain types and their depositional setting. The matrix of the

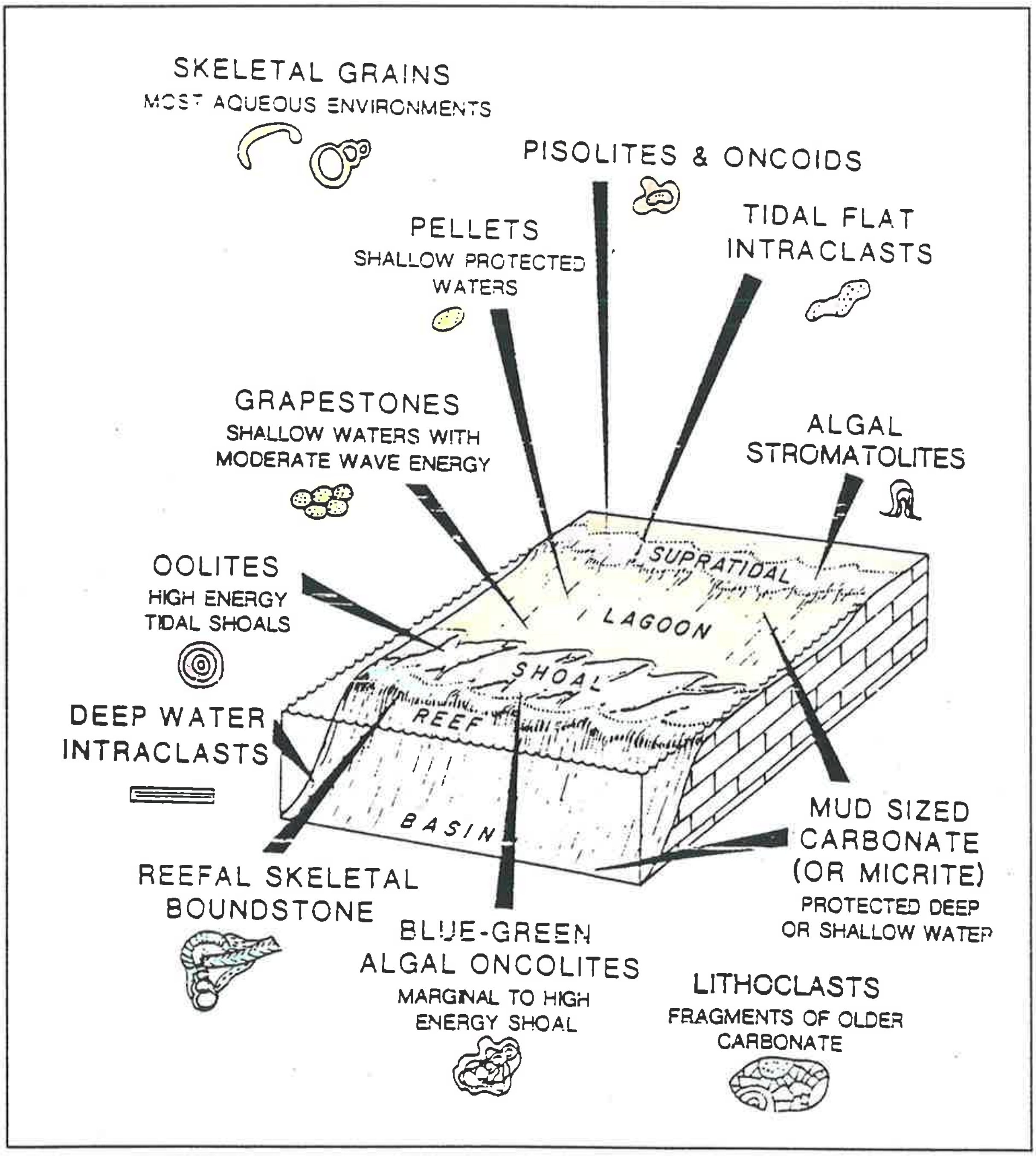


Figure 4.1-- Carbonate grain types and their depositional setting (after Harris et al., 1985).

rock is dominantly lime mudstone (micrite) or secondary interstitial calcite (sparite). Secondary dolomite, probably formed by the mixing of meteoric and saline water, is ubiquitous in the upper part of the member.

4.2.1 Ooids

An ooid is defined as a coated grain with a calcareous cortex and a nucleus which is variable in composition (Tucker, 1990). The cortex is smoothly and evenly laminated especially in its outer parts, but individual laminae may be thinner on points of strong curvature on the nucleus. The ooids are typically spherical or ellipsoidal in shape with the degree of sphericity increasing outwards. A rock largely made of ooids is called an oolite.

The microfabrics of the ooids have attracted a considerable interest and a number of detailed studies have been made of both recent and ancient ooids. Reviews have been given by Simone (1980), Richter (1983b), Medwedeff and Wilkinson (1983).

Ooids are formed in different marine and non-marine environmental settings, as shown in

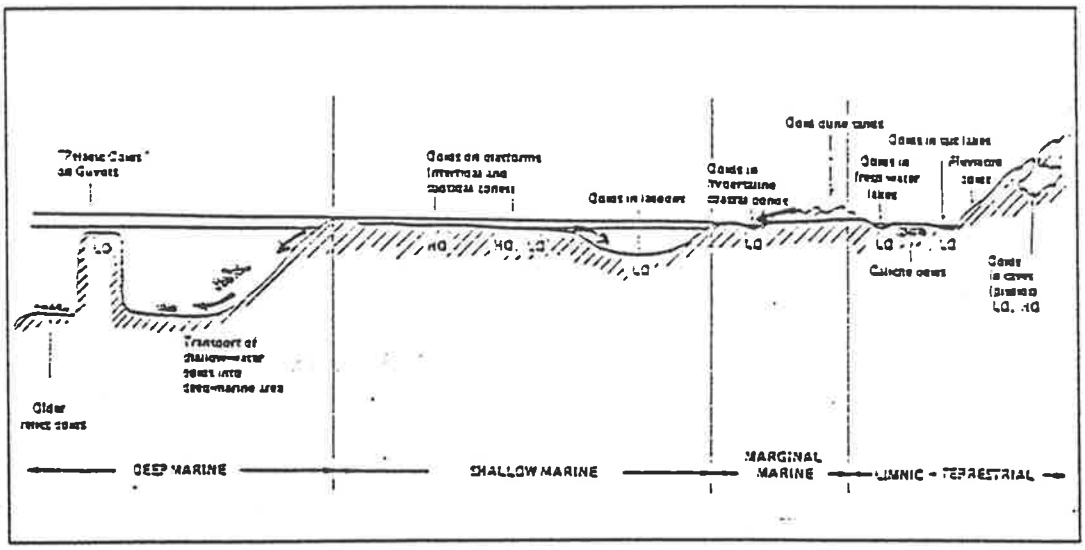


Figure 4.2-- Calcareous ooids originate in various marine and non-marine environments. High energy ooids (HO) of agitated water and low energy ooids (LO) of relatively quite water environments (After Flugel)

figure 4.2. Ooids forming at the present-day show three main microfabrics: tangential, radial and random. Tangential microfabrics are the main microfabric in Bahamian ooids and consist of aragonite grains whose long axes are aligned parallel to the ooid laminae. Radial microfabrics consist of fibrous or bladed crystals of argonite, low magnesium calcite or high magnesium calcite. As a general rule, radial aragonite fabrics in ooids are less common in marine settings than tangential fabrics but they have been described from the Trucial coast of the Arabian Gulf (Loreau and Purser, 1973) and from the Great Barrier Reef in Australia (Davis and Martin, 1976).

4.2.2. Peloids and Pellets

The term peloid is purely descriptive and was used by McKee and Gutschick (1969) to define sand-sized grains with an average size of 100-500 microns composed of microcrystalline carbonate (Tucker, 1990). They are generally rounded or subrounded, spherical, ellipsoidal to irregular in shape and are internally structureless. The term pellet is also commonly used but it has connotations for a faecal origin.

Peloids and pellets are an important constituent of shallow marine carbonate sediments. On the Great Bahama Banks west of Andros Island, the pellet mud facies covers 10 000 sq km. The low energy lagoonal sediments of the northern Belize Shelf and of the Trucial Coast are also peloidal, and in general such limestones are typical of shallow, low-energy, restricted marine environment.

4.2.3. Micrite

Micrite is a descriptive term used by Folk (1959) for the semi opaque crystalline matrix of limestones, consisting of chemically precipitated carbonate mud with crystals less than 4 microns in diameter. The term is now commonly used in a descriptive sense without genetic implication. Bissell and Chilinger (1967) extended usage of the term to include unconsolidated material that may be of either chemical or mechanical origin (and possibly biologic, biochemical, or physiochemical).

4.2.4. Matrix

Matrix is the fine grained material enclosing framework grains, or filling the interstices between the larger grains or particles of a sediment or sedimentary rock (Glossary of Geology, Bates and Jackson 1980). In carbonate sedimentary rocks the matrix usually consists of clay minerals or micritic components surrounding coarser material.

4.2.5. Bioclasts

Skeletal particles, or bioclasts, are the remains, complete or fragmented, of the hard parts of carbonate-secreting organisms. There is large variety in the mineralogy, structure and shape of skeletal material. The common components in the Cossigny Member are brachiopods, echinoderms, foraminifera and ostracods.

4.3. LITHOFACIES OF THE COSSIGNY MEMBER

Using the preceding terminology, the following three facies have been recognised within the Cossigny Member. Table 4.1 shows different lithofacies of the Cossigny Member with their depositional environments. The classification adopted for different facies is after Dunham (1962). See Appendix III for carbonate rock classification.

Oolitic Grainstone

Mixed Oolitic-Peloidal Grainstone

Muddy Peloidal Wackestone

4.3.1 Oolitic Grainstone Facies

This facies was deposited as an ooid shoal, and dominantly consists of well sorted, well rounded, medium to fine grained oolitic sands, and generally lack micrite. In the study area, only Phoenix-2 intersected this facies and probably indicates proximity of the well to an area of ooid shoals. The total thickness of the facies is 51 meters extending from 3650 to3701 meters in Phoenix-2 well. This facies was not found in Phoenix-1 and Cossigny-1 wells. Calcite is the dominant mineral with minor secondary dolomite (Fig. 4.3).

In some samples, ooids constitute more than 60% of the total rock. The ooid nuclei vary from peloids to quartz grains (Plate 1/A). Pellets and peloids are relatively rare in this facies but their concentration becomes increasingly prominent towards the upper part of Cossigny Member. There is little or no evidence of burrowing or bioturbation of the surrounding sediments. Bioclasts form a minor component and consist of disarticulated ostracod, gastropod and brachiopod fragments. Minor amounts of quartz are present throughout the bottom part of this facies and are probably eroded from the underlying Keraudren Formation. Sediments of the oolitic grainstone facies show no original interpartical or secondary moldic porosity. Most of the framework grains are surrounded by a rim of isopachous non-ferroan (pink stained) calcite cement (Plate 1/A and 1/B). This is an early marine cement and has prevented the grain to grain compaction by creating a rigid framework in the rock. The cement of the rock is dominantly coarse grained sparite, this has also occluded interpartical porosity.

Absence of bioturbation, excellent winnowing and rounding of the sediments and abundance of oolitic coating indicate that the ooid grainstone facies was deposited in high energy shoals probably in water depths less than 2 meters, the optimum zone of ooid production (Newell et al., 1960). Modern ooid shoals typically form at shelf break where waves and currents impinge the shallow sea floor. In figure 4.2 different platform setting are shown where ooid shoals commonly form. The geometry of the shoal can not be determined from the available subsurface data.

PLATE 1 Lithofacies of Cossigny Member

A. Well sorted oolitic grainstone with shelly fragments and a few peloids. Ooids are of radial-concentric texture and have quartz and peloid nuclei. Phoenix-2, 3700 meters. PPL.

B. Ooids from oolitic grainstone facies showing cortical layers with radial fabric locally alternate with layers composed of micritic calcite. It is an original texture of these ooids and is called radial-concentric texture. Phoenix-2, 3700 meters. PPL.

