UPPER JURASSIC OF THE BARROW SUB-BASIN: SEDIMENTOLOGY, SEQUENCE STRATIGRAPHY AND IMPLICATIONS FOR RESERVOIR DEVELOPMENT

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A Thesis submitted for the Degree of Doctor of Philosophy

of the Curtin University of Technology

1991

ACKNOWLEDGMENTS

There are many people to whom I am grateful for their support and assistance during the course of this research.

Firstly I would like to thank the sponsoring companies, Petroz NL, Western Mining Corporation, Bond Petroleum, Hadson, and Phillips Australian Oil Company for providing technical data, financial assistance and drafting services for this thesis.

Sincerest appreciation is extended to Professor John Scott and Dr Peter Barber, my supervisors who encouraged me to keep going when I most needed it, and for their guidance and friendship. Many thanks are also extended to the draftsmen John Lang, Adrian Finch, Ian Ross, Bruce Beer and Alan Cain who did a wonderful job of drafting many of the figures and enclosures included in this thesis.

I am greatly indebted to Liz Arnold and her husband Russ, who spent many hours typing and moulding my manuscript into a presentable and professional looking document. Their good humour about all my incessant changes and illegible handwriting combined with their dedication and reliability of their efforts were indeed great support and sincerely appreciated.

To my parents Joan and Max, and my wife Amanda, I express my love and appreciation for their support, tolerance and understanding.

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ABSTRACT

A chronostratigraphic subdivision of the Upper Jurassic synrift sediments in the eastern Barrow Sub-basin was developed from the integration of core logging, petrography, well log sequence analyses and seismic stratigraphy. From this basis, the Callovian to base Cretaceous sediments may be subdivided into five depositional sequences. The development of the sequence boundaries, in most part, is closely related to periods of major changes in basin configuration associated with the sequential breakup of eastern Gondwanaland.

Initiation of the Upper Jurassic rift complex occurred during late Callovian - early Oxfordian associated with the development of a northeast-southwest trending spreading centre on the Argo Abyssal Plain. The spreading centre propagated southwards during the Late Jurassic. This resulted in active rifting in the Barrow Sub-basin and ultimately led to the separation of the Indian and Australian plates during Valanginian time.

Upper Jurassic synrift sediments in the eastern Barrow Sub-basin consist of detached basin floor fan complexes, channelised and canyon fed fan systems, slump deposits, prograding outer shelfal to slope deposits and deep marine claystones. Post-depositional uplift of the eastern shelfal areas during the Late Jurassic resulted in erosion of the transgressive and highstand fluvial-deltaic to shelfal deposits. These periods of uplift and erosion provided much of the sediment redeposited in the basinal areas during the lowstand periods.

Seven sandstone facies were recognised in the Upper Jurassic sedimentary section based on core control. Each sandstone has unique reservoir characteristics which can be related to the depositional setting. The abundance of glauconite and belemnites combined with ichnology and biostratigraphic assemblages associated with marine environments, indicate that deposition of all the sandstone facies occurred within an outer shelfal - deep marine environment. Reservoir quality was best developed in the dominantly medium grained, moderate - well sorted sandstones, (facies 7), which were deposited as detached, basin floor submarine fan sands or interbedded turbidites. In contrast, reservoir quality was relatively poorly developed in the remaining facies which were deposited as slope fans, slumps, or distal turbidite deposits.

The abundance of quartz and presence of banded iron, jasper, and potassic feldspar grains support the provenance for the basinal sandstone facies being the Precambrian alkyl granites and banded iron formation of the Pilbara Shield and Hammersley Ranges. These Precambrian igneous rocks and metasediments mark the eastern boundary of the Barrow Sub-basin study area.

To predict the distribution of sedimentary facies in the Upper Jurassic synrift sediments of the eastern Barrow Sub-basin, the interplay between the major controlling depositional processes, namely tectonics, sediment supply and eustasy must be understood. Subdivision of the synrift sedimentary section on the basis of lithostratigraphy can be misleading and does not adequately resolve the facies relationships observed in the well intersection. The results of this research form the basis for a regional sequence analysis and seismic stratigraphic study.

1 INTRODUCTION

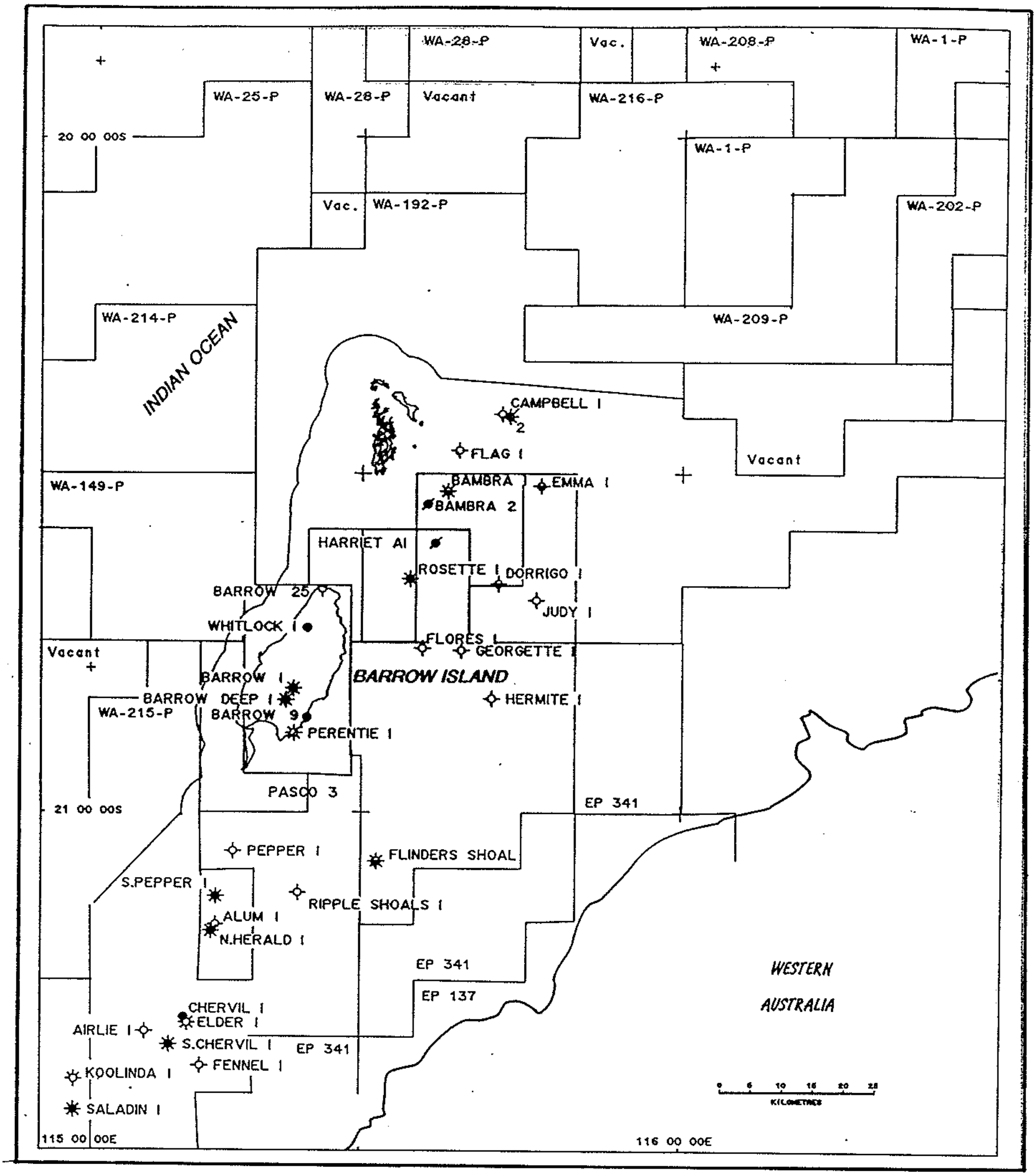
The aim of this research project was to determine the depositional history, controls on sedimentation, and reservoir development of the Upper Jurassic succession in the Barrow Sub-basin, Northwest Shelf, Western Australia. The study area covers approximately 11,000 km^2 in the eastern Barrow Sub-basin, which forms part of the Carnarvon Basin in the Northwest Shelf of Western Australia (Figure 1). The principal petroleum licences covering the study area are WA-192-P, TP/8 (Phillips Australian Oil Company), WA-149-P (Western Mining) and PL/1 & PL/2 (WAPET).

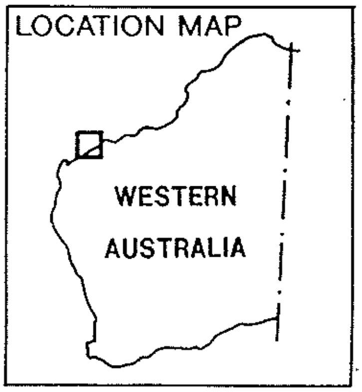
This research project is subdivided into three categories;

1 The study methods, the regional geology, and the sedimentary and sequence analysis models which form the basis for the research.

2 The interpretations based on the results of the core logging, petrography, facies and sequence analyses, and

3 The relationships between the sequence stratigraphic models proposed as a result of this research and published sequence analysis concepts and submarine fan deposition models.





Location Diagram
Eastern Barrow Sub-basin
Study Area
Northwest Shelf Australia

Figure 1

The Upper Jurassic of the eastern Barrow Sub-basin consists of sediments deposited following the intra-Callovian 'breakup' tectonic episode and prior to the early Cretaceous rift episode (Kopsen & McGann, 1985) (Figure 2). The Upper Jurassic has been previously subdivided into three lithostratigraphic formations; the Biggada Sandstone at the base, the Upper Dingo Claystone and the Dupuy Sandstone at the top (Figure 2). The results of this research however suggest that these formation names are inadequate to describe the complexity of the Upper Jurassic depositional system in the eastern Barrow Sub-basin. Syndepositional tectonism resulted in localised deposition and rapid lateral facies variations restricting the applicability of long distance lithostratigraphic correlations, especially in and adjacent to the Flinders Fault Zone. The initial evaluation of the facies distribution using lithostratigraphy was found to be inadequate to resolve the depositional controls and lithological variations between well control. Consequently, the research project was expanded to include seismic data and sequence analysis of the Upper Jurassic study interval incorporating well logs, seismic, biostratigraphy, core data and sample descriptions. This integrated approach resulted in the elucidation of the relationship between eustatic sea level fluctuations, sediment supply and tectonism on the facies distribution of the Upper Jurassic sediments.

The depositional models proposed for the Upper Jurassic by this research by no means provide a unique solution to the complex depositional history. However, they do provide the foundation on which further detailed sequence stratigraphic and sedimentological analyses may be based to unravel the complexities of this

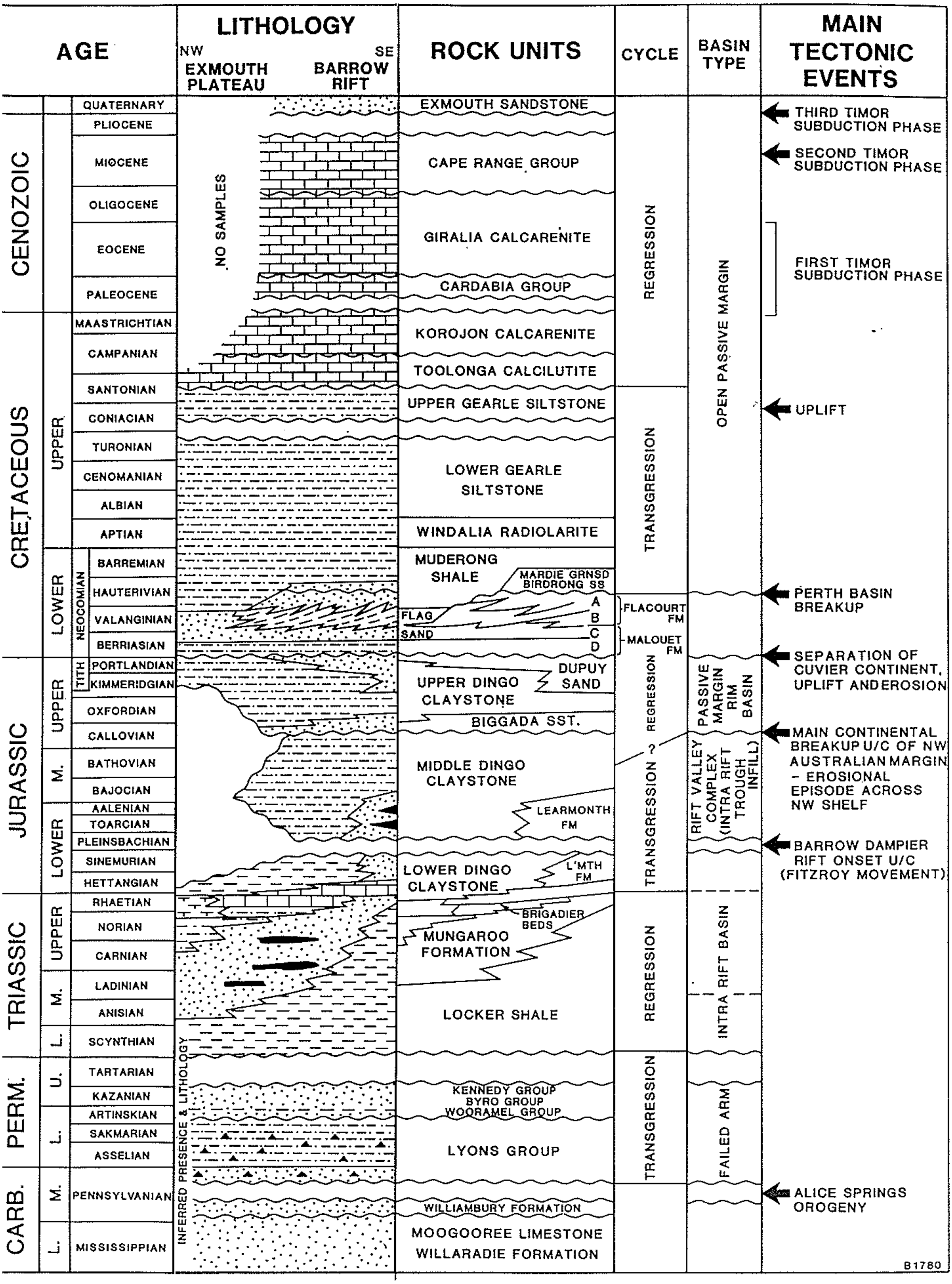


Figure 2. Generalised stratigraphic column for the Barrow Sub-basin, Northwest Shelf Australia. (after Barber, 1988)