C. A thin section from the mixed oolitic-peloidal grainstone composed of radial and concentrically laminated ooids and micritized particles. Note complete interparticle cementation by calcite spar. The grains have been micritized. Phoenix-1, 3700 meters. PPL

D. Muddy peloidal wackestone, with bioclasts of brachiopod, ostracod and echinoderms. The echinoderm fragments appear as speckled plates with uniform interference colours. Micrite walled miliolid foraminifera with pore space filled with fine grained sparite is seen in the lower left of the photograph. Cossigny-1, 2948 meters. PPL

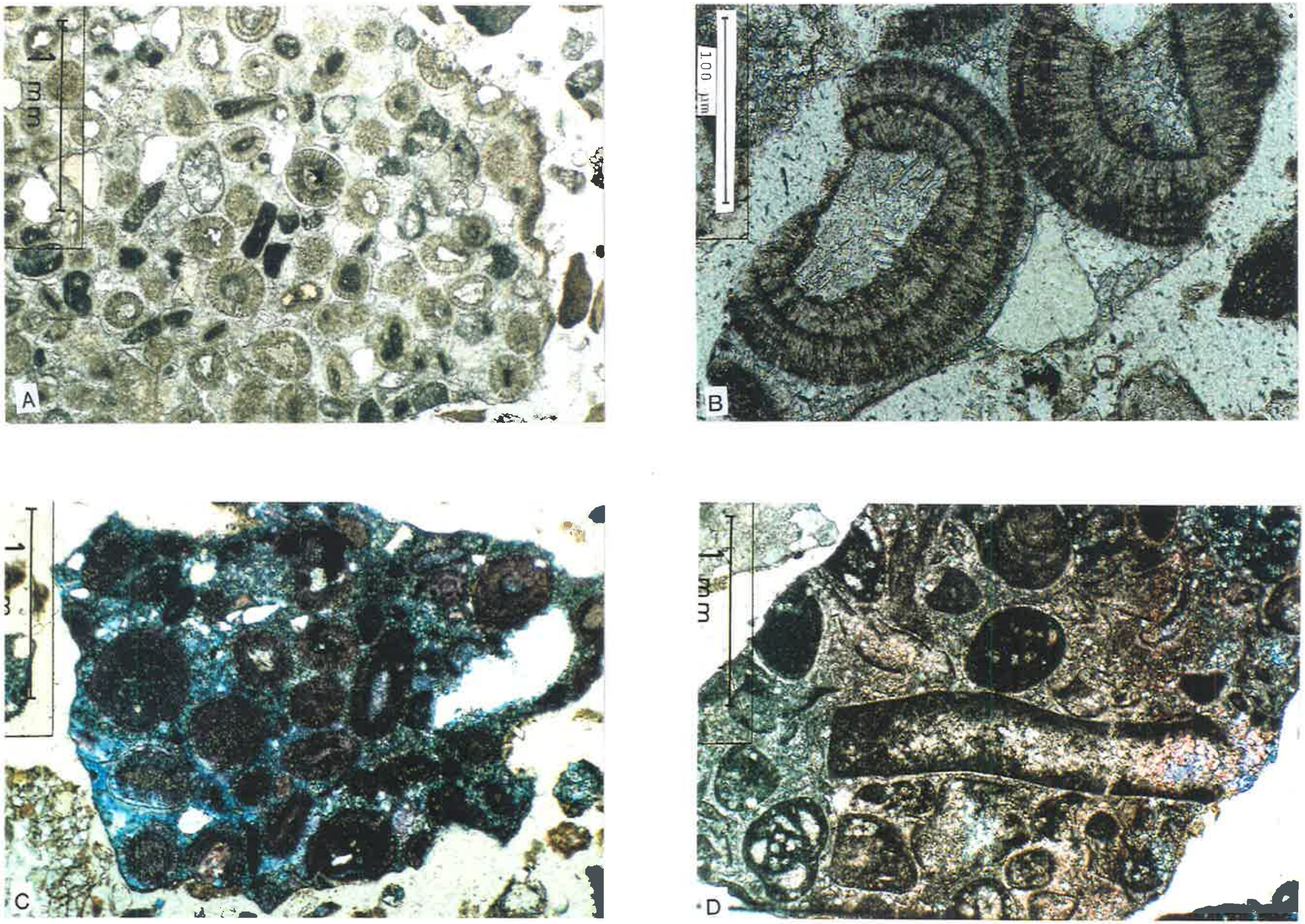
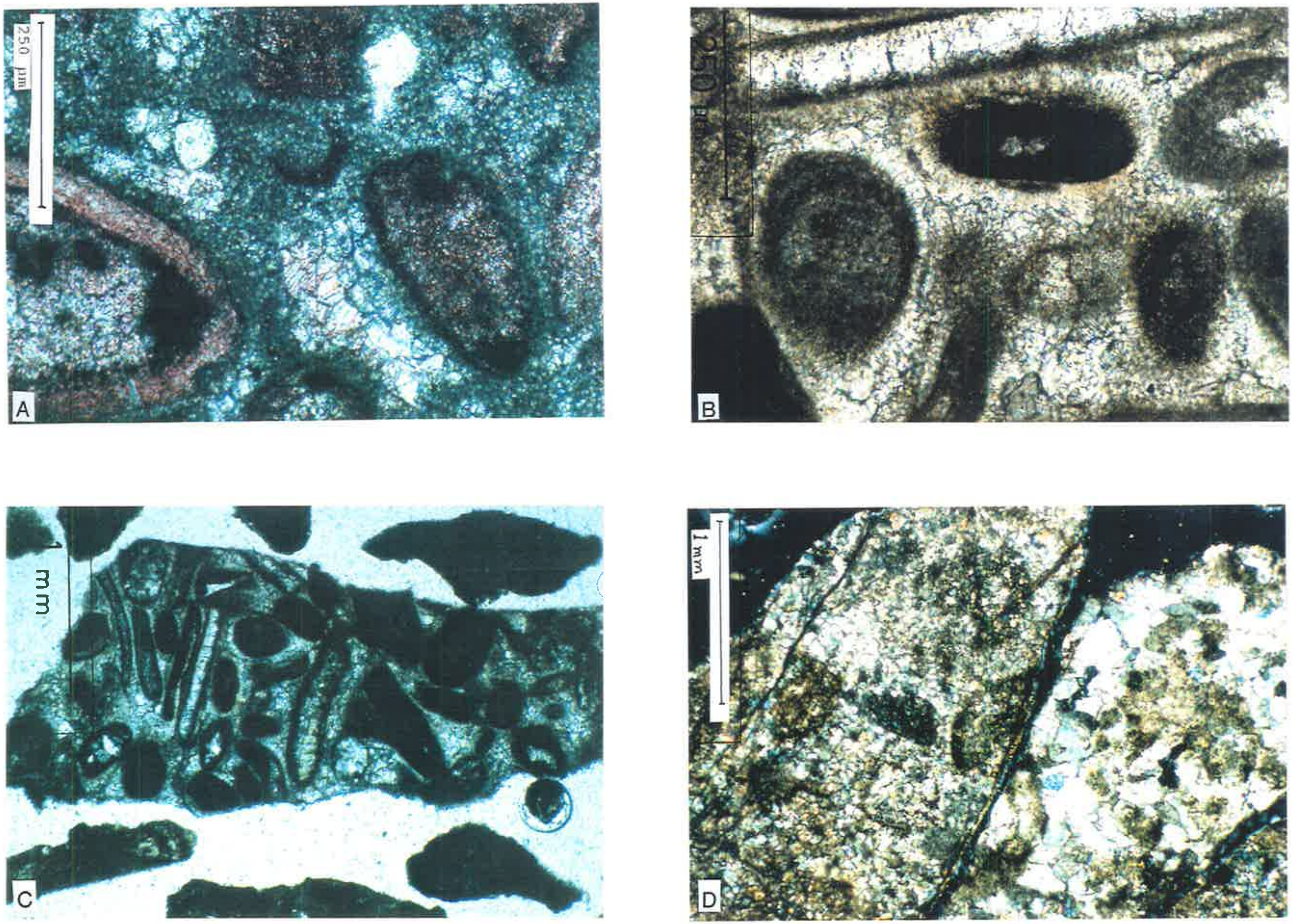

1 mm
A
100 µm
B
C
1 mm
D

PLATE 2 Lithofacies of Cossigny Member

A. Thin section from muddy peloidal wackestone facies showing micritized ostracod shell and peloids. Note the patchy development of the micrite to pseudospar. Phoenix-1, 3700 meters. PPL.

B & C. Most of the peloids from the muddy peloidal wckestone facies are faecal pellets The section also shows brachiopod and ostracod shells. The grains show a micritic envelop, with an irregular boundary between the envelopeand the grain. In C some shell walls have been leached and subsequently filled with blocky spar. 3670 meters. PPL.

D. Micrograph from muddy peloidal wckestone facies showing inequigranular crystals with xenotopic and hypidiotopic fabric. The dark patches are ghost structures of the dolomitized peloidal grains. Cossigny-1, 2924 meters. PPL.



250 µm
A
250 µm
B
1 mm
C
1 mm
D

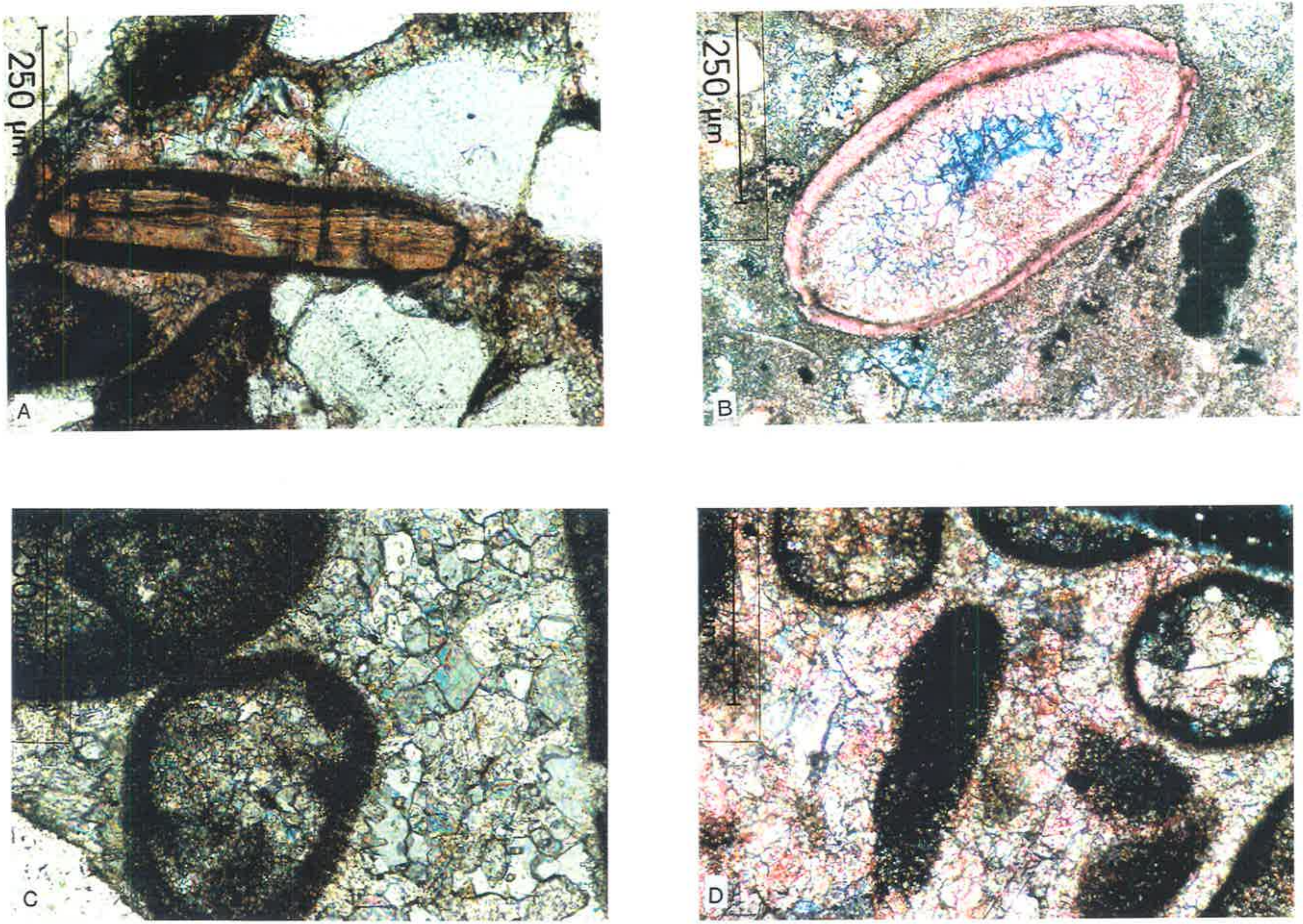
PLATE 3 Lithofacies of Cossigny Member

A. A micritized brachiopod shell with parallel fibrous structure running sub-parallel to the outer margin of shell. Phoenix-1, 3760 meters. PPL.

B. An ostracod shell filled with two generation cements. Fine grained fringe on inside of shell is followed by very coarse ferroan calcite spar. This is a typical void filling fabric. The matrix is pseudospar. Phoenix-1, 3700 meters. PPL

C. Mosaic texture of intergrown dolomite crystals. The micritic envelop of the grains is preserved because of its high organic content. The grains are surrounded by a fringe of calcite crystals. Cossigny-1, 2948 meters. PPL

D. Photograph shows a pellet in the centre of the field of view. The pellet has a characteristic round rod shaped outline of a faecal pellet. Recrystallised echinoid plates can be seen in upper part of the photograph. Note thickened coatings in embayed areas; this is typical of oolitic growth in moderately agitated waters. Phoenix-1, 3700 meters. PPL.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The ooids in this facies are spherical and the most common type of cortical fabric consists of radial-concentric crystals (Plate 1/A, 1/B) Heller et al., (1980). Wilkinson and Landing (1978) and Medwedeff and Wilkinson (1983) called this kind of fabric banded radial. In banded radial ooids, cortical layers with radial fabric locally alternate with layers composed of micritic calcite. The radial fibrous crystals of these ooids do not cut across concentric bands, suggesting the radial texture is not diagenetic (Heller et al., 1980).

Radial microfabrics have been the subject of considerable debate. It was once assumed that all ancient ooids were originally like the aragonite Bahamian ooids. The radial fabric of the ooids was considered to be a diagenetic feature formed during the replacement of aragonite by calcite (Shearman et al., 1970). However, the very delicate radial structure is quite unlike the typical aragonite to calcite replacement fabrics seen in limestones and this has led a number of workers to interpret these fabrics as original calcites (Simone, 1980, Sandberg, 1975, Wilkinson & Landing, 1978, Land et al., 1979; Milliman and Barretto, 1975). Many high Mg calcite ooids also retain a fine radial structure (Richter, 1983b). Similar ooids with primary radial-concentric textures have been observed forming in several modern environments such as Great Salt Lake (Sandberg, 1975; Halley 1977). Radial ooids of similar cortical fabric were found from the upper Smackover Formation, Swirydczuk (1988) interpreted such ooids as forming in a high-energy shoal with a calcitic origin.

Such primary calcite ooids may reflect different water chemistry to those forming at present. Friedman et al. (1973), Millman and Berretto (1975) and Halley (1977) have suggested that primary radial texture is formed under hypersaline conditions. Sandberg (1975) and Wilkinson (1979) have suggested that primary radial calcite ooids formed in Paleozoic and Mesozoic seas due to a lower concentration of Mg^{2++} which favoured the formation of calcite over aragonite during that time.

4.3.2. Mixed Oolitic-Peloidal Grainstone Facies

This facies overlays the ooid facies in Phoenix-2 and extends from 3610 to 3650 meters, while in Phoenix-1 it extends from 3700 to 3785 meters. This facies represents a transitional environment between the underlying moderate to high energy ooid shoal and overlying low energy lagoonal sediments. Peloids become increasingly prominent in this facies. The other important allochems of this facies are pellets, ooids and shelly fragments of ostracods, brachiopods and molluscs. The average size of the peloids is 200 microns. Most of the pellets are faecal in origin and show a characteristic rod shaped outline (Plate 2/A, 2/C and 3/D). Ooids generally constitute a smaller percentage of the framework grains and show a heterogenous fabric. Some ooids show a pronounced radial fabric and were probably transported from the adjacent sand shoal. The section also shows a range of locally produced ooids from those with a small nucleus and thick cortex to those with a large nucleus and a single oolitic lamina (Plate 5/A). Some echinoid fragments show thin superficial oolitic coatings. These coatings are characteristically thickened in embayed areas (Plate 3/D), and are typical of oolitic growth in moderately agitated waters. The rock is moderately sorted. The XRD trace in figure 4.4 shows calcite is the dominant mineral in this facies. Micritization of the grains is common in the mixed ooid-peloid grainstone facies. In thin sections, the micritic fabric is seen as a dark, featureless, and microcrystalline texture of the grains. Micritic fabric can result from the boring activity of endolithic algae in the marine setting (Bathrust, 1966), and can be developed in both originally aragonitic or originally calcitic ooids. Sediment of the mixed-ooid facies were stabilised by early marine cement. This cement occurs as an isopachous rim surrounding the grains. The interparticle and intraparticle porosities are filled by several generations of ferroan and non-ferroan sparry calcite cement.

The slight mud content of the sediment, bioturbation and micritization indicate that this facies was probably deposited in a semi-protected zone behind the ooid shoal. Peloids are an important constituent of shallow marine carbonate sediments. On the Great Bahama Banks west of Andros Island, the pellet mud facies covers 10 000 sq km. Many, if not all oolitically coated grains were probably swept from nearby shoals during large storms and deposited in these leeward areas. The character of sediment is typical of platform interior sand. The mixed-ooid-peloidal facies was less influenced by waves and currents than the

Phoenix - 2, 3685 meters, Oolitic grainstone facies.

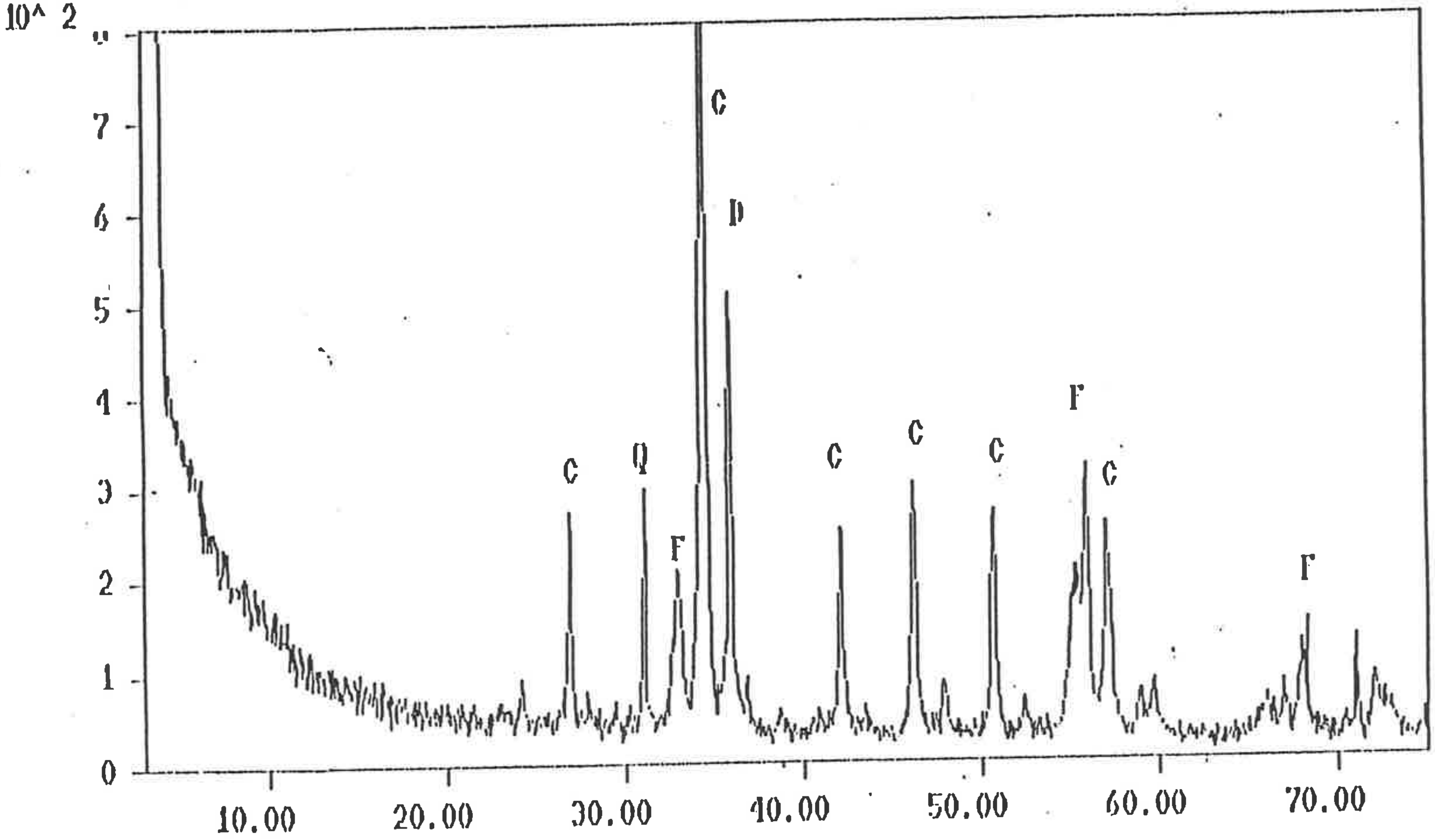


Figure 4.3.- XRD trace from a sample from Phoenix-2 at depth 3685 meters. Calcite (C) is the dominant mineral. (Q) represents quartz and (F) represents fluorite which was added to the samples as a standard.

Phoenix - 1, 3700 meters, Mixed ooid-peloid facies.

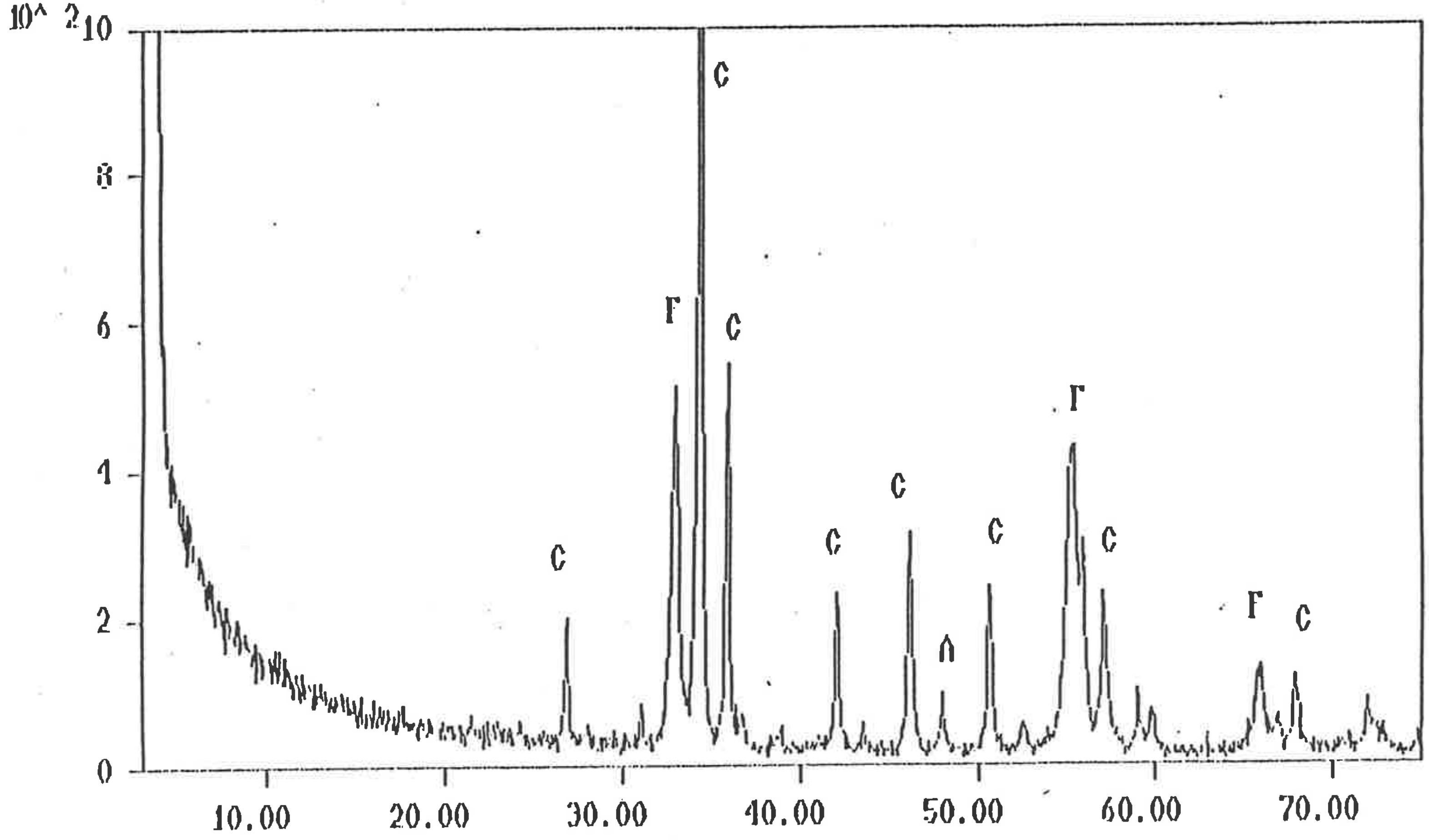


Figure 4.4.- XRD trace from a sample from Phoenix-1 at depth 3700 meters. Calcite (C) is the dominant mineral. (Q) represents quartz and (F) represents fluorite which was added to the samples as a standard.

Cossigny - 1, 2912 meters, muddy wackestone facies.