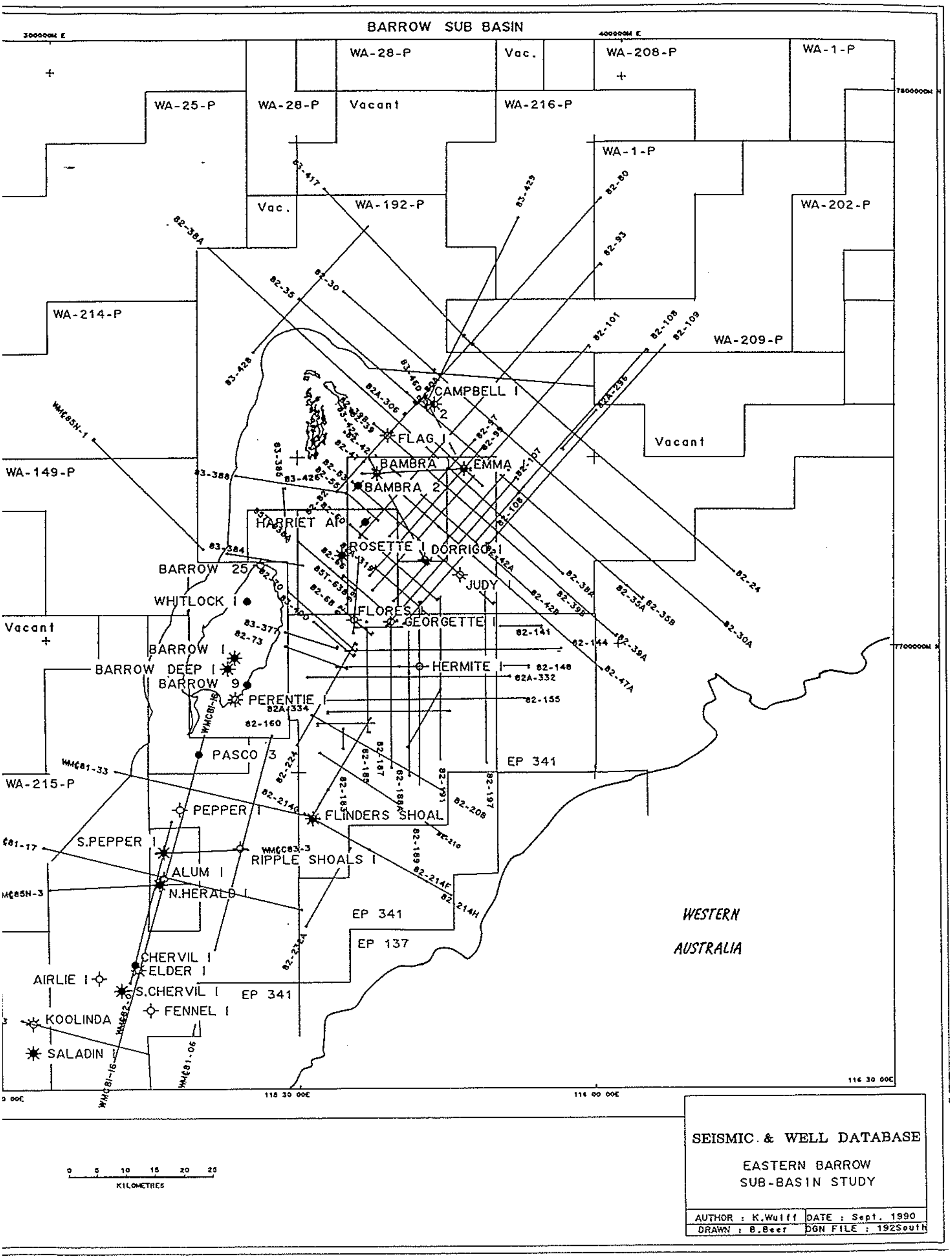
hydrocarbon prospective interval.

2 DATA BASE

A total of 31 non proprietary petroleum exploration wells were examined in the study (Figure 3). Only 3 of the 31 wells penetrated a complete Upper Jurassic interval in the basinal depocentre. Owing to the presence of a tectonically active eastern margin, significant Upper Jurassic section has been eroded, or not deposited due to highly variable isostatic adjustment of fault blocks. This has resulted in an incomplete Upper Jurassic interval present in 12 of the 31 wells studied. The remaining 16 wells did not drill deep enough to penetrate the entire Upper Jurassic section.

337 m of Upper Jurassic core was available from 14 wells in the study area. The most extensively cored intervals were 160.6 m and 64.6 m in Barrow-25 and Barrow-1 respectively. The average cored interval in the remaining 12 wells was 9.1 m. The Barrow-25 and Barrow-1 cores were cut in the Tithonian sequence providing an excellent data base from which to examine the vertical facies associations and their correlation with wireline logs and seismic. The spot cores from the remaining 12 wells were also used in conjunction with wireline logs and seismic for control on sequence stratigraphy.

A total of 3500 km of open file seismic data were reviewed with 1880 km being interpreted in detail. Well control was initially tied with the regional grid which was later expanded to enable delineation of seismically identifiable depositional sequences. The seismic quality was in general very poor to good. Seismic



SEISMIC & WELL DATABASE

EASTERN BARROW
SUB-BASIN STUDY

AUTHOR : K.Wulff	DATE : Sept. 1990
DRAWN : B.Beer	DGN FILE : 192South

Figure 3

quality of lines provided by Western Mining Corporation in the WA-149-P area were very poor and were of limited use for seismic stratigraphic mapping. The models proposed based on wireline logs, core data and seismic are based on the eastern WA-192-P area where seismic quality in the Upper Jurassic interval was of better quality and adequate for regional seismic stratigraphy.

Tables I to III and Enclosure I summarise the data used in this study. A complete list of reports and papers referred to during the project is given in the Bibliography.

TABLE I: WELL CONTROL			
WELLS	**PERMIT**	**WELLS**	**PERMIT**
Alum-1	WA-149-P	Flores-1	WA 192P
Bambra-1	WA-192-P	Georgette-1	WA 192P
Bambra-2	WA-192-P	Harriet-1	WA 192P
Barrow-1	PL/1	Hermite-1	WA 192P
Barrow-25	PL/1	Koolinda-1	TP/3
Barrow Deep-1	PL/1	North Herald-1	WA 149P
Basil-1	WA-149-P	Pasco-1	EP 61
Campbell-1	WA-192-P	Pasco-3	EP 61
Campbell-2	WA-192-P	Pepper-1	WA 149P
Chervil-1	WA-149-P	Perentie-1	PL/1
Dorrigo-1	WA-192-P	Ripple Shoal-1	WA 149P
Elder-1	WA-149-P	Rosemary-1	WA 1P
Emma-1	WA-192-P	South Chervil-1	WA 149P
Fennel-1	WA-149-P	South Pepper-1	WA 149P
Flag-1	WA-192-P	Tryal Rocks-1	WA 149P
Flinders Shoal-1	WA-192-P	TOTAL	31 WELLS

TABLE II: CORE DATA		
WELL	**CORE No.**	**DEPTH INTERVAL**
Bambra-1	2	2713 - 2730 m (15.75 m)
Bambra-2	3	4274 - 4283 m (9 m)
Barrow-1	21 - 37	1993 - 2836 m(64.6 m)
Barrow-25	12 - 31	1934 - 2129 m (160.6 m)
Chervil-1	7	1785 - 1790.6 m (5.6 m)
Dorrigo-1	3	1593 - 1607.55 m (14.55 m)
Elder-1	2	1537.5 - 1545.5 m (6.9 m)
Emma-1	3	2185 - 2194.3 m (9.3 m)
Flag-1	3	2742 - 2750.2 m (8.2 m)
	4	2993.1 - 3000.5 m (7.4)
Flinders Shoal	5	1494 - 1501 m (7.3 m)
Georgette-1	1	2156.5 - 2165.5 m (4.01 m)
	2	2273 -2282 m (8.55 m)
Hermite-1	1	1465 - 1474 m (8.4 m)
Pasco-3	1	2447 - 2451 m (4.0 m)
South Pepper-1	8	2367 - 2385.3 m (18.3 m)
TOTAL CORE LOGGED		337 m

TABLE III: SEISMIC DATA			
VINTAGE	**PROCESSING**	**SCALE**	**KM**
Australian Occidental 82	2400%, 4800%, 6000% Time & Migrated	10 cm = 1 sec	1445
Australian Occidental 82A	4800%, Migrated	10 cm = 1 sec	103
Australian Occidental 83	2400%, Migrated	10 cm = 1 sec	170
Wesminco 81	4800%, Migrated	10 cm = 1 sec	162
TOTAL INTERPRETED LINE KILOMETRES			1880

3 METHODOLOGY

The following outlines the techniques employed during the course of this study.

LITHOSTRATIGRAPHY

Wireline logs from 31 wells were loaded onto a computer data base via LIS magnetic tapes, ASCII floppy disks or by digitising paper copies. The well data software package used in this project was Petrosys LogsPep utilising one of Petroz' in-house PC computers. Cross sections, well plots and synthetic seismograms at any scale and configuration could then be easily generated.

Three regional cross sections at 1:2,500 vertical scale were generated and datummed on the Base Cretaceous unconformity (Enclosures II, III and IV). All available biostratigraphy and core locations were plotted alongside each well. Basic lithostratigraphic correlations were made between wells on the basis of lithotype and biostratigraphy. On the eastern flanks of the Barrow Sub-basin, rapid lateral facies variations indicate that deposition was dominantly local and controlled by syndepositional tectonism. Long distance lithostratigraphic correlations without seismic control were considered unreliable in evaluating the depositional sequences within the Upper Jurassic. Laterally extensive correlations of gross packages were able to be made between wells in the central basinal areas, however lithological variations were still quite marked. The average distance between wells is approximately 15 km. The initial lithostratigraphic guide for the more detailed sequence analyses incorporating seismic and sequence stratigraphic principles.

CORE LOGGING

337 m of Upper Jurassic core from 14 wells was logged during the course of this project (Table II). The cores were logged at 1:20 scale. Emphasis was placed on lithology, grainsize (determined by 10X hand lens and binocular microscope), sedimentary structures and diagenetic features.

Core log sheets generated during this project are reproduced in Appendix I. Detailed discussion of results and interpretations is given in Section 6.1, page 36. Where available Geodip dipmeter logs at 1:40 scale and Cluster processed dipmeters at 1:200 scale were correlated with the core to evaluate the reliability of observed dips from the dipmeter and to correlate sedimentary structures indicative of specific depositional environments to wireline log and dipmeter response. Much of the older WAPET core (pre 1980) had been repeatedly examined and sampled. As a result missing intervals, disordered core, lack of depth markings and occasionally extraneous pieces of cores (from other wells) made accurate detailed analysis impossible. Where this occurred, only broad lithology subdivisions, sedimentary structures and general grainsize distributions were recorded.

No cuttings samples were examined during the course of this project.

PETROGRAPHY AND S.E.M.

A total of 47 thin sections were made from selected cores to evaluate the lithology, texture and diagenetic history of the sandstone facies within the Upper Jurassic section. Emphasis was placed on lithology and grainsize distribution in order to identify variations in provenance and depositional environment. The diagenetic history, using both thin section petrography and the Scanning Electron Microscope (SEM), was evaluated to identify the cementation characteristics of specific sandstone facies.

SEQUENCE ANALYSIS

To evaluate the depositional history and controls on sedimentation, sequence analysis incorporating wireline logs, biostratigraphy and seismic was undertaken. The sequence analysis approach applied during the course of this research was that developed by Vail and his Exxon co-workers (Vail & Mitchum, 1977; Mitchum & Vail, 1977; Vail, 1987; Vail & Sangree, 1988; Vail et al, 1990). Progress in deep sea fan research in the last ten years has led to a greater understanding of the controls on the development of fan complexes. This in turn has resulted in the establishment of new models and revised exploration techniques required to identify submarine fan development.

Sequence analyses was undertaken to identify stratal surfaces and facies variations within individual systems tracts, including the effect and timing of tectonism on the development of depositional systems. The following discusses the techniques applied in this study and Figure 4 summarises the integration of the seismic with the wireline log and core facies analyses.

Wireline Log Sequence Analyses

Composite logs at 1:1,000 scale were generated for most of the wells incorporated into the study. From the basic well data, biostratigraphy, core locations and general lithology were plotted alongside the logs. Rose diagrams from dipmeters were also drawn at 50 m intervals from 'Cluster' processed dipmeters or at 25 m intervals when 'Geodip' processed dipmeters were available. These rose diagrams display changes in dip azimuth relating to variations in flow direction, structural dip, or hole conditions resulting in uninterpretable dip motifs.

Sequence analysis, initially using wireline logs (principally Gamma Ray and Sonic) was carried out on individual wells by identifying well log sequences and systems tracts. This was achieved by interpreting depositional environment and lithofacies from core, cutting descriptions and wireline log character. Utilising the dipmeter rose diagrams, biostratigraphy and lithofacies analyses, preliminary sequence and systems tract boundaries were marked. The sequences and parasequences were then correlated between wells assuming unconformities and flooding surfaces represent the most laterally extensive correlatable stratal surfaces (Section 6.4, page 82).

Regional Seismic Sequence Analyses

1880 kilometres of seismic data (Figure 3, Table III), were interpreted. Most wells incorporated into this evaluation were tied by a regional seismic grid. Additional seismic lines were included so as to enable identification of tectonic controls on sedimentation, correlate sequence boundaries and predict facies trends from seismic character over the study area. The seismic data used were predominantly 1982 and 1983 vintage recorded by Occidental Petroleum within the permit WA-192-P. Additional seismic data within WA-149-P (Western Mining) were also examined, but were in general, of insufficient data quality to resolve sequence boundaries below the Lower Cretaceous Barrow Group.

Sequence boundaries derived from analysis of the wireline logs and biostratigraphy were transferred onto synthetic seismograms. Synthetic seismograms were generated using Petroz' in-house Petrosys seismic computer package or derived from geograms provided by the sponsors. These synthetics were generated at 10 cm = 1 sec scale for each available well. The synthetics were checkshot-corrected where possible and were generated using zero phase wavelets with 30, 35 and 40 hertz frequencies. Gamma ray, sonic and reflection coefficient logs were also plotted for comparative purposes.

Five steps were taken in the seismic stratigraphic interpretation:

i) Regional correlation of the Base Cretaceous and intra-Callovian unconformities to define the gross interval throughout the study area.

ii) Reflection truncations and peculiar reflections namely downlap, onlap, toplap, unconformity surfaces, mounded forms, channels, etc. were marked on sections in the style of Vail et al (1988).