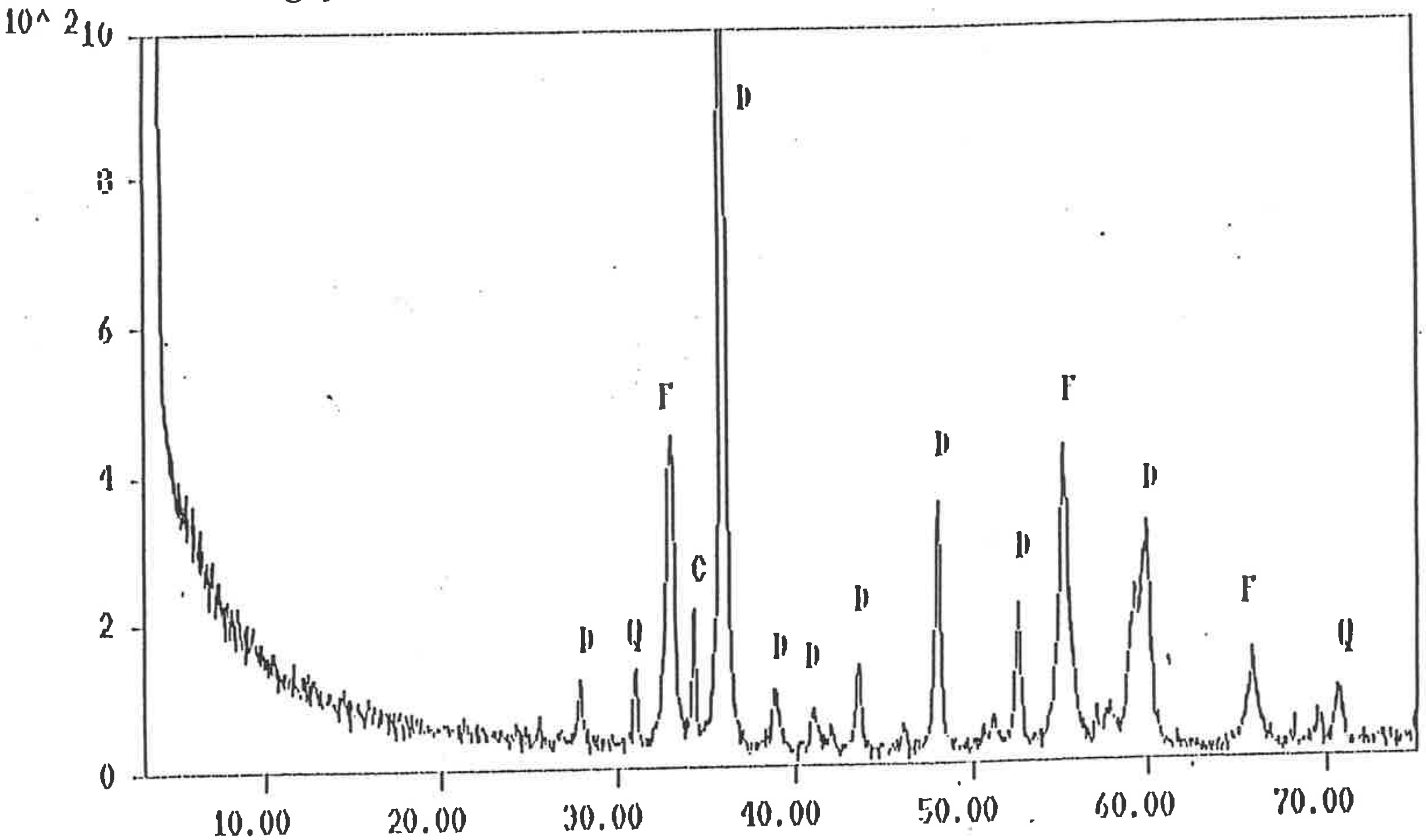


Figure 4.5.- XRD trace from a sample from Cossigny-1 at depth 2912 meters. Dolomite (D) is the dominant mineral. Traces of quartz (Q) are present in the sample. (F) represents fluorite which was added to the samples as a standard.

Cossigny - 1, 2922 meters, muddy wackestone facies.

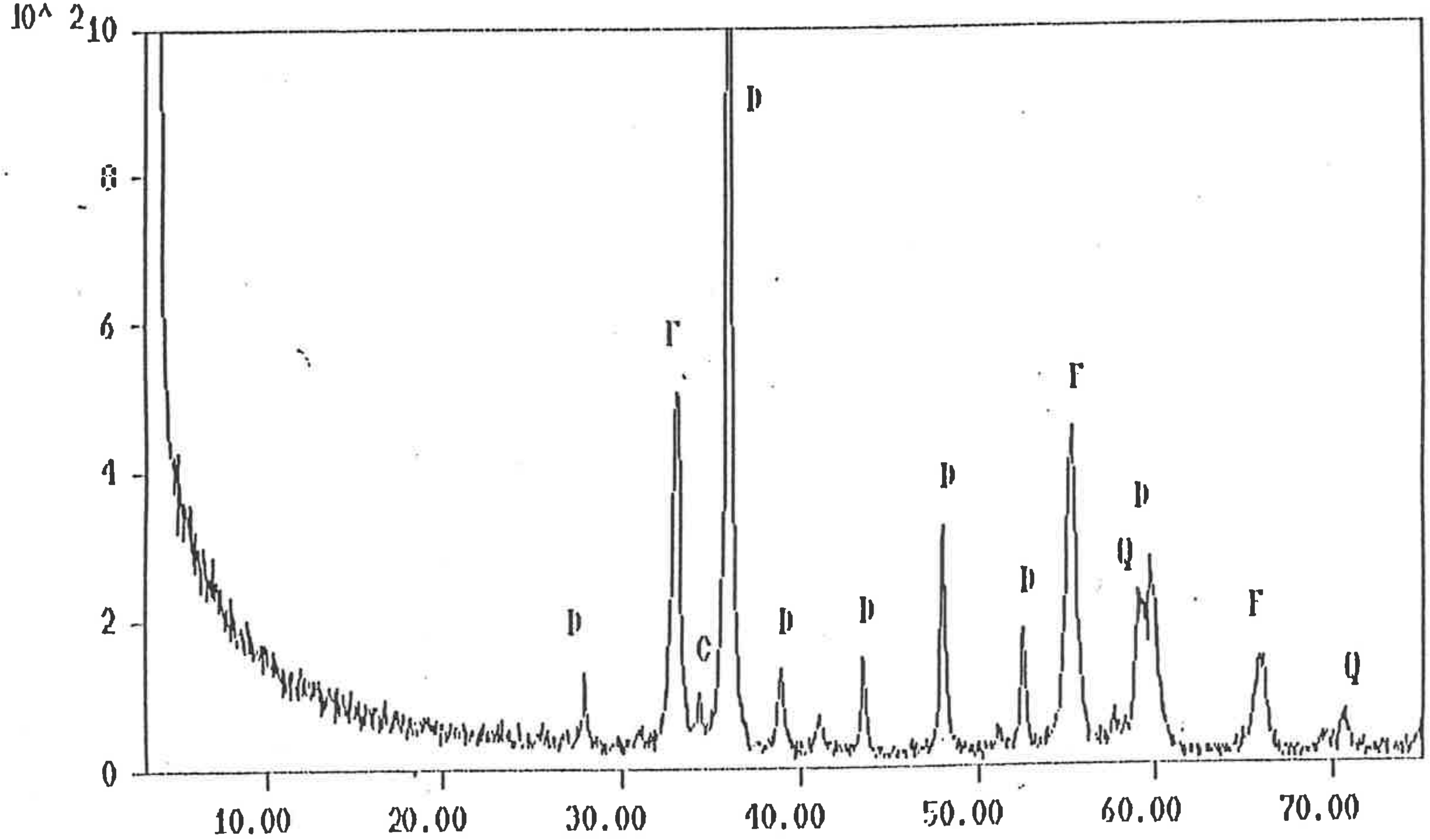


Figure 4.6.- XRD trace from a sample from Cossigny-1 at depth 2922 meters. Dolomite (D) is the dominant mineral. (Q) represents quartz and (F) represents fluorite which was added to the samples as a standard.

underlying pure-ooid wackestone, as evidenced by fewer ooids, more mud and poorer sorting (Plate 1/C).

4.3.3. Muddy Peloidal Wackestone Facies

The mixed-oolitic-peloidal grainstone facies grades upwards into a peloidal wackestone facies in Phoenix-1 and Phoenix-2 with total thickness of more than 30 meters. In Cossigny-1, it is more than 80 meters thick ranging from 2855-2935 meters. This facies was deposited in a lagoon shoreward from the ooid shoal. The sediment is, like its modern counterparts, muddy and intensely bioturbated. This facies dominantly consists of pellets and peloids (Plate 2/B & C). The average pellet size is 0.2 mm in diameter and they show the characteristic rounded, rod-shaped outline of the faecal pellets. The micritization of the grains is very dominant in this facies. Some bioclasts have been progressively micritized and developed into rounded particles (Plate 1/D). Because of their lack of any original fine structure these particles are called peloids. Beales (1958) called such peloids as Bahamites, because of their similarity to the carbonate sediments found in Bahama Bank. Micritization has also altered walls of miliolid foraminifera and the pore spaces filled with fine grained sparite (Plate 1/D). Micrite is the dominant matrix material and presumably represents an original carbonate mud. In some samples micrite shows a patchy recrystallization to pseudo-spar (Plate 5/C). In the Cossigny-1 well, the upper part of this facies has been dominantly dolomitized. The dolomitization is non-selective, altering both grains and matrix. The dolomitization has occurred probably by mixing of the marine water with meteoric water. The details of the dolomitization are given in the next chapter.

The rock is poorly sorted with a mud-supported framework, indicative of relatively calm conditions. The quiet-water environment supported a low-diversity community dominated by ostracods. The disarticulate and comminuted remains of gastropods, brachiopods and foraminifera are found throughout this facies and occur in all size ranges. However, skeletal debris does not account for more than 20% of the total rock.

Lithology	Facies	Environment	Eustacy Trns. Reg.	Bioclast	Comments
	Muddy Wackestone	**Lagoonal**			The rock is muddy and intensely bioturbated. This facies dominantly consists of pellets and peloids Micritization of the grains is very dominant. Micrite is dominant matrix material. The upper part of the facies is dominantly dolomitized.
	Mixed ooid-peloid grainstone	**Sand flat**			This facies consists of ooids, peloids, pellets and bioclasts. Most of the pellets are faecal in orgin and show a characteristic round rod shaped out line. Ooids show a heterogenous fabric. Some grains show superficial oolitc coatings. the rock is moderately sorted. The grains show micritic coating.
	Oolitic grainstone	**Ooid shoal**			The rock dominantly consists of well sorted, well rounded oolitic sands. Ooids show a radial microfabric. The radial texture of the ooids is original and not diagenetic. The matrix dominantly is medium to coarse grained sparite. Calcite is the dominant mineral with little dolomite.

Table 4.1.- This table show the different lithofacies of the Cossigny Member and their depositional environments.

The intense bioturbation, high mud content and mottled appearance of the sediments indicate that this facies was deposited in a lagoon landward to the ooid shoal. In modern environments such as west of Andros Island and in the Bight of Abaco, pellet muds are deposited in the most protected part of the platform, usually in a water depth of less than 4 meters (James, 1984a). Tidal currents and waves are weak in these environments. Faecal pellets and peloids are common in the lagoonal environment (Bathrust, 1975; Tucker, 1990). The low energy depositional environment is also supported by poorer sorting and little mechanical abrasion of the sediment and the presence of miliolid foraminifera (Plate 1/D) and more mud.

4.4. DEPOSITIONAL MODEL OF THE COSSIGNY MEMBER

The Cossigny Member was deposited within paralic/continental sediments of the Mungaroo Formation in the Beagle Sub-basin and Keraudren Formation in the Bedout Sub-basin. This carbonate unit was deposited in shallow water conditions on a broad gently sloping shelf, similar to the modern day Persian Gulf. Shelf refers to areas of extensive shallow-water environments bordered, on their shoreward side, by near shore or continental sediments and off shore by slope and basinal sediments (Wilson, 1975).

The Cossigny Member represents a transgressive then a regressive sequence and was deposited as a result of a short lived marine transgression during the Ladinian times (Blevin et al 1993, Bradshaw et al., 1988). The initial transgression resulted in landward migration of clastic sedimentation to higher on the shelf, allowing carbonate sedimentation to establish on the lower shelf. The off-shore ooid shoal was first deposited as the sea level rose. The moderately well sorted sediment, an almost pure oolite sand, was deposited on paralic Keraudren Formation. On the leeward side of the sand shoal was a sand flat. Ooids transported from the adjacent shoal were mixed with the locally produced sediments. Thus the resultant deposit was a moderately sorted mixed ooid-peloid grainstone facies. Landward of the shoal a muddy peloidal facies was deposited in a low-energy lagoonal environment. The sediment is like its modern counterparts, intensely bioturbated containing abundant faecal pellets. The quiet water environment of the lagoon supported a low diversity fauna.

A sea level drop during the late Ladinian stopped the oolite deposition. As a result of this regression, the environments were shifted basinward and lagoonal mud started to deposit on the sand shoal. In the shoreward Cossigny-1 well the whole sequence consists of bioturbated lagoonal sediments, which show little facies differentiation. Dolomitization of the sediments occurred as the supratidal environment regressed across the study area.

CHAPTER 5

DIAGENESIS OF THE COSSIGNY MEMBER

5.1. INTRODUCTION

Carbonate diagenesis operates in three principle environments (Fig. 5.1): the submarine, subaerial, and subsurface (Richard, et. al., 1985). The submarine environment refers to that area at or slightly below the sediment sea-water interface where diagenetic processes occur contemporaneously with sedimentation. Subaerial diagenesis occurs when sediments are exposed to the air, either as a result of vertical accretion or low stands of sea level. The subaerial environment includes the vadose (above the water table) and phreatic (below the

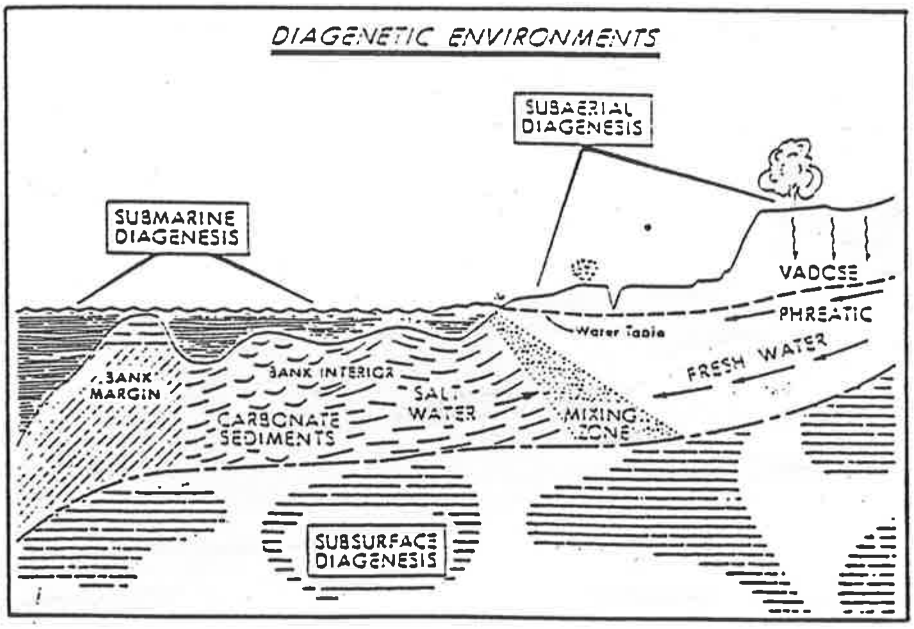


Figure 5.1.- --Schematic representation of the three major diagenetic environments (after Richard et al., 1985)

water table) settings. The subsurface environment is an extensive area occurring below the deeper reaches of the phreatic aquifer in carbonate rocks and is unaffected by near surface processes. The subsurface diagenesis can begin at a few tens of meters below the surface and extend to depths of thousands of meters. There are features of the cement fabrics and other textures which can be diagnostic of a particular diagenetic environment (Fig. 5.2).

Current studies have revealed that the Cossigny Member carbonates have gone through several phases of diagenesis; including micritization, several generations of cementation, and dolomitization. The stages at which most of the individual processes and products occur cannot be precisely defined. Two or more processes may be active simultaneously, they may overlap, or the termination of one may mark the commencement of another process. Still other alterations may occur independently in both space and time. To fully elucidate the multiple overprinting of these diagenetic effects is beyond the scope of this work. The following is a brief overview emphasising those textures which may be used to infer an original environment of deposition or better define the setting of subsequent diagenetic overprint.

The precipitation of cements in carbonate sediments is a major diagenetic process and takes

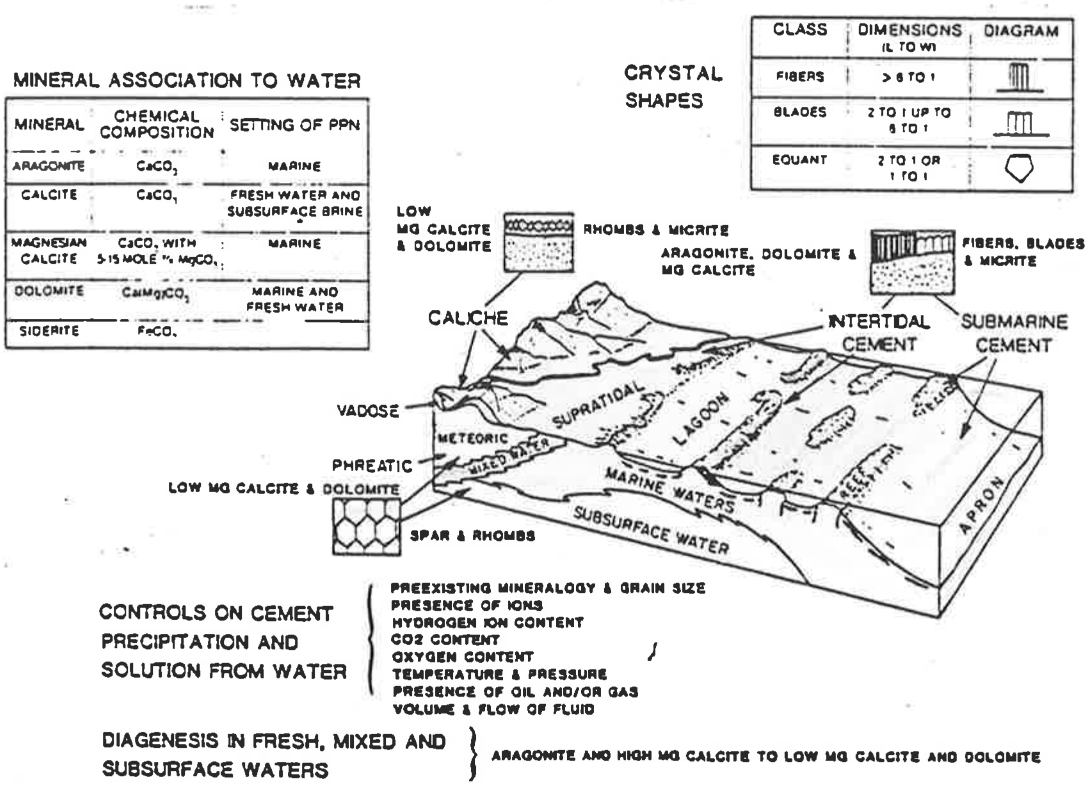


Figure 5.2.- Pattern in carbonate cementation for various environments (modified after Folk).

place when pore-fluids are supersaturated with respect to the cement phase and there are no kinetic factors inhibiting the precipitation. The cement is precipitated into cavities of many types and between grains. Many cement crystals show particular fabrics indicative of void-filling (Fig.5.2). Artificial staining (Dickson, 1966) is used in compilation of an overall "cement stratigraphy", (see Appendix II for identification of the different carbonate rock grains by staining method).

5.2. DIAGENESIS OF THE COSSIGNY MEMBER

5.2.1. Micritization and Micritic Cements

Micritization is a process whereby carbonate grains and bioclasts are altered while on the sea floor or just below by endolithic algae, fungi and bacteria. Micritization of carbonate allochems of Cossigny Member are nearly ubiquitous (Plate 2/B, 3/C, 1/D). Micritization is dominant in the muddy wackestone facies where the envelope normally develops around the periphery of the grains and has progressivly replaced the core by centripetal replacement (Bathurst, 1966). This progressive micritization has reduced the grains to a structureless opaque pseudomorph. In the mixed-ooid facies some ooids have lost all their fabric as a result of micritization and show a cryptocrystalline texture (Plate 1/C). The micritic envelop is preserved (Plate 3/D) because of its high content of organic matter (Kendall et al., 1973). The thickness of the envelope varies from 10-15 microns and the boundary between the micritic envelope and the skeletal core is seldom regular. Petrographic analysis of the samples indicate that the micritization of the Cossigny sediments was more prevalent in the lagoonal environments. Ooids from the underlying facies were not micritized to the same extent.

Bathrust (1964, 1966), Alexandersson (1972), Kobluk and Risk (1977b) and Schneider (1977) attribute the evolution of micrite envelopes to the process of boring and infilling. The mechanism involves repeated infillings of vacated algal borings on carbonate grains. The endolithic algae which are principally responsible for the perforation of grain surfaces are not directly responsible for the subsequent infillings of micrite cement. The micrite is presumed to precipitate in the boring posthumously after the algae decay (Bathrust, 1964; Kobluk and Risk, 1977a, 1977b). Taylor and Illing (1969) recorded that the recent calcarenites around the Qatar Peninsula in the Persian Gulf are bored by the algae to a depth of about 200 microns.

Besides the micritic envelope some grains from muddy wackestone and mixed-ooid facies show a coating of micritic cement on the outer surface of the particles and unlike micritic envelopes, line the walls of intragranular pores and outer surfaces of the grains. The micritic cement consists of a thin film 2-8 microns in thickness (Plate 4/B, 4/C). A close look at the photomicrographs 4/B and 4/C show the micritic calcite cement forms a regular isopachous coating around grains which appears as a dark line in thin sections, and is therefore distinct from micritic envelopes which result from alteration of particle surfaces. Micritic calcite is known to precipitate directly from sea water (Bricker, 1971).

5.2.2. Circumgranular Cement

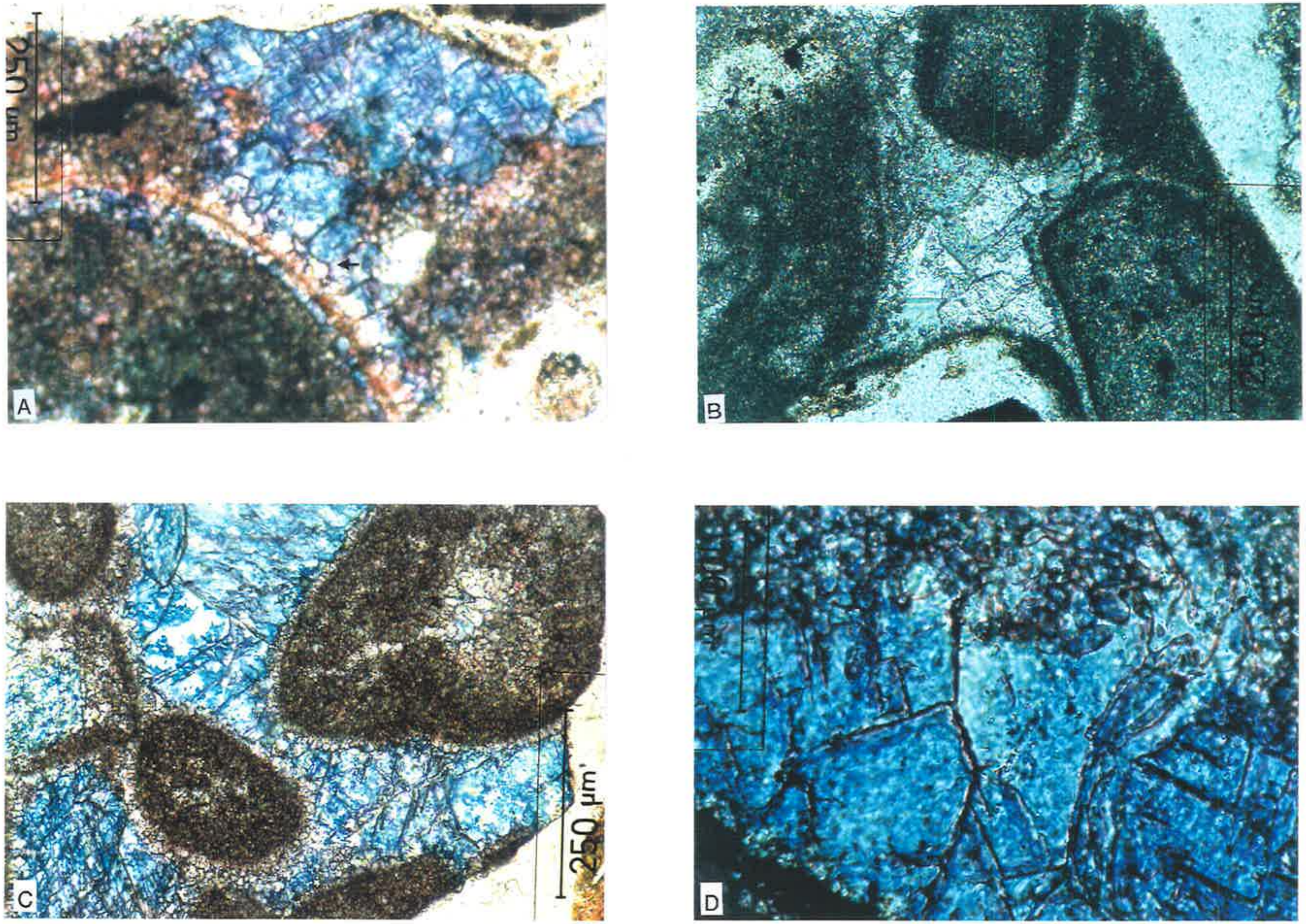
Artificial staining of the thin sections from the Cossigny Member reveal two cement generations filling the pore spaces. The first generation cement consists of pink-stained iron-poor calcite crystals. The crystals form an isopachous rim around ooids, peloids, and skeletal grains (Plate 1/B, 4/C, 4/A). The isopachous rim cement is followed by blocky euhedral calcite crystals. The crystals are often blue stained and occlude the remaining pore spaces. In the oolitic grainstone facies, the crystals of early cement form an isopachous fringe growing perpendicular to the substrate, and are uniformly distributed around the grains while as in the muddy wackestone facies it is non-isopachous (Plate 4/A). Crystals appear as poorly developed scalenohedra 4-8 micron in width and 10 -60 micron in length, with rhombic terminations. The boundary between the crystal foundations and the substrate is sharp. The isopachous cement is thought to be produced by continued growth on the upper faces of rhombs constituting the micritic calcite cement (Longman, 1980). This is an early diagenetic cement which prevented the grain to grain compaction by creating a rigid frame work in the sediments.

PLATE 4 Diagenesis of the Cossigny Member

A. Circumgranular bladed cement (arrow) growing perpendicular to the substrate. It is an early diagenetic cement of non-ferroan calcite. The pore space is filled with ferroan sparite. Phoenix-2, 3640 meters. PPL.

B. & C. Peloidal grains from muddy peloidal wackestone facies, grains show a rim of non-ferroan calcitic bladed cement. The remaining pore space is filled with blue stained ferroan calcite. Cossigny-1, A; 2948 meters, B; 2942 meters. PPL

D. Blue stained interpartical sparite. The intercrystalline boundaries in the mosaic are made up of plane interfaces with a high percentage of enfacial junctions. Phoenix-1, 3700 meters. PPL.


250 µm
A
250 µm
B
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C
D

PLATE 5 Diagenesis of the Cossigny Member

A. Thin section from mixed-oolitic-peloidal wackestone. Ooids have peloidal and quartz nuclei. Phoenix-2, 3620 meters. PPL.

B. Thin section showing two stages of cement generations, an early non-ferroan calcite surrounding the grains and a blue stained ferroan calcite growing in the pore spaces. Cossigny-1, 2948 meters.

C. An ostracod shell with micritic envelop. The shell is filled with red stained non-ferroan and blue stained ferroan cement. Micritic matrix with a patchy development to pseudospar form a significant proportion of the sediment. Phoenix-1, 3700 meters.