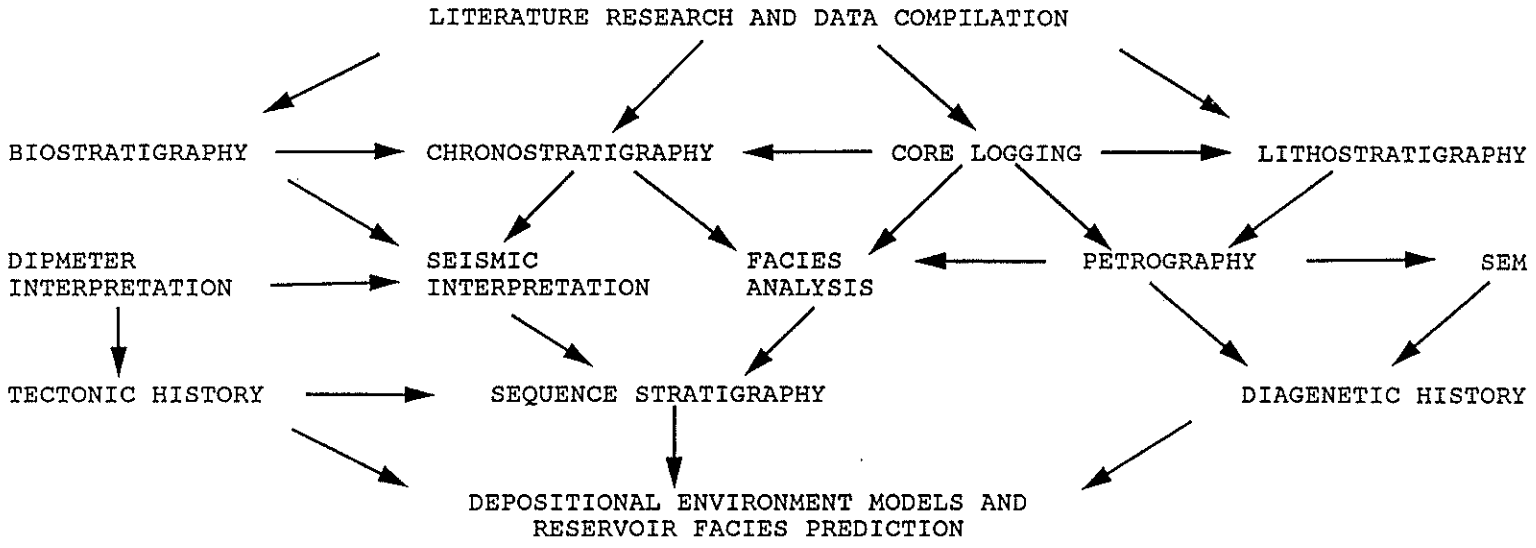
iii) Synthetic well log ties were used to match well log events with the seismic sections intersecting the well locations. Lithofacies, depositional environment and biostratigraphy data were then tied to the seismic profiles at the locations of the wells. Well log sequences and system tract boundaries were also correlated with stratal surfaces or unconformities identified on seismic.

iv) Regional stratal surfaces and sequence boundaries were mapped away from well control using well-tie lines.

v) The seismic expression of the interpreted systems tracts from seismic stratigraphy were then tied to regional facies and sequence correlation from well control.

FIGURE 4. SUMMARY OF THE METHODOLOGY EMPLOYED TO DEVELOP DEPOSITIONAL MODELS FOR INTERPRETED DEPOSITIONAL SEQUENCES IDENTIFIED WITHIN THE UPPER JURASSIC INTERVAL

METHODOLOGY FLOWCHART



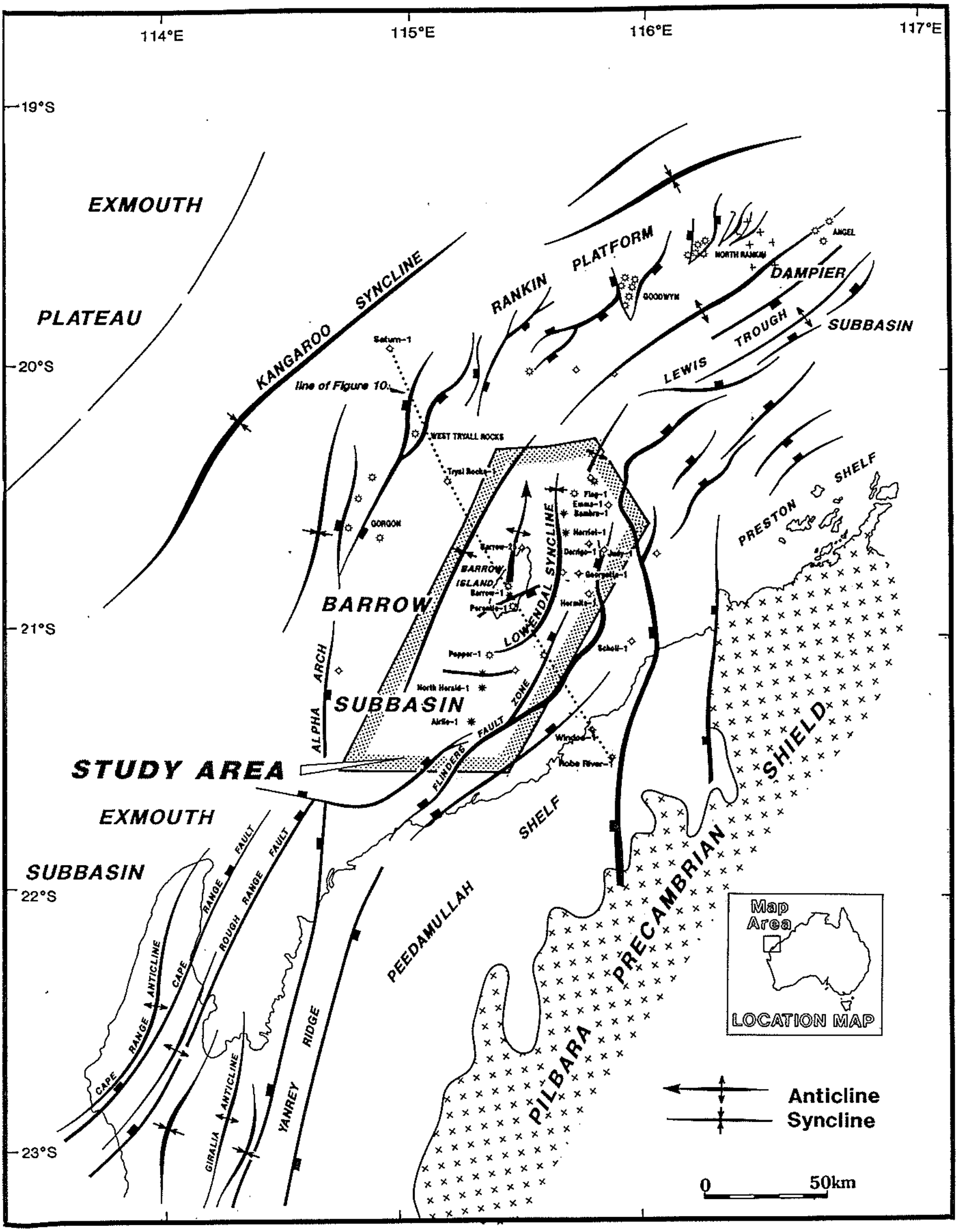
4 REGIONAL GEOLOGY

4.1 TECTONIC SETTING AND GEOLOGICAL HISTORY

The study area is located in the Barrow Sub-basin within the offshore northern Carnarvon Basin of Western Australia (Figure 5). The Barrow Sub-basin is one of two areas of tensional rift margin basins in the North Carnarvon Basin. These rift basins contain in excess of 10,000 m of sedimentary fill and began to develop as early as the Permian (or older?) continuing through to Late Neocomian times (Kopsen and McGann, 1985). The rifting along the northwest margin of Australia was associated with the sequential continental breakup of eastern Gondwanaland prior to the separation of the Indian plate from the Australian continent during the Valanginian (Barber, 1982; Veevers, 1984; Veevers, 1988).

The Barrow Sub-basin is flanked to the east by broad northeast - southwest trending shelves (Preston Shelf and Peedamullah Shelf) which are separated from the axis of the Barrow Sub-basin by a major north-south trending, westerly hading en-echelon fault system (Flinders Fault System). The western and northern margin of the Barrow Sub-basin is flanked by the southern Rankin Platform which is a regional northeast - southwest high trend generated during the onset of rifting in the Early Jurassic (Figure 5) (Woodside, 1988).

Deposition within the Barrow-Dampier Sub-basins began in the Permian (or earlier) in an intracratonic downwarp (Barber, 1988). During the Permian in



gure 5. Location of the study area relative to the regional tectonic elements of the Barrow & Dampier Sub-basins, offshore North Carnarvon Basin, Northwest Shelf, Australia.

(after Boote & Kirk, 1989 ; Hocking, 1988) excess of 5000 m of section was deposited consisting of marginal marine and fluvioglacial sediments. These sediments are principally known from the Merlinleigh Sub-basin in the Southern Carnarvon Basin.

Transgressive conditions during the Early Triassic resulted in a rapid transition from the fluviatile - glacial sediments at Late Permian to fluvial deltaic and marine shales (Locker Shales) of the Lower Triassic (Figure 6). A return to regressive conditions in the Middle Triassic resulted in west-northwesterly prograding fluviodeltaic sedimentation (Mungaroo Formation). Relatively rapid downwarping combined with high deposition rates allowed a thick pile of fluviodeltaic sediments to accumulate. Dominantly non-marine conditions persisted throughout the Mid-Late Triassic (Figure 7).

During the Late Triassic, rapid transgressive conditions returned and continued well into Early Jurassic times (Veevers, 1984; Barber, 1988) (Figure 8). A reduction in the clastic influx was associated with the return to marine conditions, and a shallow epicontinental sea extended across the entire area. Sedimentation was dominantly calcareous with thicker nearshore units comprising of oolitic and skeletal bioclastic calcareous sands, while more distal shelf equivalents tended to be micritic (Boote & Kirk, 1989). These calcareous units are time transgressive, ranging in age from Late Rhaetian on the Exmouth Plateau to Late Hettangian on the Rankin Trend and terminating in the Lower Pliensbachian at the eastern basin limits (Figure 9).

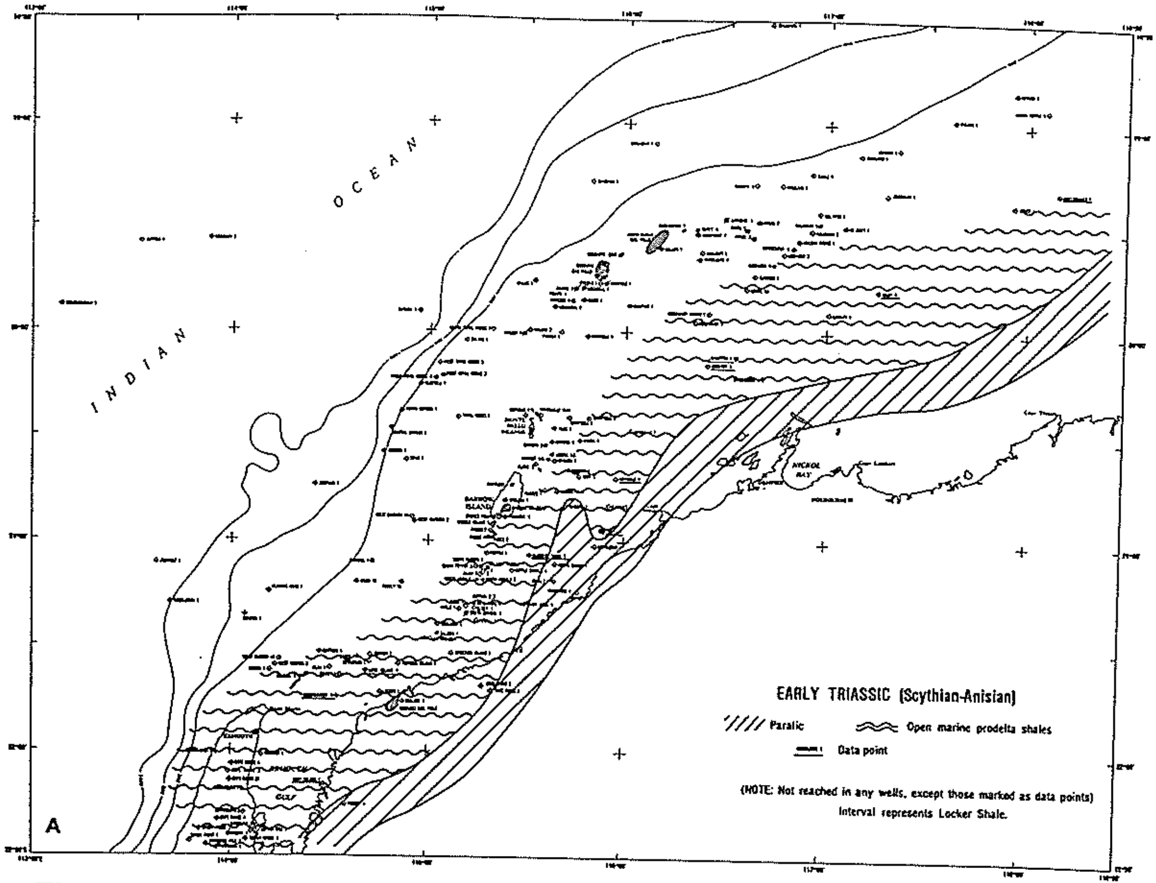


Figure 6. Early Triassic palaeogeography showing regional distribution of the Locker Shale in the Barrow-Dampier Sub-basins
(Robertson Research, 1986)

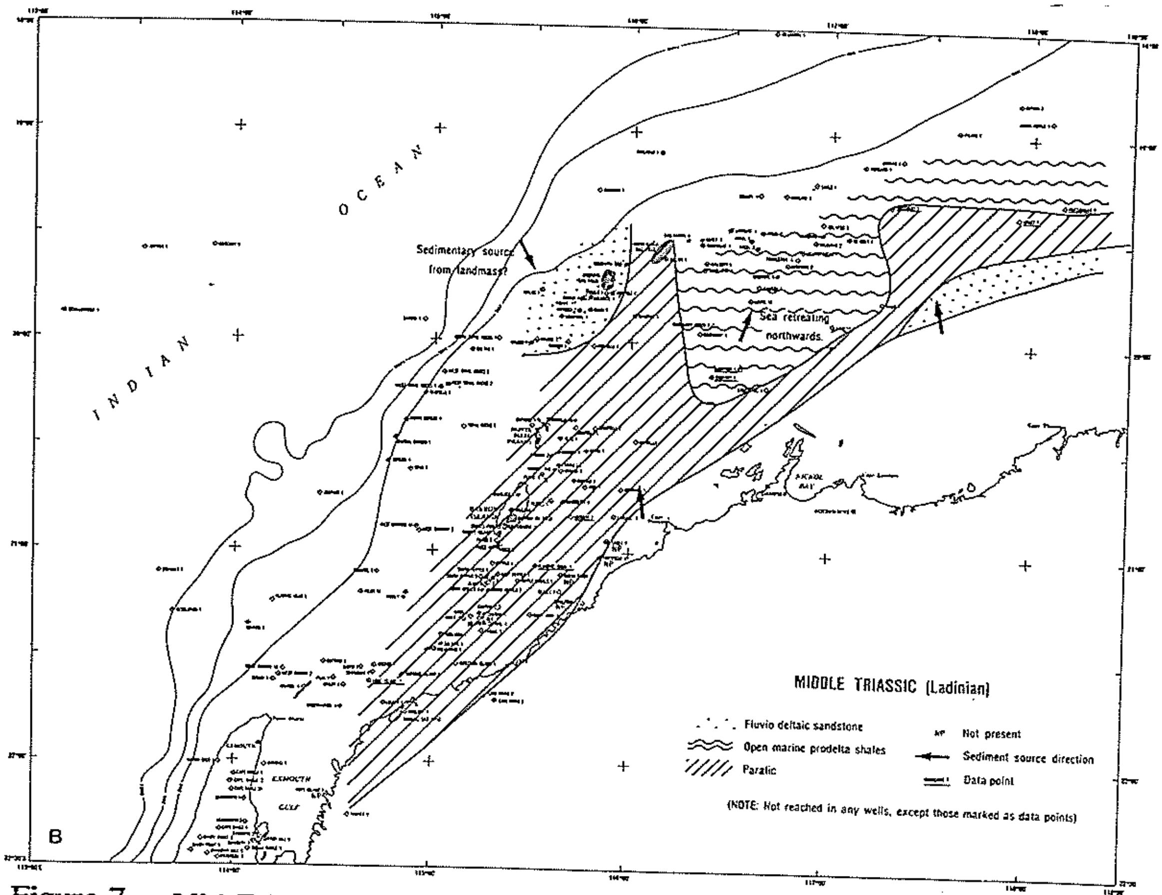


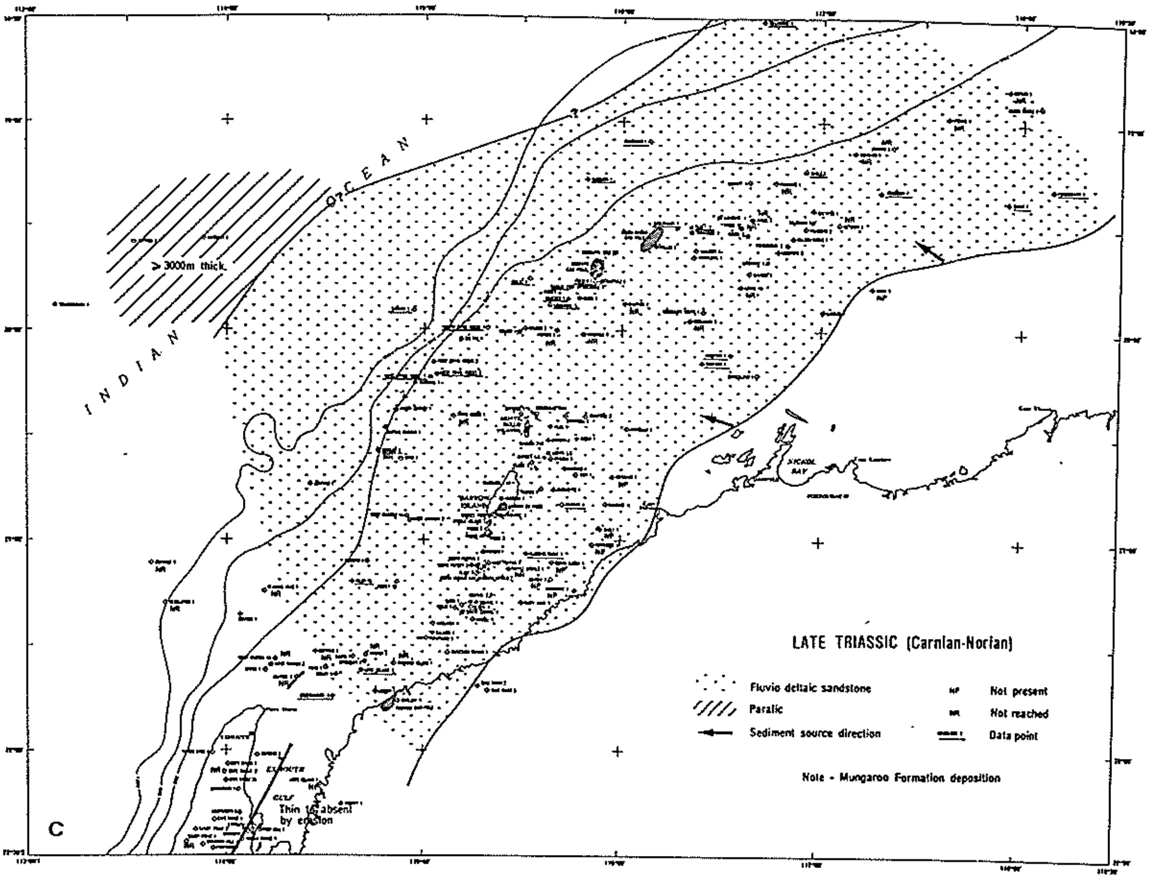
Figure 7. Mid Triassic palaeogeography displaying inception of regressive conditions (Robertson Research, 1986)

The transgression resulted in transition from dominantly calcareous sedimentation to calcareous inner-shelf claystone deposition with fluviodeltaic regimes along the northeastern margins. Sedimentation during the earliest Jurassic was passive with no more than 750 m of sediments deposited.

Post-Pliensbachian sedimentation in the Barrow Sub-basin was directly controlled by Mesozoic rift and drift associated with the breakup of Gondwanaland, in contrast to Permian - Triassic intracratonic deposition mentioned earlier.

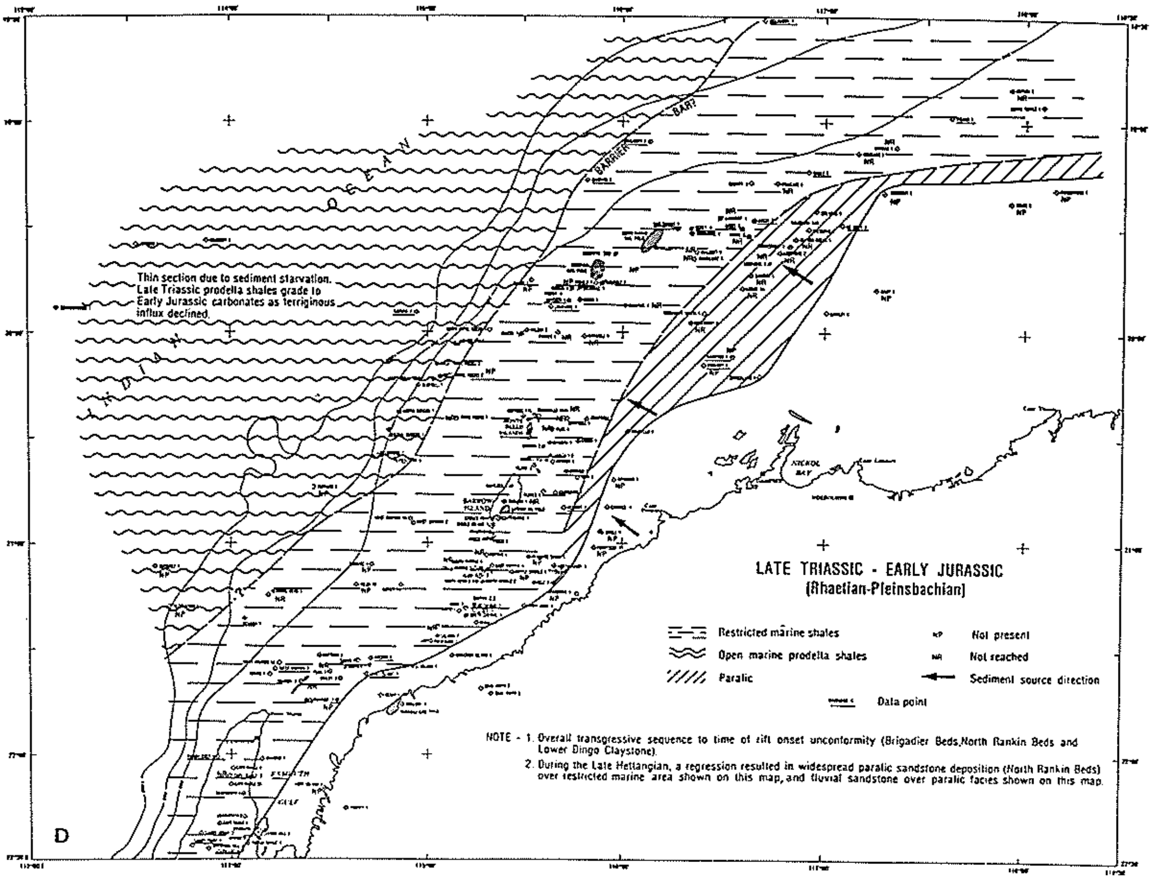
The Barrow-Dampier Rift, of which the Barrow Sub-basin forms the southern extension, developed along a NE-SW to NNE-SSW strike. Associated with the major rift bounding faults were synthetic, normal, down-to-the-basin faults which developed terraces, allowing progressive step down of fault blocks into the basin (Figure 10). This terracing is clearly observable along the Peedamullah Shelf, the eastern boundary of the Barrow Sub-basin (Bentley, 1988; Delfos et al, 1988).

Sedimentation during the Early Jurassic rift phase occurred in marginal marine-restricted marine environments within the developing rift itself (Figure 9). Following transgressive marine conditions in the Early Jurassic, generally passive sedimentation prevailed throughout the Mid Jurassic prior to the Callovian breakup. The transition from transgressive to regressive conditions began during the Mid Bajocian and is recorded in the rock record as transition from slightly calcareous claystone to non calcareous, carbonaceous claystone facies. The carbonaceous claystones pass upward into interbedded sandstones, siltstones and



Note - Mungaroo Formation deposition

Figure 8. Late Triassic palaeogeography displaying regional distribution of the fluviatile-deltaic Mungaroo Formation (Robertson Research, 1986)



Thin section due to sediment starvation. Late Triassic prodelta shales grade to Early Jurassic carbonates as terriginous influx declined.

NOTE - 1. Overall transgressive sequence to time of rift onset unconformity (Brigadier Beds,North Rankin Beds and Lower Dingo Claystone).
2. During the Late Hettangian, a regression resulted in widespread paralic sandstone deposition (North Rankin Beds) over restricted marine area shown on this map, and fluvial sandstone over paralic facies shown on this map.

Figure 9. Late Triassic - Early Jurassic palaeogeography displaying return to transgressive marine conditions and the deposition of the Lower Dingo Claystone (Robertson Research, 1986)

claystones deposited in a fluviodeltaic - shallow marine regime. This mild regression reached its maximum towards the Late Bajocian and Early Callovian (Figure 11).

The unconformity bounding the basal interval of this study has been conventionally referred to as the 'Callovian Breakup Unconformity' as mentioned previously and is associated with the onset of sea floor spreading on the Argo Abyssal Plain to the north (Veevers, 1984; Osborne & Howell, 1987, and Barber, 1988,). Most Barrow Sub-basin workers believe that the unconformity in this area was associated with major uplift of surrounding plateau and rifting, virtually isolating the Barrow and Dampier Sub-basins from open marine conditions. (Kopsen and McGann, 1985; Kirk, 1985).

Along the eastern margin of the Barrow Sub-basin, the intra-Callovian event resulted in an extensive and anastomosing rift complex. The margins of the resulting Barrow Sub-basin rift displayed enormous submarine topographic relief with up to 2 km of topographic expression recognised along the flanks of the western and eastern rift shoulders (Figure 10) (Boote and Kirk, 1989; Veenstra, 1985; Barber, 1988). This tectonic episode interrupted deposition in all but the deepest areas of the Sub-basin, and was largely responsible for developing the basin configuration seen in the Barrow Sub-basin today. The Callovian unconformity also resulted in uplift and erosion of the Rankin Trend and Alpha Arch along with the formation of large scale north-south trending listric faults, hading to the east, towards the axis of the developing rift system (Figures 5 & 10)

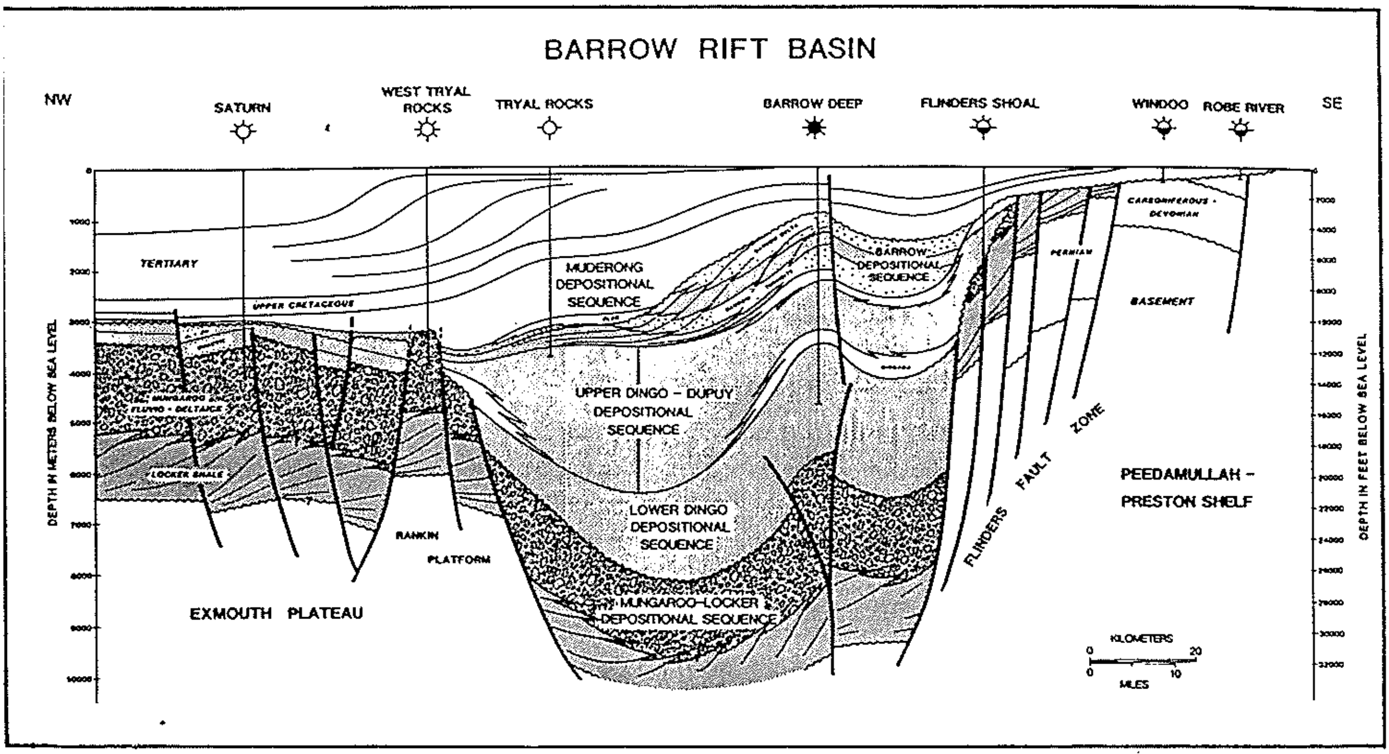


Figure 10. Simplified structural cross-section across the Barrow Sub-basin displaying the tectonic terrains & stratigraphic distribution(location shown on fig.5) (after Boote & Kirk , 1989)

(Barber, 1982). To the east, existing NNE-SSW trending faults were reactivated by the Callovian tectonism.