D. Thin section showing neomorphism. Note the patchy development and irregular intercrystalline boundaries. Cossigny-1, 2942 meters. PPL

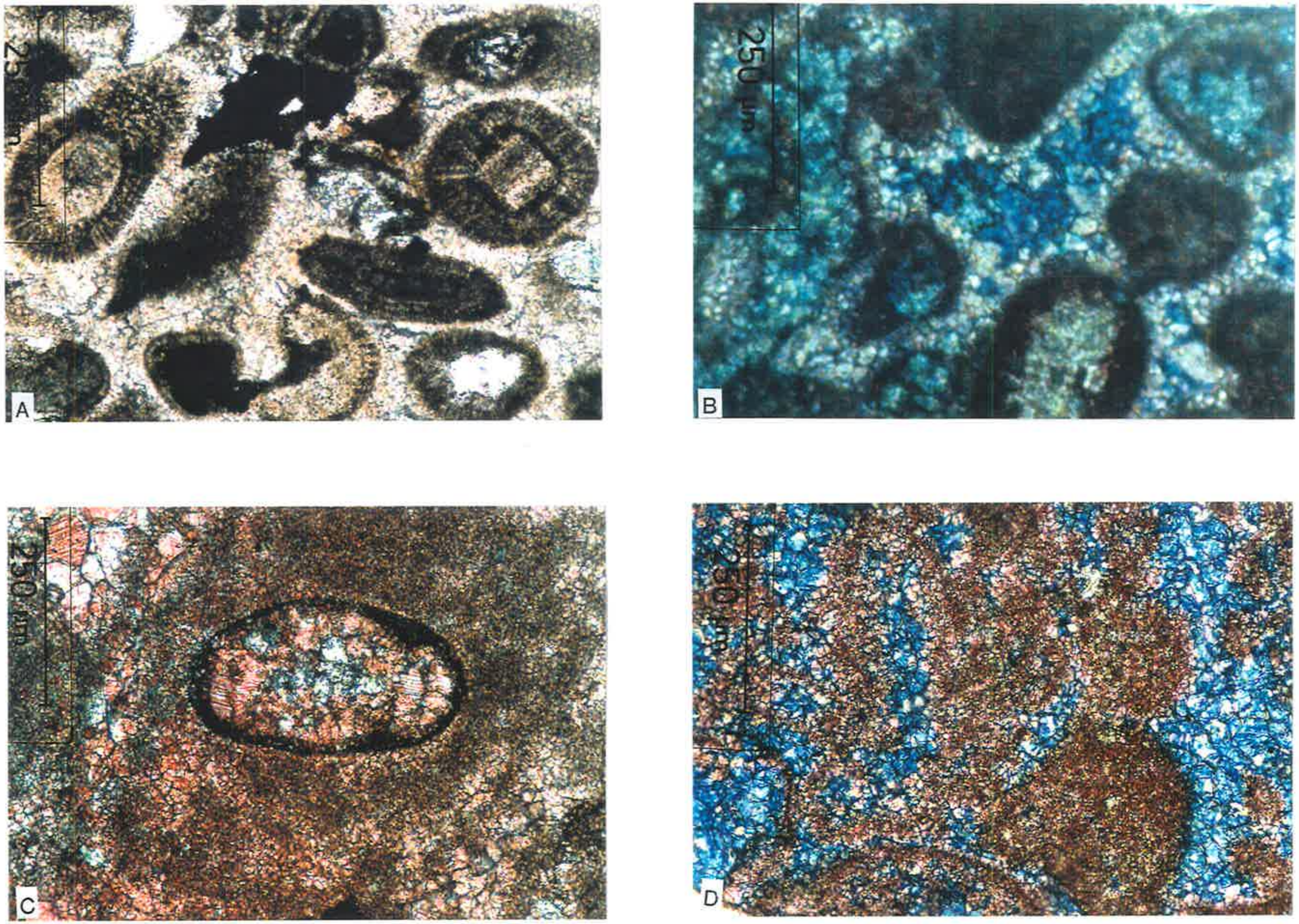

A
250 µm
B
250 µm
C
D

PLATE 6 Diagenesis of the Cossigny Member

A. Thin section from the muddy peloidal wackestone facies showing neomorphism of the grains and cement. Cossigny-1, 2942 meters. XPL.

B. Thin section showing fabric selective dolomitization of the peloids. Phoenix-1, 3725 meters.

C. Dolomite rhombs occluding porosity. Dolomites were formed in a mixing-zone environment. Phoenix-1, 3650 meters.

D. Thin section showing cross-cutting dolomitization. Cossigny-1, 2942 meters.

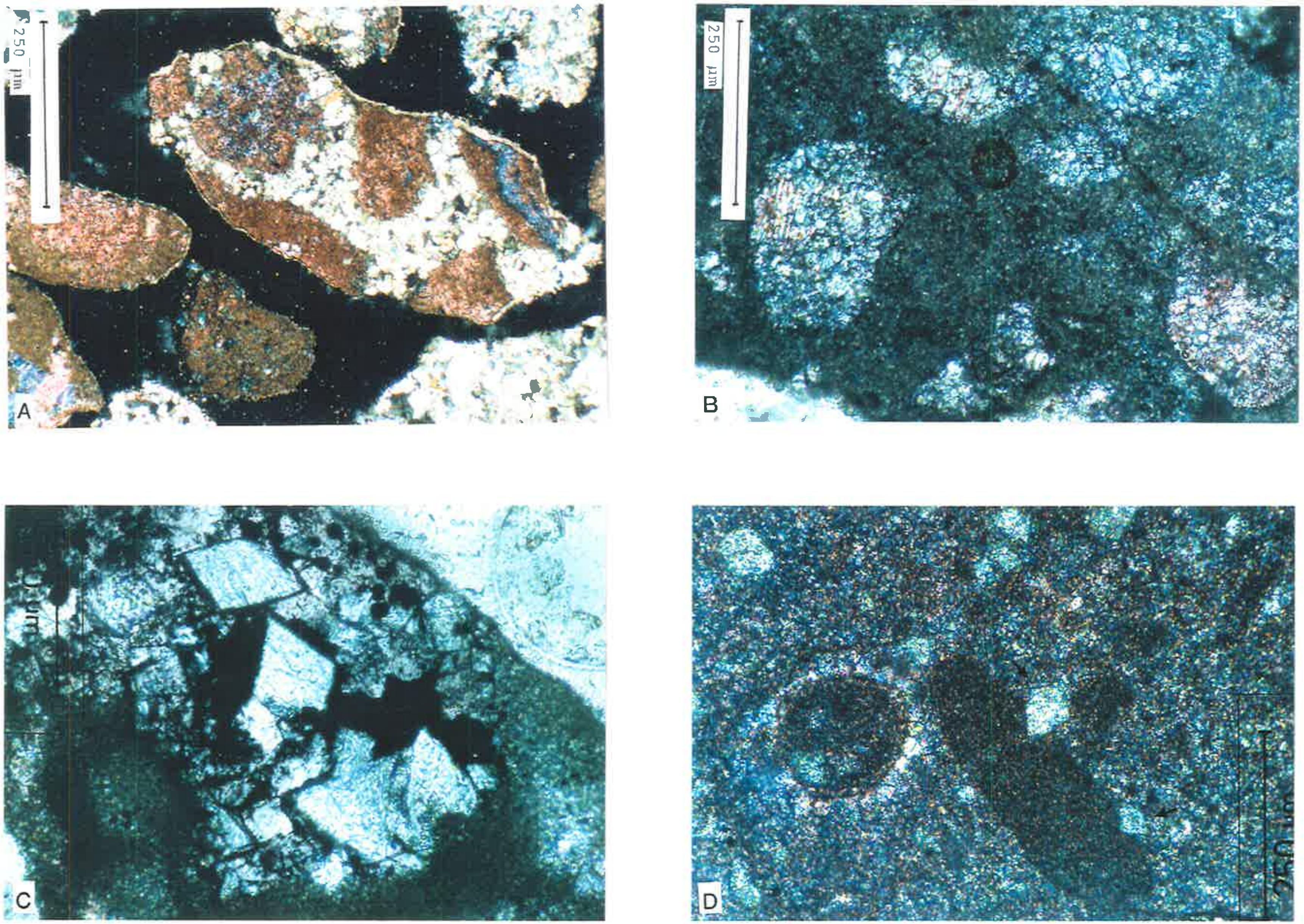

250 μm
A
250 μm
B
C
D

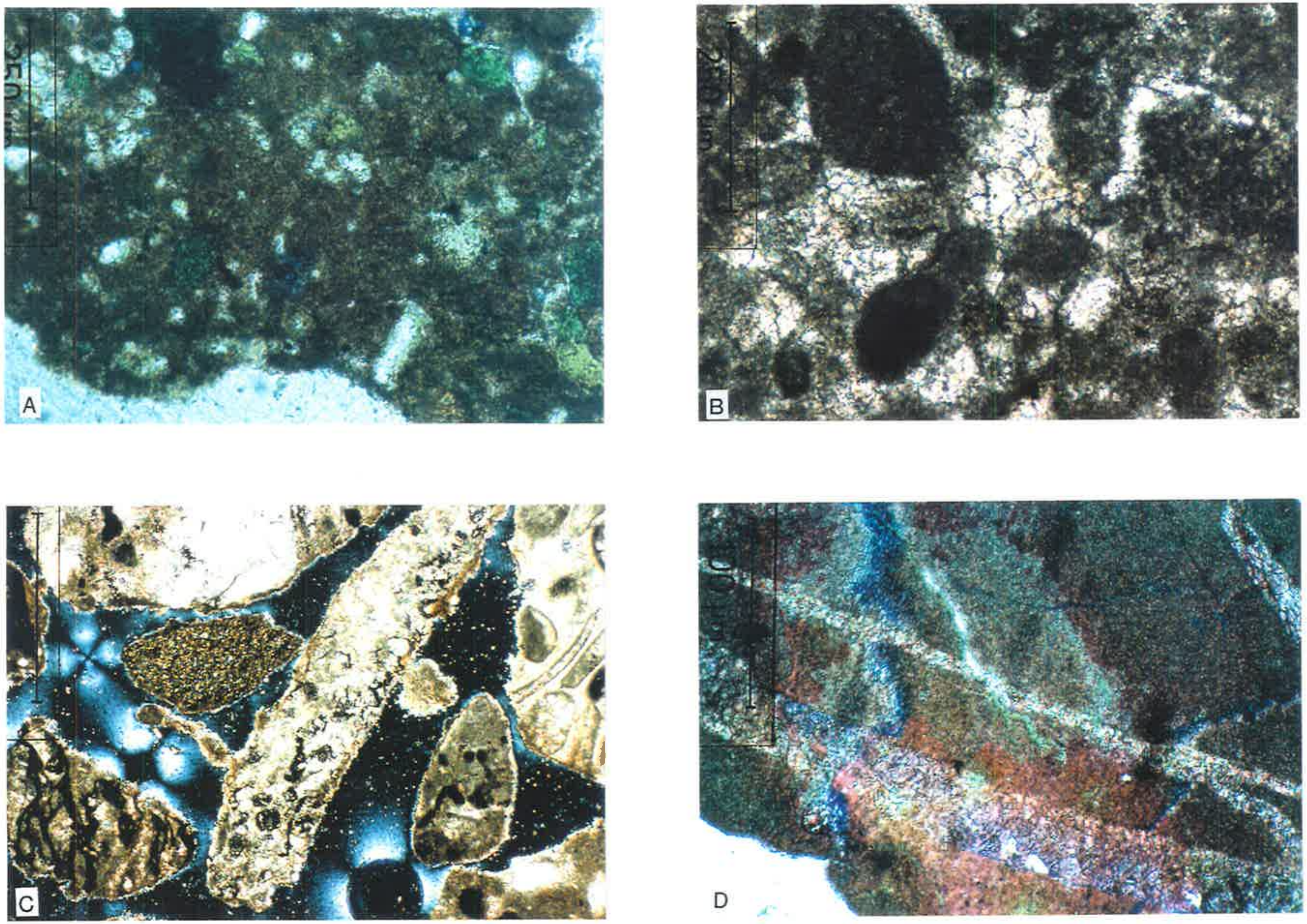
PLATE 7 Diagenesis of the Cossigny Member

A. Green patches of glauconite in a micritic ground mass. Glauconite is probably of faecal pellet in origin. Cossigny-1, 2942 meters. PPL

B. Porosity occluding dolomitization within a peloidal wackestone. Cossigny-1, 2878 meters. PPL.

C. Grains showing bioturbation, burrows filled with pyrite. Phoenix-1, 3670 meters.

D. Thin section showing irregularly arranged calcite veins, these are related to local tectonic movement. Cossigny-1, 2948 meters.


A
B
C
D

Bladed calcite cement precipitates from marine waters (Bricker, 1971). Petrographic analysis show no relics of original aragonite in the Cossigny carbonate grains or cements, indicating a calcitic precursor. The isopachous cement of the Cossigny Member is clear with optically and morphologically radial texture such calcite cements cannot be derived from aragonite precursor (Sandberg, 1975). Kosteck (1978) presented a careful appraisal of the possible origins of such fine radial cements from the Triassic of Poland, rejecting an inference of pseudomorphic calcitization and concluding that they must have been originally calcitic.

5.2.3. Intergranular Cement

The second generation of cement consists of a blocky mosaic made up of equant anhedral crystals. The crystals are composed of blue stained ferroan calcite (Plate 4/A, and 5/B). This cement grows centripetally into the voids or the intraskeletal cavities remaining after the formation of the first generation cement. The calcite is coarsely crystalline (average crystal size 0.5 mm). Crystal size normally increases away from the substrate indicating high original crystal nucleation and its precipitation probably in a fresh water phreatic environment (Halley and Harris, 1979), and Longman (1980). In plane light, the crystals are transparent and clear, and show plane intercrystalline boundaries and enfacial junctions (Plate 4/D). The boundary between the drusy mosaic and the substrate is sharp.

5.2.4. Neomorphism

This term was introduced by Folk (1959) to cover processes of replacement and recrystallization where there may have been a change of mineralogy. Recrystallization, on the other hand, strictly refers to changes in the crystal size without any change of mineralogy.

Neomorphism is common in fine grained sediments from the muddy wackestone facies, some samples from mixed-ooid facies also show neomorphic spares. The fabric exhibits a mosaic form with irregular crystal boundaries (Plate 5/D) when viewed under plane polarised light. When seen under crossed polars, however, the irregular crystal boundaries often display planar interfaces. This feature indicates the existence of earlier or relict crystal faces prior to neomorphic recrystallization or overgrowth development. The fast vibration direction of the neomorphised cements are randomly oriented and have undulose extinction. Micritic sediments from the muddy wackestone facies also show a patchy development of fine grained pseudospar. The pseudospar is often cloudy and contrasts with the coarse clear mosaic replacing the wall in the same samples (Plate 5/B).

5.2.5. Dolomitization

Dolomitization of the Cossigny Member is dominant in the upper part of the muddy peloidal wackstone facies. Dolomitization is pervasive, altering both grains and cements. Where dolomite has replaced ooids and peloids, it contains abundant inclusions of organic matter and pyrite which mark the grains former existence (Plate 2/D). On the other hand, dolomite that has replaced intergranular cement is cleaner showing an euhedral texture with an average crystal size of 100 microns. In some samples dolomite occurs as isolated crystals or small crystal aggregates of euhedral to subhedral idiotopic to hypidiotopic texture. Dolomite contains some relics of the original calcite. Some grains show dolomite rhombs cross-cutting the original fabric,(Plate 6/D). Clear coarse grained dolomite rhombs also occur as pore filling cement in some samples from the mixedoolitic-peloidal grainstone facies (Plate, 6/A).

Dolomite is a complex diagenetic mineral and forms in many depositional settings. A number of dolomitization models have been given by different authors. They are:

1. Sabkha model
2. Brine-reflux model
3. Coorong model
4. Mixing-zone model
5. Sulfate-reduction model
6. Burial-stage model
7. Solution-cannibalisation model

To fully define the dolomitization of the Cossigny Member is beyond the scope of this work. In the absence of core and reliance on ditch cuttings it is difficult to predict a dolomite model for the Cossigny Member. Petrography points out the possibility of a mixing-zone dolomitization for the Cossigny Member sediments. Mixing-zone models can be used only when sediments were dolomitized in humid settings. Triassic climates were temperate to warm (Dickins, 1985) and humid, as indicated by coal occurrences. Redbed sediments suggest that there may have been periods of seasonal aridity in the Middle and Late Triassic. Arid-zone settings lack sufficient fresh water to form an extensive mixing zone and their meteoric water flow rates are too sluggish to supply the required volume of magnesium (Warren, 1989). The mixing zone dolomitization is also supported by the presence of an unconformity at the top of the Cossigny Member; Ancient mixing-zone dolomites often occur directly below regional unconformities (Warren, 1989). Occurrence of glauconite in the samples Cos-1, 9440 and Cos-1, 9500 from the muddy wackestone facies discount the sabkha modal. Glauconite occurs principally in sandstones, siltstones, mudstones and limestones, but is never associated with evaporitic deposits or other chemical deposits (Odin and Matter, 1981).

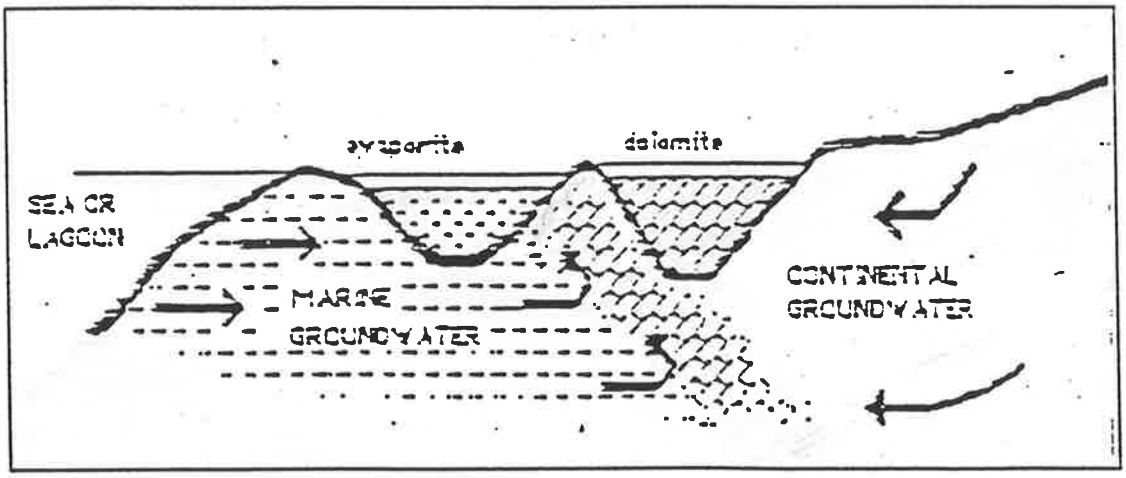


Figure 5.3-- Schematic representation of the mixing-zone dolomitization model (after Warren, 1989)

The model involves forming a dolomitizing solution by the subsurface mixing of seawater and meteoric water (Fig 5.3). It was first used by Hanshaw et al., (1971), and by Land (1973a and 1973b) to explain dolomite in Quaternary limestones in Florida and Bermuda. In chemical sense the mixing zone process is quite simple. When CO_2-saturated meteoric groundwaters mix with seawater, the resulting solution may be unsaturated with respect to $CaCO_3$ and supersaturated with respect to dolomite. A mechanism for introduction of fresh water into subsurface sediment exists in certain modern settings. Magaritz et al., (1986) reported mixing-zone dolomites forming at the coastal zone of Israel. The dolomite rhombs found in this area are subhedral up to 50 microns across. Back et al. (1986) reported that within the sediments underlying both the Florida and Yucatan peninsulas, a lens of fresh water and a thicker zone of brackish water overlie an extensive body of salt water.

5.2.6. Authigenic Glauconite

Very rare traces of authigenic glauconite have been identified in several thin sections of the Cossigny Member. The glauconite occurs as a slightly pleochroic bright green mineral occurring in small patches and is common in muddy wackestone facies (Plate 7/A). The samples studied under the microscope show faecal pellets form the predominant substrate for glauconitisation in the wackestone facies. Glauconite of faecal origin has been recorded from many ancient and modern sediments (Giresse and Odin, 1973). Most of the glauconite grains in the samples studied from the muddy wackestone facies are true faecal pellets and are, therefore, essentially characteristic of the inner part of the continental shelf. Millot (1949) recorded authigenic glauconite present in lagoonal deposits at Pechelbronn (France). Odin and Matter (1981) limit glaucony formation to quiet marine waters, below wave base, with cool temperatures. Glaucony is also regarded to be unstable to survive reworking. Glauconite occurs principally in sandstones, siltstones, mudstones and limestones, but is never associated with evaporitic deposits or other chemical deposits (Odin and Matter, 1981).

5.2.7. Pyrite

Pyrite normally forms during early diagenesis and it is one of the best known authigenic minerals (Berner, 1981). In thin sections pyrite occurs as a thin black mass, round, occasionally oval-shaped and often infilling worm burrows (Plate 7/C). Pyrite is randomly distributed throughout the rock.

Formation of pyrite is well known as originating in the reaction between H_2S from bacterial sulphate reduction and reactive detrital iron minerals (Berner, 1980). The amount of pyrite formed in a sediment depends on three factors; These are, the availability of dissolved sulfate, the concentration of the organic matter which can be metabolised by the sulfate reducing bacteria, and the concentration of iron minerals in the environment.

5.2.8. Calcite Veins

The calcite veins occur as an irregular crosscutting network. The calcite veins are displacive and in sharp contact with the host wall rock. The vein fill consists of a medium crystalline subhedral to anhedral ferroan and non-ferroan calcite spare with rare pyrite (Plate 7/D). The veins show an irregular arrangement and are related to local tectonic movements.

5.3. SUMMARY OF DIAGENETIC HIŞTORY

Diagenesis in the Cossigny Member began immediately following deposition, and probably at the sediment water interface. Some of the grains are completely micritized, indicating significant biochemical activity at the seafloor. Immobilised grains were subject to metabolic activity of algae that, with time, triggers micritization in the grains. Other organisms such as foraminifera and bacteria also played a role in micritization of the Cossigny Member sediments. Most of the grains from mixed-ooid facies ånd muddy lagoonal facies are surrounded by a dark micritic cement, which precipitated from sea water.

Formation	FACIES	Micritization	Isopachous circumgranular cement	Intergranular cement	Dolomitization
COSSIGNY MEMBER	Muddy Wackestone				
	Mixed ooid-peloid Grainstone				
	Oolitic Grainstone				
		Early			Late

Table 5.1.- Major diagenetic events identified in the Cossigny Member Carbonates. Thickness of the coloured bars show the intensity of the diagenetic processes.

The micritic cement is, in most grains, coated by a late bladed cement. This second generation cement was probably deposited in a marine phreatic environment (Bricker,1971). This cement formed a rigid framework and thus prevented early grain to grain compaction of the sediments. The last generation of cement is an equant spar that fills the rest of the pore spaces. The coarsening of cement crystals toward the centre of pores indicates that this cement was probably deposited in a meteoric-phreatic environment (Friedman, 1968; Longman, 1980).

In the Cossigny-1 well the muddy wackestone facies is dominantly dolomitized in the upper part. The dolomites have replaced both the constituent grains as well as the cements. The dolomites were probably formed by the mixing of meteoric water with sea water, the resultant brackish water was supersaturated for dolomites (Badiozamani, 1973). The influx of meteoric-water for dolomitization occurred probably during the period of subaerial exposure.

The major diagenetic events which took place are;

1- micritization and micritic cementation.

2- early marine cementation

3- equant intergranular cementation

4- neomorphism

5- dolomitization.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Triassic sediments in the Northern Carnarvon Basin are clastic-dominated and are distributed as a thick "blanket" with identifiable depocentres. Notable depocentre Barrow-Dampier Sub-basins, the Exmouth Plateau Arch, Browse Basin and the Malita Graben. All these basins are aligned along the northeast-southwest trend. The Cossigny Member represents the only significant carbonate deposition in the Triassic of the Beagle and Bedout Sub-basins. Interest in the Triassic carbonates has increased since the discovery of a new exploration reef play of Late Triassic age on the Wombat Plateau. At this stage, reef complexes of Late Triassic Early Jurassic age are known only from the Wombat Plateau (Williamson et al., 1989). The Wombat Plateau lies at the western end of the North West Shelf, which was part of the southern margin of a warm Tethys Ocean in the Late Triassic, at a palaeolatitude of 25-30 degrees South (Bradshaw et al., 1988). Williamson et al.(1989) suggest that the reefs are likely to be present only on the outer shelf and slope. The facies interpretation indicates that the Cossigny Member was deposited on an inner shelf in shallow water environment.

The Cossigny Member represents a transgressive than a regressive sequence and was deposited following a Ladinian transgression (Ingram 1990). Three major lithofacies are recognised in the Cossigny member;

Oolitic grainstone facies

Mixed ooid-peloid grainstone facies

Muddy peloid facies

The Oolitic grainstone facies was deposited in a moderate to high energy ooid shoal environment. The ooids show a concentric-radial fabric. This fabric represents the original fabric of the ooids and not a diagenetic one. Overlying this facies is mixed-ooid facies deposited on the leeward side of the ooid shoal. Most of the ooid grains in this facies were swept off from the ooid shoal and mixed with locally formed peloidal grains. Muddy peloid facies represents the uppermost depositional unit of the Cossigny Member. This facies was deposited in a lagoon shoreward to the ooid shoal and dominantly consists of faecal pellets and peloids.

The carbonate grains of the Cossigny Member have under gone several phases of diagenesis. Micritization is common in mixed ooid facies and dominant in muddy facies. The grains show an early marine cementation. This cement is seen as bladed crystals growing on a previously micritized surface. The bladed cement was responsible for creating a rigid framework in the rock and thus preventing grain to grain compaction. The last phase of cementation is an equant spar with an increasing grain size towards centre, indicating precipitation in a meteoric environment. Dolomitization is very dominant in the upper part of the member. The dolomites were probably formed by the mixing of meteoric water with sea water.

No reef sediments were found in the samples studied. The acquisition of a high resolution seismic across the study area can be helpful to identify the different carbonate facies. If reefs are the target then this survey should be designed to acquire a good coverage of the slope and outer shelf ares where the presence of the reefs is more likely. While the current seismic coverage appears extensive, much of data is old and of moderate to poor quality. However, its quality is adequate for the correlation of the Cossigny Member over the inner shelf area. The coring of the Triassic carbonate intervals is further recommended to help understand the process of dolomitization and allow a better understanding of cement stratigraphy.