Sedimentation following the Callovian tectonism consisted of initial turbiditic sands and mass flow deposits known as the Biggada Sandstone, forming a downlapping package directly above the breakup unconformity (Figure 12). A decline in tectonic activity and a rise in sea level caused the shoreline systems to retreat across the eastern shelf with resulting onlapping basin fill sedimentation dominated by marine shales of the Upper Dingo Claystone (Boote & Kirk, 1989). As identified by this study periodic fault movements and isostatic readjustment of fault blocks occurred affecting sedimentation throughout the Jurassic. This resulted in depositional sequences along the active rift shoulder being extremely localised and confined within the structurally controlled topography. Following a period of Late Oxfordian/Kimmeridgian? tectonism and reactivation of the north northeast - south southwest trending rift bounding listric faults, the Dupuy deltaic system prograded across the eastern shelf areas (Boote & Kirk, 1989; Kopsen and McGann, 1985; Barber, 1988) (Figure 13). This research has shown that the Dupuy system is characterised by major canyon incision on the shelfal margins, downlapping mound forms, prograding clinoform depositional wedges with overlying marine onlap, indicative of relative sea level fluctuations with periods of sediment bypass and slumping.

Jurassic sedimentation was terminated by tectonic activity or a major eustatic sea level fall in the early Neocomian. This resulted in a change in provenance

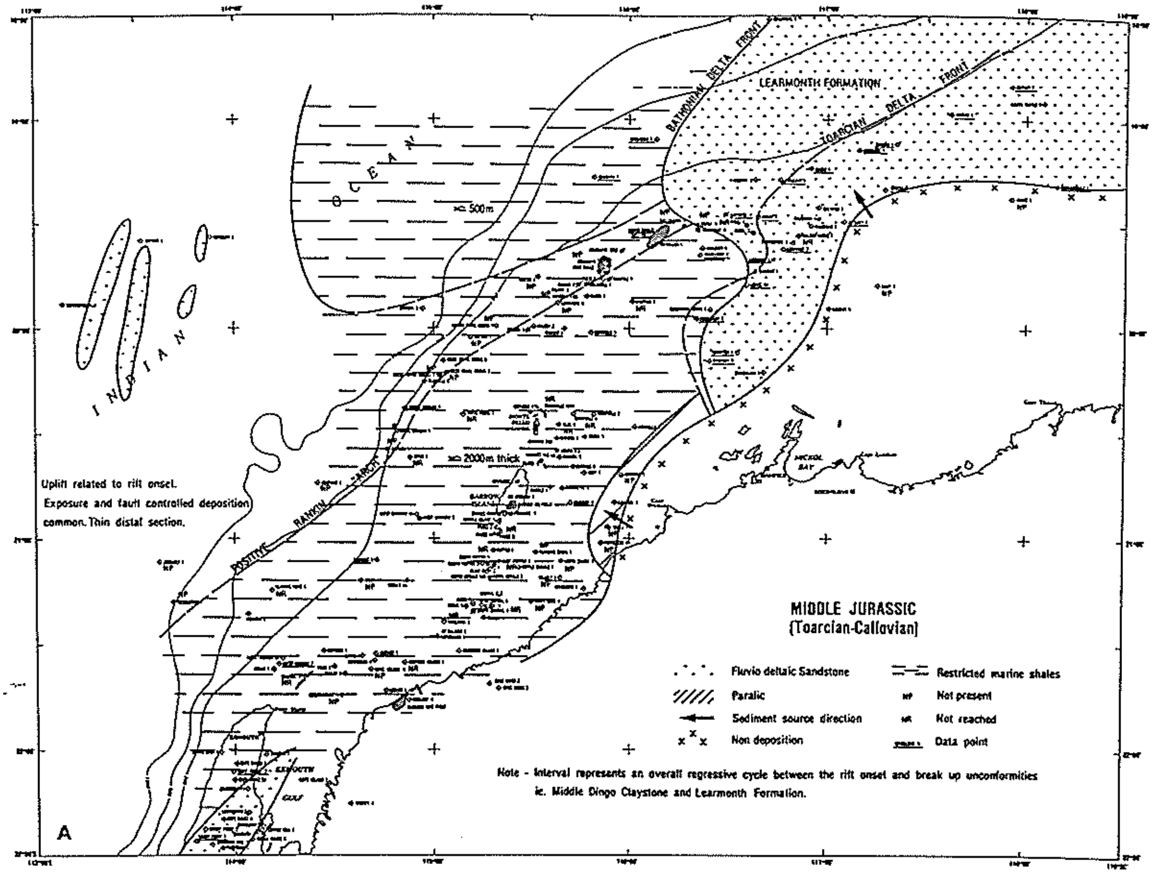


Figure 11. Mid Jurassic palaeogeography displaying marine Dingo Claystone deposition in the Barrow Sub-basin and the inception of lowstand progradational sedimentation in the Dampier Sub-basin (Robertson Research, 1986)

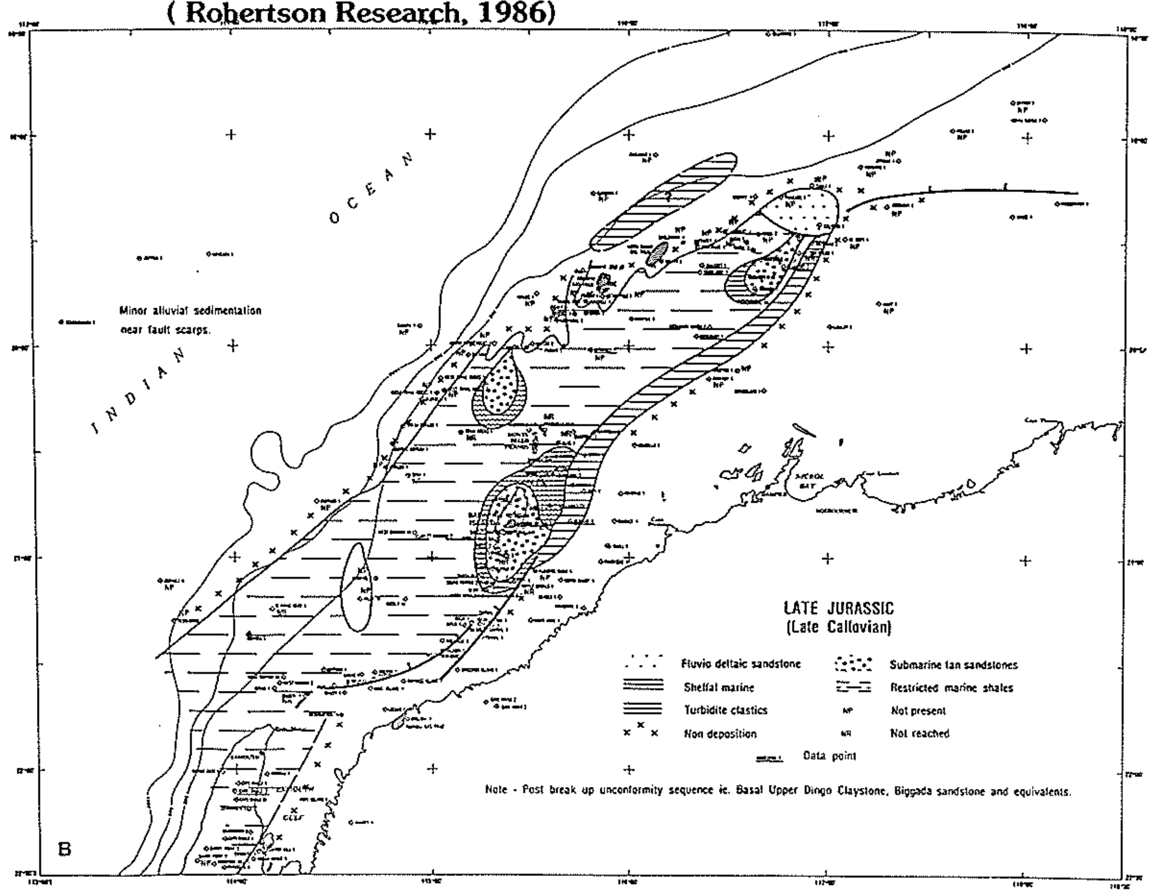


Figure 12. Late Jurassic palaeogeography displaying displaying Biggada Sandstone deposition (Robertson Research, 1986)

direction from the east to a dominantly southerly provenance which resulted in the rapid northward progradation of the Barrow Group deltaic complex independent of the underlying Jurassic rift (Figure 14) (Tait, 1985; Veevers, 1988).

The boundary between the Barrow Group and the underlying Jurassic is recognised as an unconformity on the eastern shelfal areas in the northern half of the study area. In the south, it is most likely that sediment was being derived from both the east and the south penecontemporaneously. This has resulted in difficulty in defining the Base Cretaceous unconformity in the southern study area. The Barrow Group dominantly consists of a deltaic sequence with associated prodelta submarine fan complexes. By late Neocomian final breakup during Valanginian time, sea level rose and drowned the Barrow Delta. This resulted in a transgressive marine shale (Muderong Shale) blanketing the entire area (Barber, 1988).

With continuous deepening of the seas, the dominantly clastic facies of the Lower Cretaceous yielded to outer shelf and bathyal conditions with marls and calcilutite being the major lithologies. The transition from clastic to carbonate sedimentation was enhanced by the peneplanation of the continental provenance areas and the warming of the climate associated with the northward migration of the Australian continental plate into lower latitudes. Passive erosion, thermal cooling and subsidence allowed the development of northerly prograding carbonate platform facies to develop as thick wedges over much of the Northwest Shelf. Global eustatic and tectonically induced sea level fluctuations occurred during the

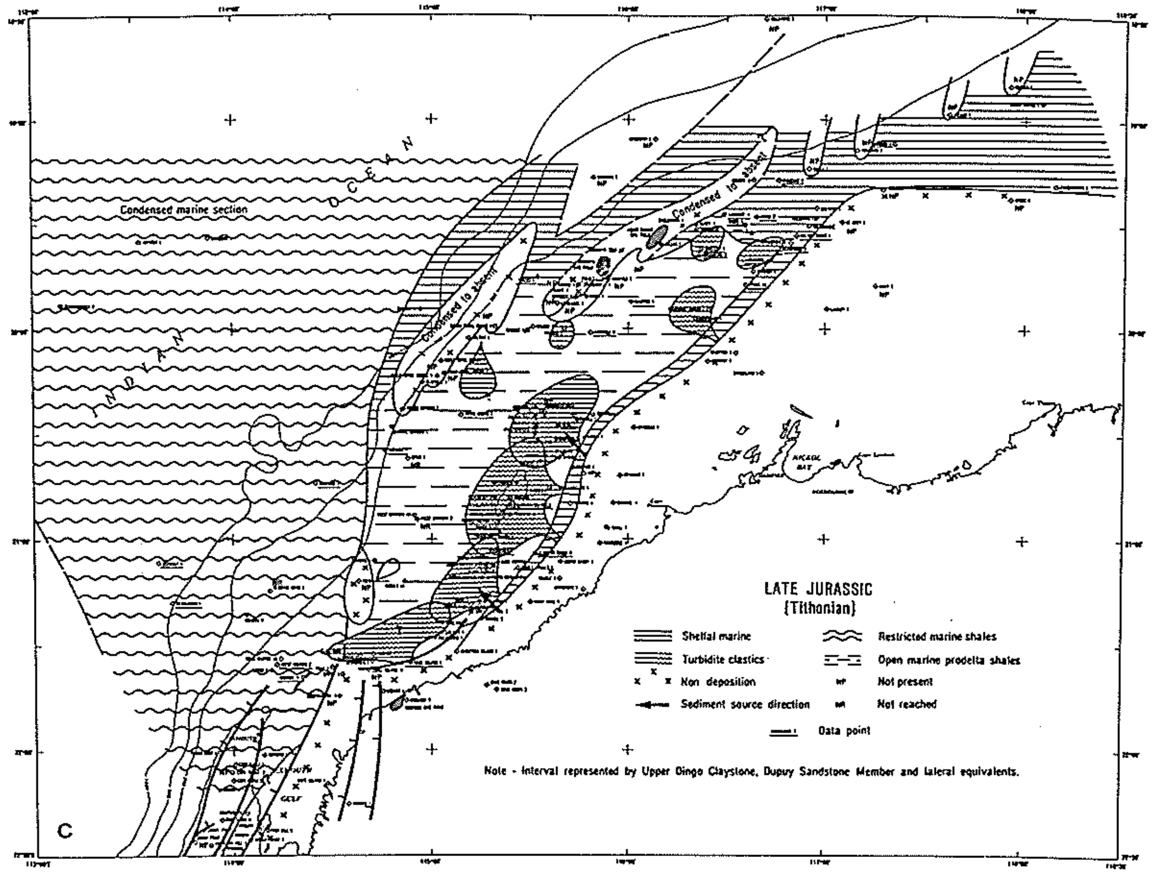


Figure 13. Late Jurassic palaeogeography displaying schematic Dupuy Formation distribution. (Robertson Research,1986)

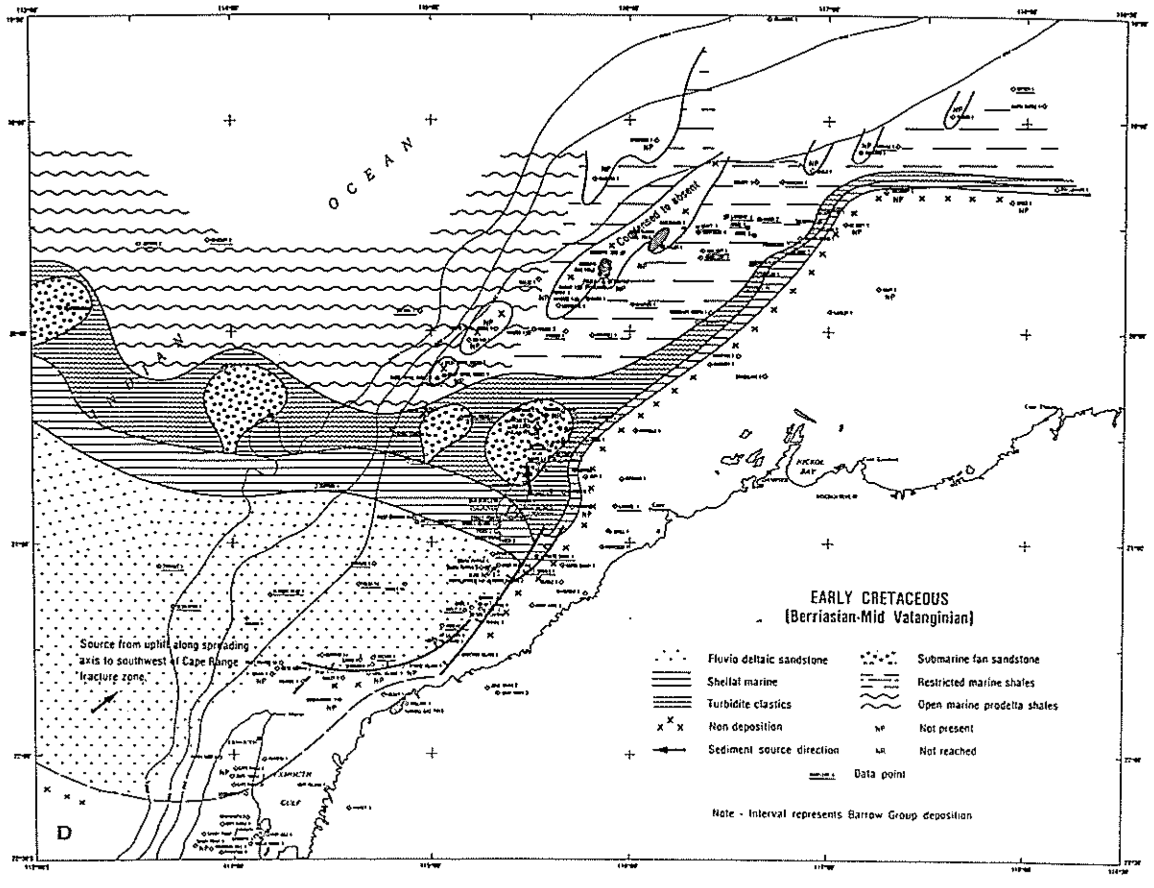


Figure 14. Early Cretaceous palaeogeography displaying northward prograding Barrow Delta (Robertson Research,1986)

Late Tertiary, in particular associated with renewed tectonism during the Miocene caused by the collision between the Australian continental plate and southeast Asian plate. This period of Miocene tectonism resulted in significant fault reactivation.