The hydrocarbon potential of the Triassic sediments in the Beagle or Bedout Sub-basins can not be discounted . The fluvio-deltaic/epicontinental sandstones of the Keraudren Formation and Mungaroo Formation are considered as potential reservoirs (Parry and Smith, 1988; Crostella and Barter, 1980). The chemical analysis shows Locker Shale to be organic-rich (Cook and Kantsler (1980), Alexander (1986). Geologists consider the Locker Shale to be the source for the gas discovered on the Exmouth plateau (Brikke, 1982). Kopsen and McGann (1985) reported that thin zones above the basal transgressive sandstone in the Locker Shale are enriched in sapropel and have distinct oil generating potential. Whether the Cossigny Member locally acts as a seal or reservoir is clearly of critical importance where vertical migration from Lower to Middle Triassic source rock is invoked.

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APPENDICES

APPENDIX - I SAMPLE LIST

Sample No.	Depth in meters	Well Name	XRD	Petrographic Analysis	Lithofacies
Cos-1	2878	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2884	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2890	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2896	Cossigny-1	Yes	Yes	Muddywacke stone facies
Cos-1	2902	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2911	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2918	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2924	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2932	Cossigny-1	Yes	Yes	Muddy wackestone facies
Cos-1	2942	Cossigny-1	Yes	Yes	Muddy Wackestone facies
Pnx-1	3650	Phoenix-1	Yes	Yes	Muddy wackestone facies
Pnx-1	3660	Phoenix-1	No	Yes	Muddy wackestone facies
Pnx-1	3670	Phoenix-1	No	Yes	Muddy wackestone facies
Pnx-1	3680	Phoenix-1	No	Yes	Muddy wackestone facies
Pnx-1	3700	Phoenix-1	Yes	Yes	Mixed ooid-peloid facies
Pnx-1	3725	Phoenix-1	Yes	Yes	Mixed ooid-peloid facies
Pnx-1	3740	Phoenix-1	No	Yes	Mixed ooid-peloid facies
Pnx-1	3760	Phoenix-1	Yes	Yes	Mixed ooid-peloid facies
Pnx-2	3580	Phoenix-2	No	Yes	Muddy wackestone facies
Pnx-2	3585	Phoenix-2	Yes	Yes	Muddy wackestone facies
Pnx-2	3600	Phoenix-2	Yes	Yes	Muddy wackestone facies
Pnx-2	3640	Phoenix-2	Yes	Yes	Mixed ooid-peloid facies
Pnx-2	3645	Phoenix-2	Yes	Yes	Mixed ooid-peloid facies
Pnx-2	3660	Phoenix-2	Yes	Yes	Oolitc grainstone facies
Pnx-2	3685	Phoenix-2	No	Yes	Oolitic grainstone facies
Pnx-2	3700	Phoenix-2	Yes	Yes	Oolitic grainstone facies

APPENDIX - II THIN SECTION STAINING

Thin section Staining

The optical properties of calcite and dolomite are similar and therefore they can be difficult to distinguish optically. Simple chemical staining techniques are often employed by carbonate sedimentologists to distinguish calcite from dolomite and to distinguish ferroan from non-ferroan minerals. The procedure adapted in this thesis is after Dickson (1965), and is detailed below:-

1. Two staining solutions were prepared;

   Solution A: Alizarine Red S - concentration of 0.2g/100 ml of 1.5% hydrochloric acid (15 ml pure acid made up to 1 litre with water)

   Solution B: Potassium ferricyanide - concentration 2g/100ml of 1.5% hydrochloric acid.

2. Solution A and B were mixed in the proportion 3 parts by volume of A to 2 part of B

3. The thin section (with no coverslip on) were cleaned to ensure that no dirt or grease is adhered to the surface. Half of the thin section was then immersed in the mixture of solutions for 30 - 40 seconds, agitating gently for at least part of the time to remove gas bubbles from the surface.

4. The stained section were washed in running water for a few seconds and allowed to dry.

5. The section was then covered with a coverslip in the normal way.

Results of the staining process are shown below in the Table:

Mineral	Combined results with solutions A & B
Calcite (non-ferroan)	Pink to red-brown
Calcite (ferroan)	Mauve to blue
Dolomite (non-ferroan)	colourless
Dolomite (ferroan)	Very pale blue (appears turquoise or greenish in thin section)

APPENDIX - III

CARBONATE ROCK CLASSIFICATION (After Dunham, 1962)

Dunham's classification (1962) and modifications by Embry and Klovan (1971) is widely used in carbonate petrography. Dunham's classification is primarily textural in nature, it is simple, and easily used in the field. Dunham's major rock classes are based on the presence or absence of organic binding, presence or absence of carbonate mud and the grain versus matrix support.

<table>
<tr><th colspan="5">DEPOSITIONAL TEXTURE RECOGNIZABLE</th><th rowspan="2">DEPOSITIONAL TEXTURE NOT RECOGNIZABLE</th></tr>
<tr><td colspan="4">Original Components Not Bound Together During Deposition</td><td rowspan="4">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.</td></tr>
<tr><td colspan="3">Contains mud (particles of clay and fine silt size)</td><td rowspan="3">Lacks mud and is grain-supported</td><td rowspan="2">Crystalline Carbonate</td></tr>
<tr><td colspan="2">Mud-supported</td><td rowspan="2">Grain-supported</td></tr>
<tr><td>Less than 10 percent grains</td><td>More than 10 percent grains</td><td rowspan="2">(Subdivide according to classifications designed to bear on physical texture or diagenesis.)</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Boundstone</td></tr>
</table>

APPENDIX - IV

PETROGRAPHIC DESCRIPTION OF THE ROCK SAMPLES

SAMPLE NO.: Pnx-1, 3760 **WELL:** Phoenix-1

FORMATION: Cossigny **DEPTH:** 3760 Meters

ROCK TYPE: Mixed oolitic-peloidal grainstone

DESCRIPTION

The rock is mainly composed of pellets, peloids and ooids. The thin section also shows shelly fragments of echinoids, ostracods and brachiopods. The peloids are spherical with an average size of 0.5mm. Some of the echinoid fragments show thin superficial oolitic coatings. These coatings are thickened in embayed areas, this is typical of oolitic growth in moderately agitated waters. Micritization of the allochems is common and has altered some grains into a cryptocrystalline mass. The sediments show complete interpartical cementation by fine grained non-ferroan sparite. The rock is moderately sorted, and shows no visible porosity.

DIAGENETIC FEATURES

-Micritization of the framework grains

-Radial cement surrounding the grains

-Pore space filled with blue stain non-ferroan cement.

-The rock shows some degree of dissolution.

-Dolomitization

XRD ANALYSIS

XRD analysis show calcite as the dominant mineral with minor dolomite.

SAMPLE NO.: Pnx-1, 3725 **WELL:** Phoenix-1

FORMATION: Cossigny **DEPTH:** 3725 Meters

ROCK TYPE: Mixed oolitic-peloidal grainstone

DESCRIPTION

The framework grains of the rock mostly consist of pellets, peloids, ooids and shelly fragments. The peloids are spherical 0.2-0.5mm in diameter some peloids are less regular and have a trace of internal structure although its nature cannot be identified under the microscope. These peloids were possibly formed by the progressive micritization of the fossils. The pellets are round rod-shaped faecal pellets. The echinoid fragments appear as speckled plates with uniform interference colours. The section shows a range of locally produced ooids from those with a small nucleus and thick cortex (the oolitic coating) to those with a large nucleus and a single oolitic lamina. Shell moulds have been infilled with blue stained ferroan calcite crystals. The sediments are moderately to poorly sorted. The matrix of the rock is dominantly blue stained ferroan calcite. The rock shows no visible porosity.

DIAGENETIC FEATURES

- Micritization
- Dissolution
- Cementation
- Dolomitization

XRD ANALYSIS

XRD trace shows calcite a dominant mineral with very minor dolomite.

SAMPLE NO.: Pnx-1, 3700 **WELL:** Phoenix-1

FORMATION: Cossigny **DEPTH:** 3700 Meters

ROCK TYPE: Mixed oolitic-peloidal grainstone

DESCRIPTION

The rock mainly consists of peloids and pellets. Pellets are of faecal origin and show the common rounded rod-shaped outline. Micritization is dominant and has altered the grains into a structureless cryptocrystalline mass. Some peloids have an irregular shape, it is probable that these peloids were formed by the intense micritization of bioclasts, thus accounting for their vague relict structures. The frame work grains are largely micritized. The contact between the micritic envelop and the framework grains is irregular. The matrix of the rock is dominantly micritic mud with a little sparite showing a patchy development. Some shell walls show fracture both in micritic envelop and early cement and the fracture then healed by fine grained sparite. Some of the grains are partially dolomitized. Dolomite is also present as a pore filling cement in small quantities. Bioturbation is common throughout the sediment.

DIAGENETIC FEATURES

- Micritization of the framework grains
- Radial cement growing perpendicular to the grains
- Very fine grained interpartical cement showing patchy development
- Dolomitization

XRD ANALYSIS

The XRD trace shows calcite dominant with minor dolomite

SAMPLE NO.: Pnx-2, 3585 **WELL:** Phoenix-2

FORMATION: Cossigny **DEPTH:** 3585 Meters

ROCK TYPE: Muddy wackestone

DESCRIPTION

The composite grains consist of pellets, peloids and bioclasts of echinoids, brachiopods, ostracods and other shelly fragments. Miliolid forams are present with walls largely micritized and pores filled with fine grained sparite. The section also shows traces of authigenic glauconite. The glauconite occurs as a slightly pleochroic bright green mineral occurring in small patches. The pellets are mostly faecal in origin. Peloids are spherical with average diameter of 0.1mm. Some bioclasts have been largely micritized and are grouped as peloids since the nature of their structure cannot be determined. The sediments are dominantly bioturbated and the barrows filled with pyrite. The rock is very poorly sorted with micritic matrix. The micrite show a patchy development to pseudospare.

DIAGENETIC FEATURES

- Micritization of the constituent grains is very dominant.
- Cementation,
- Dissolution
- Dolomitization

SAMPLE NO. : Pnx-2, 3640 **WELL**: Phoenix-2

FORMATION: Cossigny **DEPTH**: 3640 Meters

ROCK TYPE: Mixed oolitic-peloidal grainstone

DESCRIPTION

The constituent grains consist of ooids pellets and peloids with some shelly fragments of echinoids, brachiopods and forams. Ooids of varied nature occur in the sediments, some with a small nucleus and thick coatings and others with a large nucleus and a single oolitic lamina. A few radially formed ooids are also present. Some echinoid fragments show a superficial oolitic coating. Micrite walled forams are also present. Section shows two valve ostracod shells filled with two different cements. Fine grained fringe on inside of shell is followed by very coarse blue stained ferroan calcite spare. The crystal size increases towards the centre. This is a typical void filling fabric. The rock is moderately to poorly sorted, with fine grained sparite matrix.

DIAGENETIC FEATURES

- Micritization
- Cementation
- Leaching of the shelly fragment and subsequent filling by fine grained sparite.
- Recrystallization

SAMPLE NO. : Pnx-2, 3700 **WELL:** Phoenix-2

FORMATION: Cossigny **DEPTH:** 3700 Meters

ROCK TYPE: Oolitic grainstone

DESCRIPTION

The section dominantly consists of ooid grains. The ooids are spherical and their nuclei vary from quartz grains to peloids. The ooids show a radial-concentric fabric, where cortical layers with radial fabric alternate with layers composed of micritic calcite. Rare bioclastic debris include fragments of brachiopod and forams. Pellets are very rare. The ooid grains show a rim of calcite cement. The remaining pore space is filled with calcite spare. The rock is well sorted.

DIAGENETIC FEATURES

- Cementation
- Dissolution
- Recrystallization
- Dolomitization

XRD ANALYSIS

XRD analysis show calcite a dominant mineral with minor dolomite present.

SAMPLE NO.: Cos-1, 2878 **WELL:** Cossigny-1

FORMATION: Cossigny **DEPTH:** 2878 Meters

ROCK TYPE: Muddy wackestone

DESCRIPTION

The section dominantly consists of dolomitized pellets, peloids and bioclasts. The dolomite is non selective altering both framework grains and interpartical cement, and in some cases cross cutting the grains. The dolomite has a bimodal distribution. The dolomite which has replaced the cement is clear and coarse grained while as dolomite that has replaced the constituent grains is darker and fine grained. Most dolomite crystals are subhedral to anhedral with straight compromise boundaries.

DIAGENETIC FEATURES

- Dolomitization
- Micritization
- Dissolution
- Neomorphism

XRD ANALYSIS

XRD analysis show dolomite a dominant mineral with minor calcite and pyrite.

SAMPLE NO : Cos-1, 2896 **WELL:** Cossigny-1

FORMATION: Cossigny **DEPTH:** 2896 Meters

ROCK TYPE: Muddy wackestone

DESCRIPTION

The rock dominantly consists of pellets and peloids with fragments of brachiopods and ostracods. The rock is partially dolomitized the pellets and peloids have resists dolomitization. Rounded glauconite grains occur in patches and are characterised by speckled greenish birefringence. The rock shows an irregular cross cutting network of calcite veins. The vein fill consists of coarse calcite crystals, with rare pyrite. The veins have a sharp contact with the host rock.

DIAGENETIC FEATURES

- Micritization
- Cementation
- Dissolution
- Dolomitization