4.2 MESOZOIC BIOSTRATIGRAPHY

The Mid Jurassic - basal Cretaceous biostratigraphy utilised in this study is adopted from Helby, Morgan and Partridge, (1987). This zonation was considered the most up to date and widely applicable biostratigraphy scheme for the Northwest Shelf and is summarised in Figure 15. The dinoflagellate zonation developed by Helby et al is used by most Australian biostratigraphers, and is an updated version of an earlier Helby (1984) scheme.

Biostratigraphy forms the basis from which age dating of seismically definable time lines and facies associations recognised by sequence stratigraphy can be made.

The biostratigraphy was correlated with well logs and seismic sections via synthetic seismograms at well ties which aided in the elucidation of stratal surfaces for regional correlation purposes. The emphasis has been placed using the dinoflagellate zonations due to more detailed age resolution given the wide range of dinoflagellate species diversity and abundance within marine depositional environments which characterise the Upper Jurassic interval. Age information was derived from open file and proprietary data provided by sponsoring companies.

Age dating using dinoflagellate zonations prior to the establishment of a regionally applicable biostratigraphic scheme in 1984 by Helby are frequently conflicting. It was found that all available biostratigraphic ages should be plotted, so that comparison of age zonations with identifiable time lines from seismic or well log correlation can substantiate the reliability of the data.

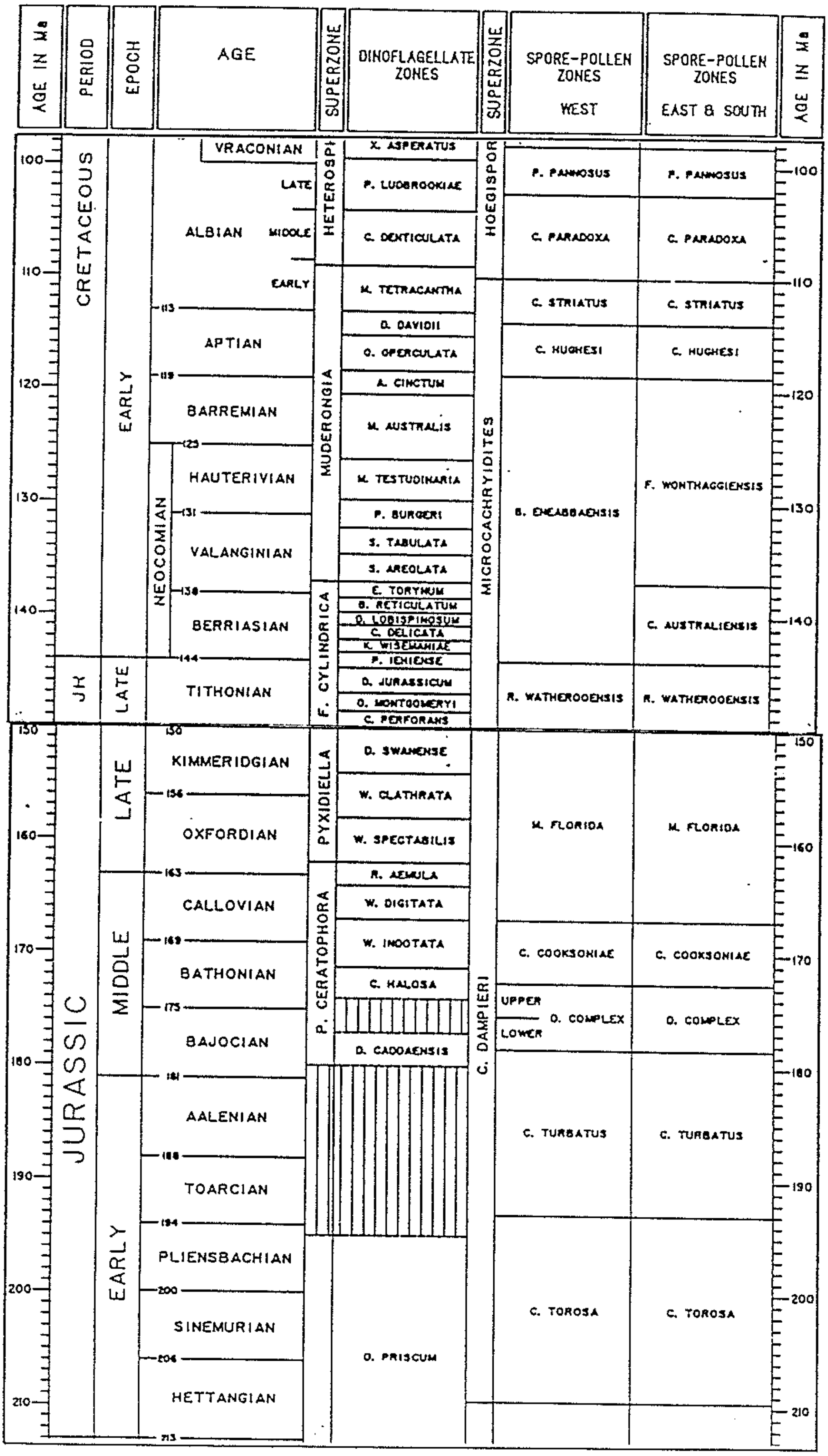


Figure 15. Jurassic - Early Cretaceous biostratigraphy zonation (after Helby,Morgan & Partridge, 1987)

5 SEDIMENTARY MODELS FOR FAN DEPOSITION AND ASSOCIATED FACIES

5.1 SEQUENCE STRATIGRAPHY

5.1.1 Introduction

Due to the rapid lateral facies changes within the Upper Jurassic study interval and the relatively sparse well control (1 well per 350 km^2), regional correlations based on lithostratigraphy and biostratigraphy alone are inadequate to identify controls on facies trends. Sequence stratigraphy principles integrating biostratigraphy with seismic stratigraphy and wireline log correlations have been applied to evaluate the relationship between eustacy and tectonism and subsequent effects on sedimentation in the study area.

The following section discusses the concepts and principles of sequence stratigraphy which were used in this study.

5.1.2 Concept of Sequence Stratigraphy

Sequence stratigraphy provides a means to develop models for a stratigraphic succession by relating the following variables; rate of subsidence (tectonics), eustacy, sediment supply and climate to establish depositional systems, environments and lithofacies relationships within sequences deposited during specific time intervals (Vail 1988, Sangree and Sneider, 1988).

'A depositional sequence is a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities'. (Mitchum, Vail and Thompson, 1977) A depositional sequence is chronostratigraphically significant because it was deposited during a specific geologic time interval bounded by unconformities or correlative conformities marking the time boundaries of the depositional sequence.

Vail's sequence stratigraphic analyses technique relies on eustatic sea level fluctuations being the overriding controlling factor and he has based his models on a consistent rate of subsidence. As shown by this study, tectonism (rate of subsidence) is highly variable in the Barrow Sub-basin, with frequent periods of major faulting and isostatic adjustment of fault blocks. Consequently, sea level curves are highly modified by tectonism causing incomplete depositional sequences or variable facies associations due to changing rates of subsidence and variations in sediment supply. Nevertheless, the fundamentals of Vails sequence stratigraphic concepts can be used for systems tract analyses in the Barrow Sub-basin.

Vail's (1988) stratigraphic sequence analysis allows the identification of the following systems tracts within a gradually subsiding basin subjected to eustatic sea level fluctuations. The development of each systems tract is controlled by the relative sea level and each systems tract has unique depositional characteristics. The four system tracts that constitute a depositional sequence are:

(i) Lowstand Systems Tract
(ii) Transgressive Systems Tract
(iii) Highstand Systems Tract
(iv) Shelf Margin Systems Tract

Lowstand Systems Tracts (LST)

The unconformity marking the basal boundary of a depositional sequence is related to a eustatic sea level fall exceeding the rate of subsidence (Figure 16). Two types of unconformities can be recognised as a result of a eustatic sea level fall:

(i) Substantial drop in sea level faster than the rate of subsidence results in entire shelf margin being exposed to subaerial erosion and the re-establishment of the shore-face basinward of the shelf margin (Figure 17). Under these conditions, a type I unconformity develops and is characterised by the development of river valleys incised into the exposed shelf and submarine canyon development at the shelf margin producing deposition of basin floor fans and associated lowstand system tract sediments.

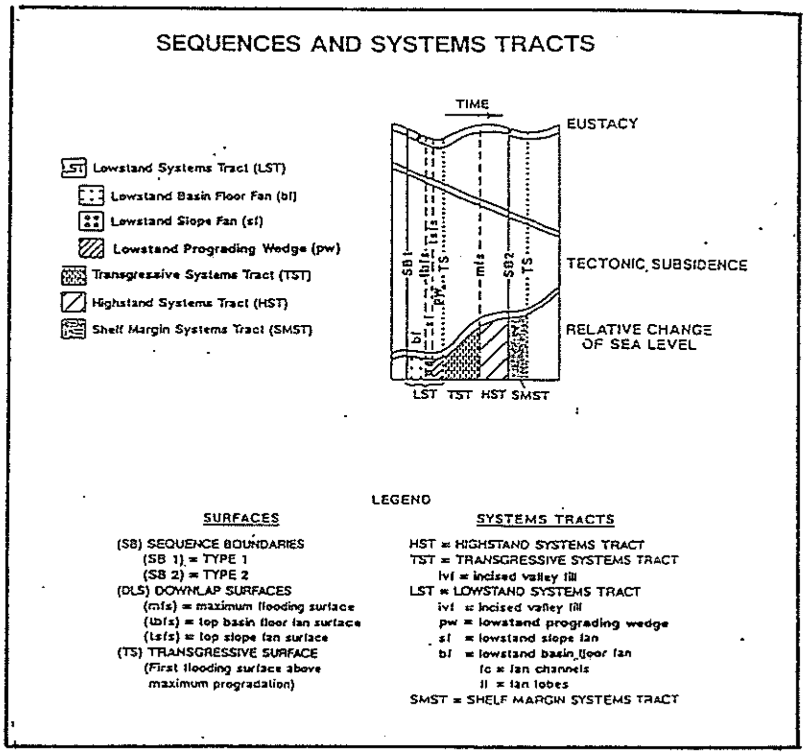


Figure 16. **Relationship between eustasy and system tracts in a single depositional sequence assuming uniform rate of tectonic subsidence (after Vail etal 1988)**

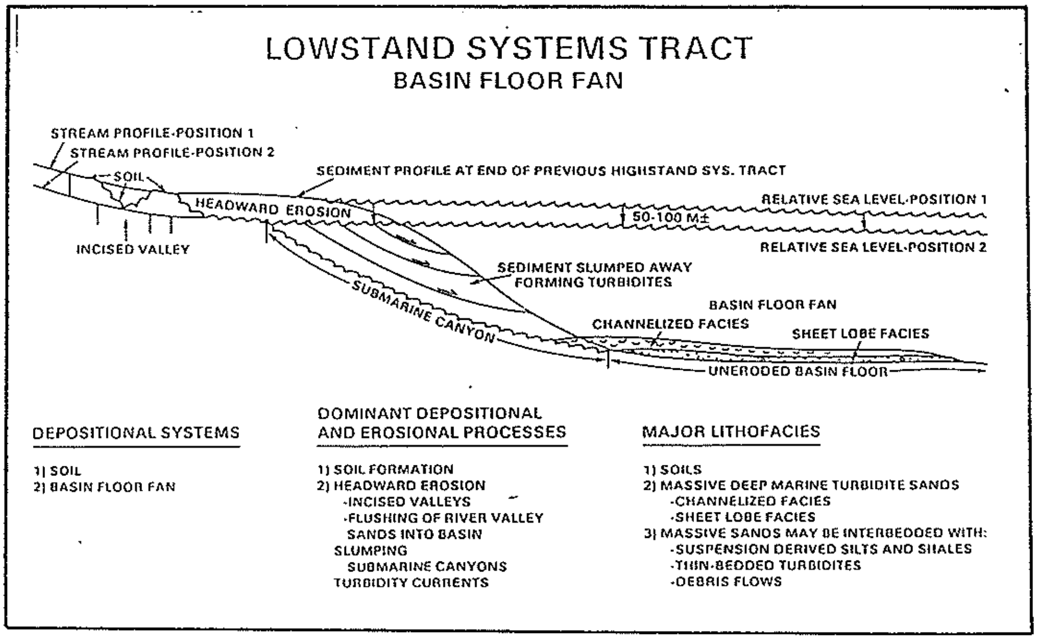


Figure 17. **Lowstand systems tract associated with a Type I unconformity. Figure displays the development of basin floor fan fan deposition, sediment instability and canyon incision on the exposed shelf. (after Vail etal, 1988)**

(ii) If the eustatic sea level fall is slower than the rate of subsidence and fails to bring the shoreline position to the shelf edge then a regressive shelf margin tract forms producing a type II unconformity.

In lowstand system tracts associated with type I unconformities three separate depositional units develop. The oldest depositional unit is the basin floor fan sand which develops during periods of maximum sea level fall and high sediment availability on adjacent shelfal areas (Figure 18). If the sediment supply is low or sea level does not fall significantly below the shelf edge then no basin floor fan complex will develop. As the rate of sea level fall declines slope fan and levee channel complexes develop and downlap on to the underlying basin floor fan (Figure 19). As the rate of sea level fall continues to decline or rise slightly in relation to subsidence, shallow water sediments onlap the old foreslope. This stage constitutes the prograding lowstand complex. The shoreward position of the prograding lowstand complex terminates at the shelf edge of the previous highstand, at which stage the shoreline rapidly transgresses across the generally flattened, older shelf (Figure 20) (Vail, 1987; Vail et al, 1990).

The glacio-eustatic sequence stratigraphy model provides for basin floor fans to develop only associated with lowstand deposits. This is not entirely true in that sediment instability can develop during highstand periods resulting from tectonism, storm activity, or very high rates of sediment supply (Boyd, pers. comm., 1990 & 1991). These may cause massive slumping of the topsets and foresets of a deltaic system or shelf margin clastic wedge and re-deposition as

Figure 18.

Basin floor fan deposition with canyon incision on exposed shelf during maximum period of sea level fall
(Vail etal,1988)

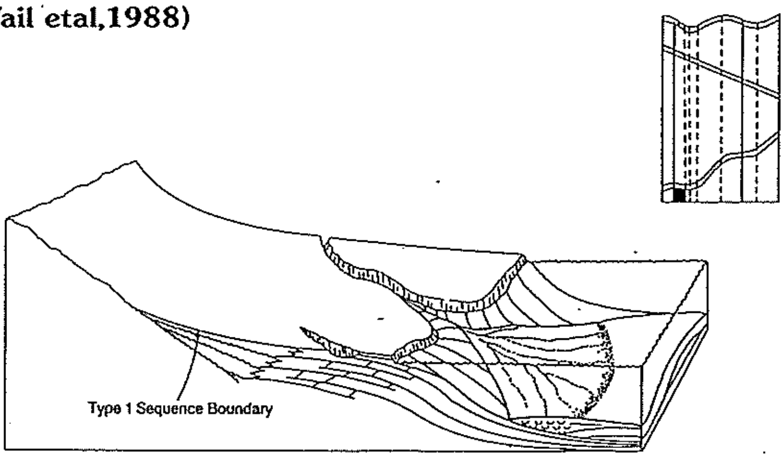


Figure 19.

Slope fan deposition downlapping basin floor fan associated with slight decline in the rate of sea level fall
(Vail etal,1988)

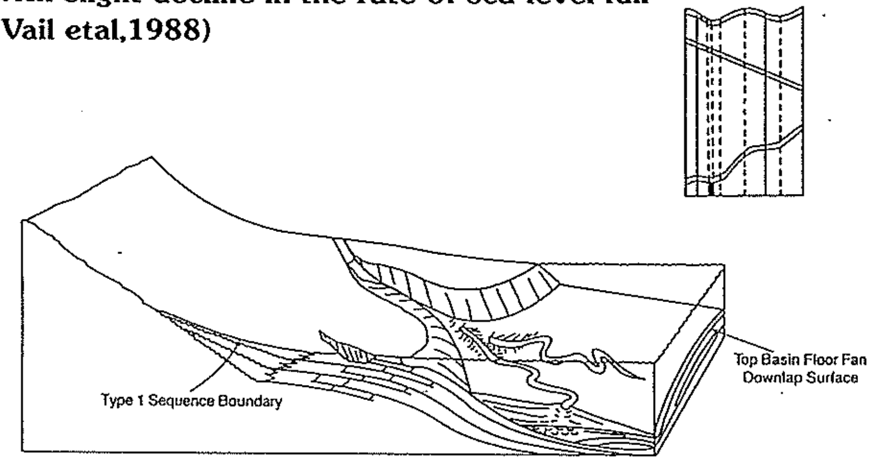
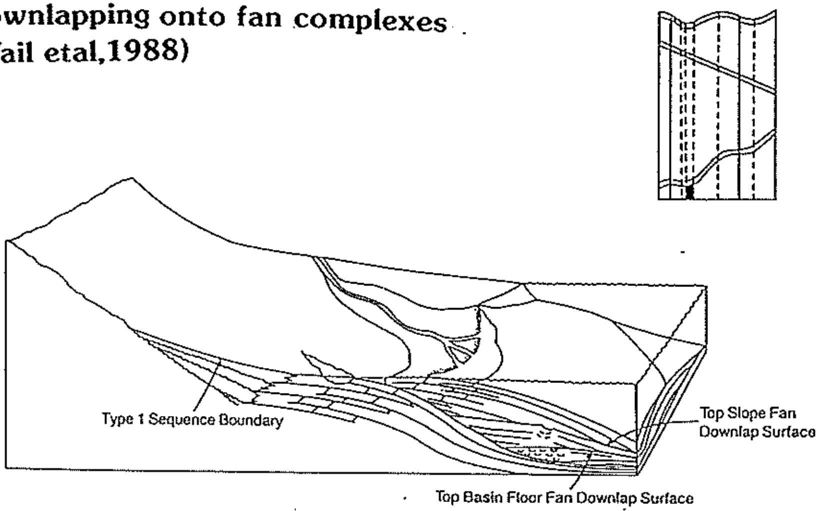


Figure 20.

Lowstand prograding wedge infilling canyon incision and downlapping onto fan complexes
(Vail etal,1988)



localised submarine fans or basin floor sheet sands. This also applies to high sedimentation rates within a prograding lowstand complex.

During the initial periods of rapid sea level fall, river systems developed during the previous highstand period become incised into the subaerially emerging shelfal platform in an attempt to seek an equilibrium profile at the new lowstand base level. Sands previously deposited in upper delta plain or alluvial plain environments are rapidly channelled to the shelf edge, where they build up until sediment instability results in slumping and deposition of the sediments on to the basin floor via turbidity currents or other mass flow processes.

As the eustatic sea level fall slows and approaches zero (Figure 16) with constant basinal subsidence, the position of the sea level begins to rise relative to the basin margin. As a result, thick packages of sediment build up adjacent to point sources at the paleoshelf margin which at some stage undergo slumping due to sediment instability, resulting in deposition of the slope fan. Channel levee deposits form an important part of the slope fan deposits (Figure 19).

As the eustatic sea level position begins to rise past the lowstand curve (Figure 16) the relative position of the sea level moves upward toward the old shelf break. Dependent on rate of sediment supply, rivers that developed on the shelfal areas during the lowstand period may continue to deposit continental derived and reworked shelfal sediments basinward the old shelf break. As a result, deltaic and shoreface sands begin to accumulate and prograde laterally into the basin producing the lowstand prograding wedge complex. Deposition on the slope consists of mainly shales with thin turbiditic interbedded sands associated with storm activity.

Prograding lowstand complex sediments frequently infill the incised canyons cut into the shelf edge during the earliest lowstand periods (Figure 19).

Transgressive System Tracts (TST)

The prograding lowstand wedge complex is terminated when the sea level begins to rise rapidly (Figure 16) resulting in a major flooding of the shelf margin and re-establishment of shoreline, well landward the former shelf edge. During this period of rapid sea level rise, the top of the underlying prograding complex is reworked and re-deposited as a basal transgressive sand (Figure 21). Following this period of reworking, deposition of marine transgressive systems tract can often be identified on seismic by its onlapping relationship onto the type I unconformity on the shelf margin and downlapping relationship onto the underlying lowstand system tract (Figure 21). The maximum flooding surface, which corresponds to the furthest updip development of shoreface sediments, is the boundary between the transgressive and overlying highstand systems tract.

Highstand Systems Tract (HST)

Highstand systems tracts are made up of three cycles; early highstand, later

Figure 21.

Transgressive systems tract deposition during period of rapid sea level rise. Diagram displays transgressive surfaces, backstepping of shoreface sediments and sediment starvation in basin depocentre. (after Vail etal, 1988)

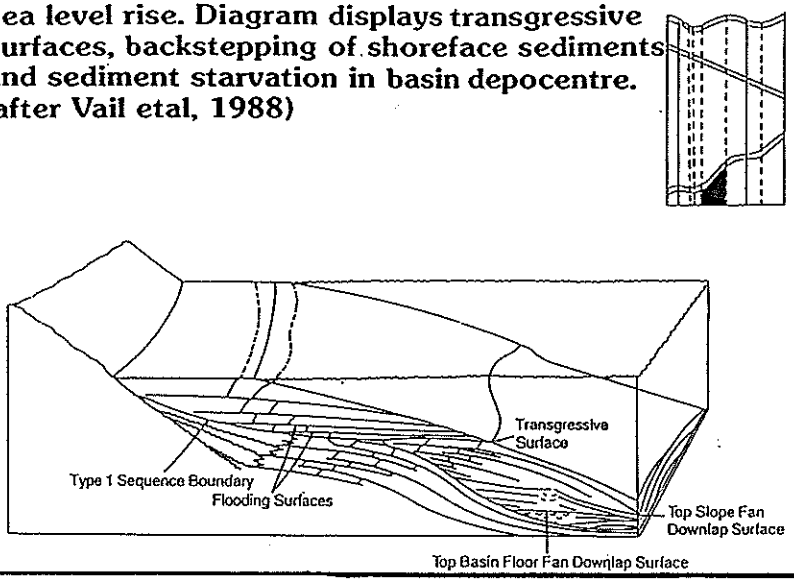


Figure 22.

Highstand sytems tract associated with decrease in the rate of sea level fall. Diagram displays progradation of shoreface and downlapping onto maximum flooding surface. (after Vail etal, 1988)

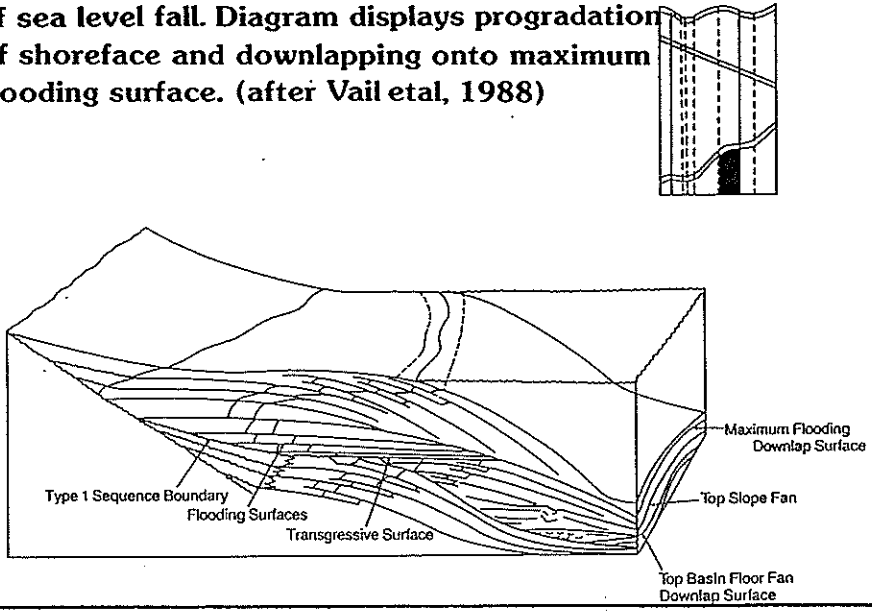
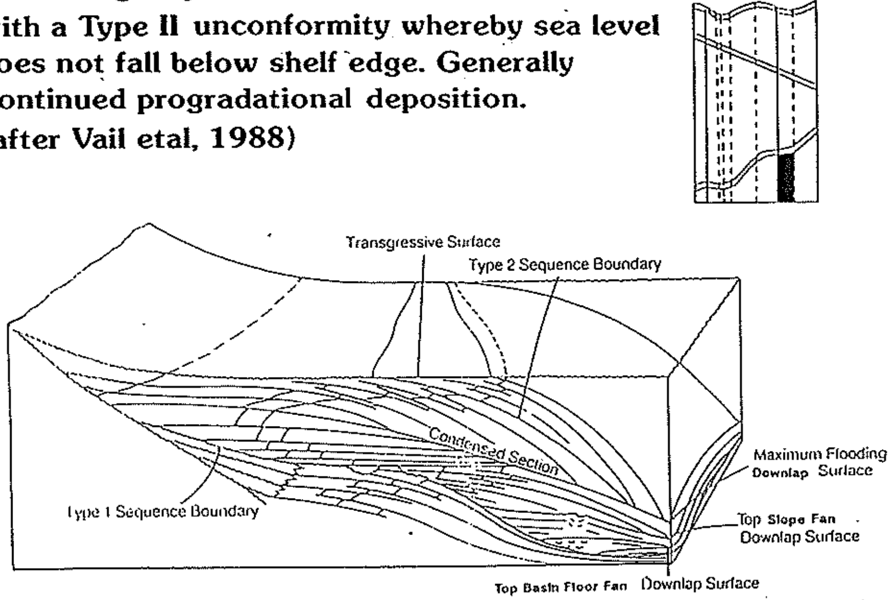


Figure 23.

Shelf margin systems tract (shelf margin wedge) associated with a Type II unconformity whereby sea level does not fall below shelf edge. Generally continued progradational deposition. (after Vail etal, 1988)



highstand prograding complex and the late highstand subaerial complex. The early highstand is characterised by an upward and sigmoidal progradational stratal pattern. The late highstand prograding complex is characterised by an outward oblique progradation pattern while the late highstand subaerial complex is dominated by sediments deposited above sea level (Figure 22). The late highstand prograding complex and the late highstand subaerial complex are deposited contemporaneously.

Major storm activity or periods of tectonism during highstand periods can result in the development of turbidites at the toe of the shelfal slope (toe fans). These toe fans associated with highstand systems tracts have been identified by this study in the Barrow Sub-basin.

Shelf Margin Systems Tracts (SMST)

The shelf margin systems tract is a prograding and aggradational sediment wedge that overlies a Type II sequence boundary and laps out on the shelf, landward of the preceding depositional shoreline break (Figure 23). The shelf margin prograding wedge is usually characterised by aggradational progradation, with a lower conformable sequence boundary. The top of the shelf margin system tract is characterised by a transgressive surface.

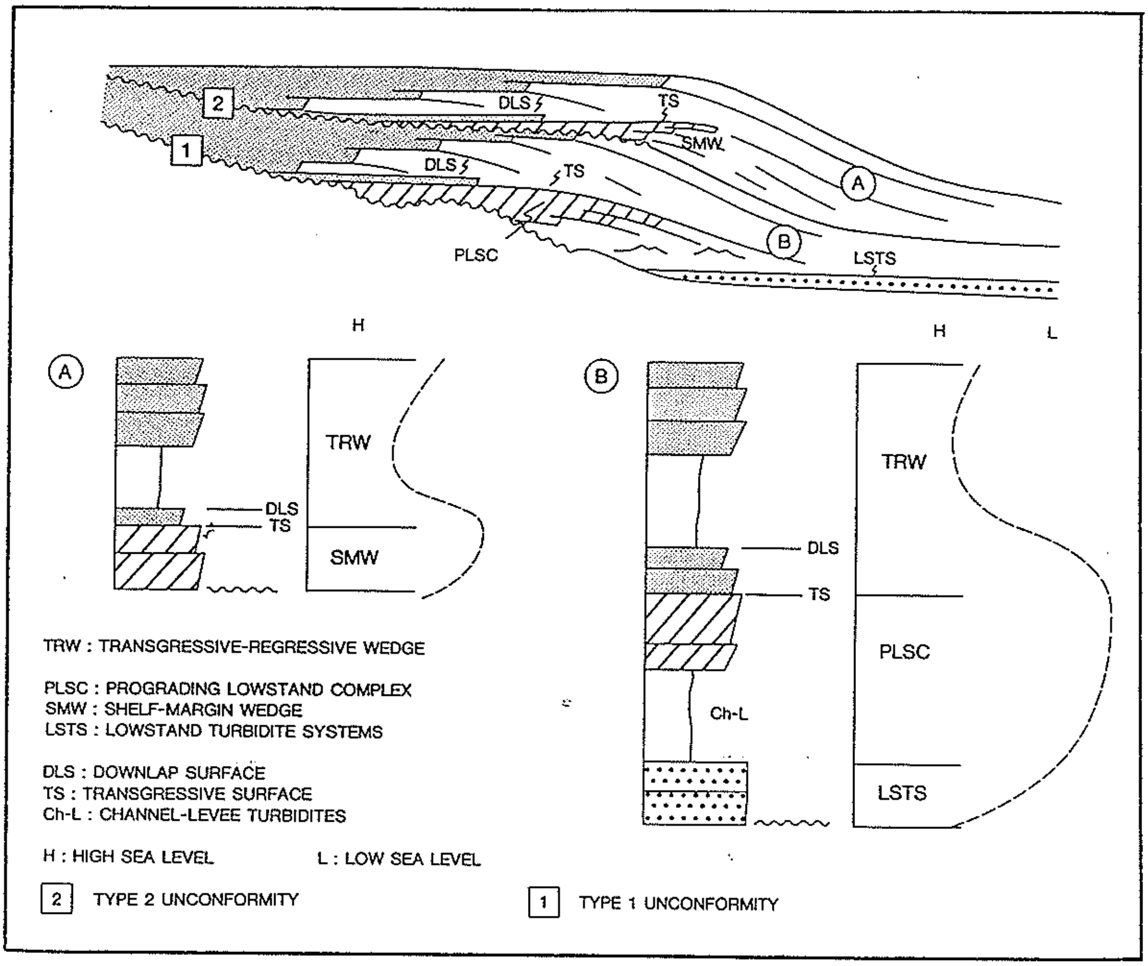


Figure 24. Models of depositional sequences of divergent continental margins. (Mutti & Sgavetti, 1987)

A summary of the models of depositional sequences of divergent continental margins is given as Figure 24 and summarises the spatial relationship of the individual system tracts. Mutti and Sgavetti (1987) use slightly different terminology in their subdivision of system tracts within a depositional sequence compared to Vail et al (1987, 1988, 1990). Mutti and Sgavetti's transgressive - regressive wedge displayed on figure 24 is equivalent to the combined transgressive and highstand system tracts of Vail et al.

5.2 SUBMARINE FAN MODELS

5.2.1 Introduction

The morphology, geometry and facies associations of submarine fans are primarily controlled by the long term tectonic stability of the subsiding basin and the volume of sediment available for redeposition into basinal areas. The largest submarine fan systems generally form over a period of millions of years in a stable basin with long term supply of sediment. It is within these long lived settings that eustatic sea level fluctuations as described by Vail et al (1988) have the most pronounced control on sedimentation. Turbidite depositional systems deposited in tectonically active settings tend to be short lived with tectonic activity being the principle control on facies associations and size of submarine fan complexes.

A major factor controlling the relative stability of a basin receiving turbiditic deposition is the type of crust underlying the basin (Mutti and Normark, 1987). Long lived submarine fan associations are generally deposited on oceanic crust, the size of the fan reflecting the sediment supply, and not the confines of the basin. Conversely turbidite systems formed on continental crust, especially along active continental margins, are mostly of relatively short duration even when sedimentation rates are high. This is clearly demonstrated in the Barrow Sub-basin where several lowstand turbidite depositional episodes have been recognised by this research (Section 6.4) within the Upper Jurassic period alone. These turbiditic episodes are primarily related to periods of active tectonism and uplift along the basin margins.

5.2.2 Turbiditic Basin Types

Mutti and Normark subdivide turbidite basins into four (4) categories:

(i) Type A - basins formed on oceanic crust with large, long lived sediment source and little or no tectonic activity.

(ii) Type B - basins formed on oceanic crust with relatively short-lived sediment supply but with active tectonism.

(iii) Type C - basins formed on continental crust with relatively large and long lived sediment supply with active tectonism controlling basin configuration.

5.2.4 Submarine Fan Types and Facies Associations

A plethora of fan models and types has been proposed by numerous authors over the past two decades. The following discusses only those models incorporated into this study and relates the effects of local tectonism and eustatic sea level fluctuations on facies associations and submarine fan type, distribution and size.

Mutti (1985) and Mutti and Normark (1987) subdivided turbidite depositional systems into three categories. This subdivision can be used as a tentative reference in describing the depositional pattern of most ancient turbidite systems (Mutti and Normark, 1987).

Type I turbidites are characterised by 'highly efficient' sediment dispersal and are commonly composed of non channellised sandstone lobes. These sandstone lobes are correlative with erosional channels and particularly with large scale erosional features that are probably extensive slump scours in the shelf edge deposits from which the bulk of the sand is derived. These systems most commonly develop associated with Type 1 unconformities whereby the sea level falls below the shelf edge, exposing the previous shelfal highstand sediments and allowing rapid progradation of fluvial deltaic sediments to accumulate on the shelf. Sediment instability induced by high rates of sedimentation, tectonism or earthquakes initiates massive slumping, providing large volumes of sand-laden sediment for redistribution into basinal localities. The sandstone bodies are characterised by lateral continuity and roughly tabular geometry over distances up to several tens of kilometres parallel to current direction. Each lobe, commonly between 3-15 m thick, is characteristically thick bedded and grades in a down-current direction into thinner bedded and finer grained deposits. In some systems, the aggregate thickness of the sandstone lobes and associated lobe-fringe deposits may reach several hundreds of metres (Mutti, 1985).

The depositional setting of Type I turbidites suggests that the sandstone lobes are detached from the provenance as shown on Figure 25 and are not time equivalent to the channel and scour infill deposits on the adjacent shelf. Figure 27 displays a photograph of some massive Bouma A cycles within a basin floor sheet (lobe) while Figure 28 displays a photograph of Bouma cycles within a distal lobe of a turbiditic system. Both photographs were taken in the South Central Pyrenees, Spain, of the Eocene Hecho Group. These photographs provide an indication of the physical characteristics of the submarine fan deposits and related sediments associated with deep marine clastic deposition in a tectonically active setting.

Type II turbiditic systems are typically smaller and coarser grained than Type I systems. Type II deposits are composed of depositional and mixed channel-fill sediments that grade downslope into sandstone lobes. These sandstone lobes are considerably less extensive than Type I lobes as shown on Figure 25 which displays the depositional relationship between the different turbidite systems. Type II systems are most commonly associated with Type C and D basins (Section 5.2.2, page 28). Lobe and channellised deposits are physically attached vertically and laterally by well defined transitional facies. Very coarse grained

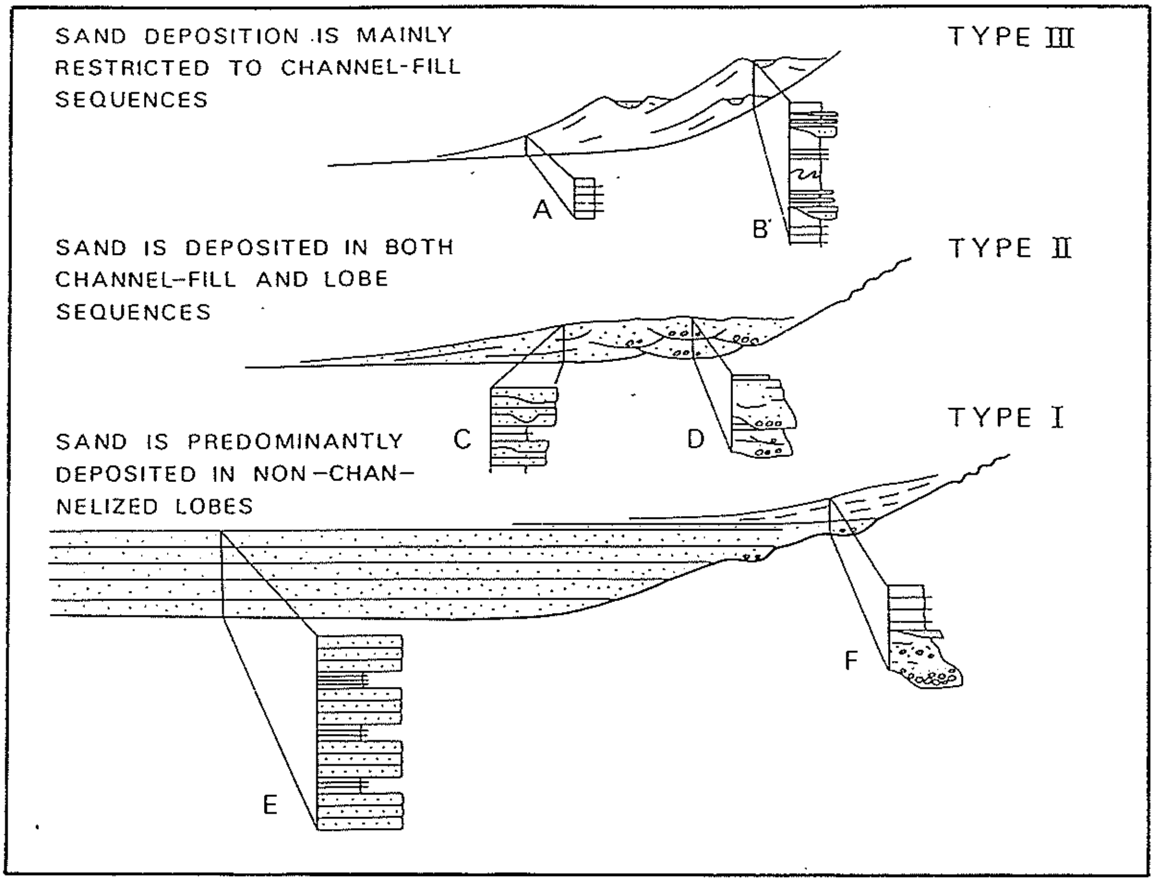


Figure 25. Schematic representation of three main types of turbidite deposits as characterised by relative amount of and position within the deposit of the sandy component. (Mutti & Normark, 1987)

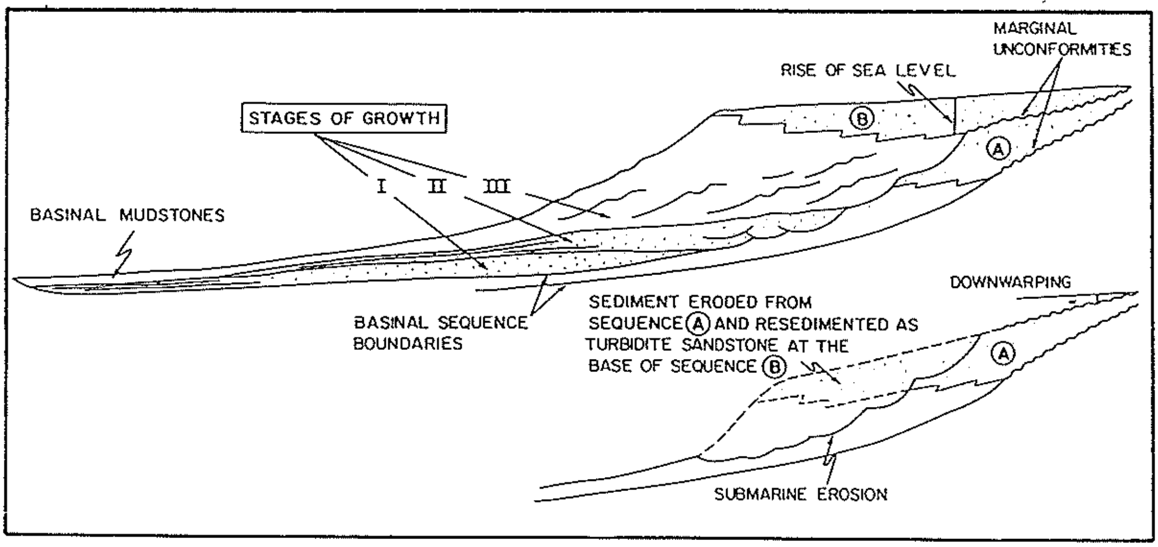


Figure 26. Conceptual diagram relating relative changes of sea level and different stages of growth of turbidite systems within depositional sequences (Mutti, 1985)

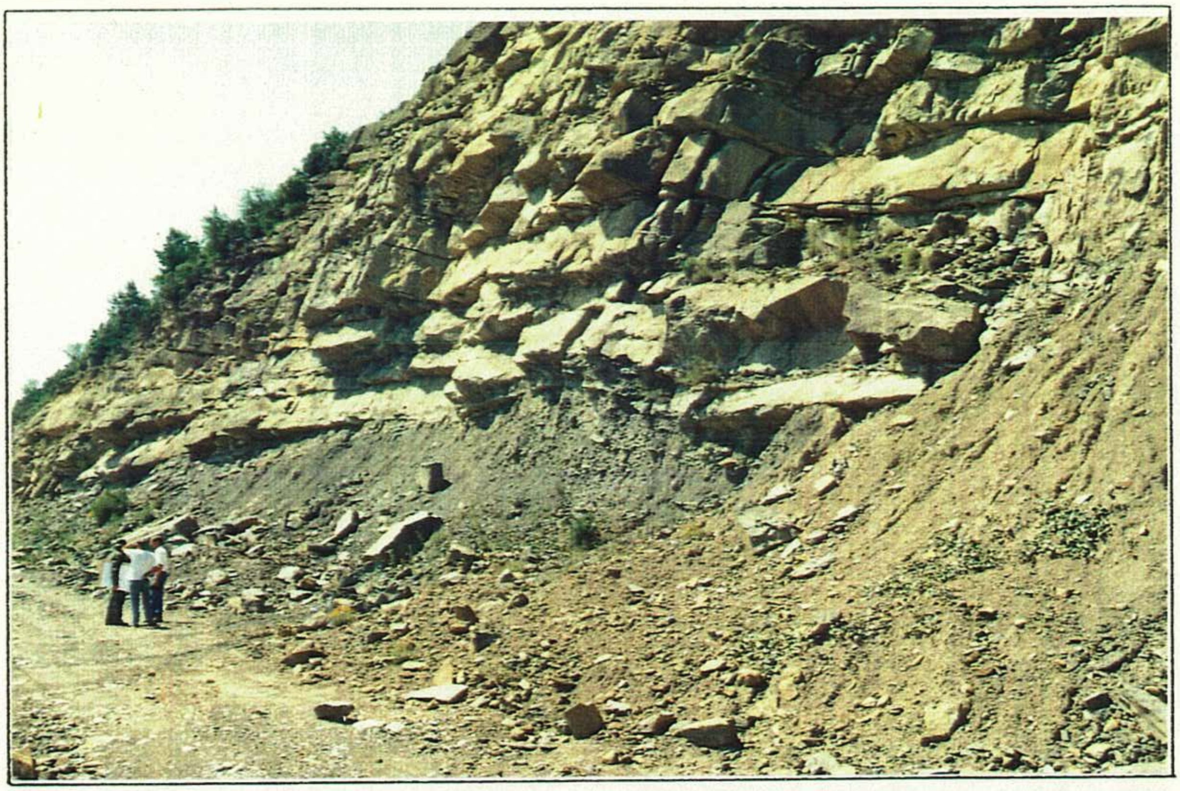


Figure 27. Photograph displaying Bouma A cycles within a basin floor fan sand lobe, (Type I) associated with a Type I unconformity. Photograph is from the Hecho Group, south central Pyrenees, Spain.

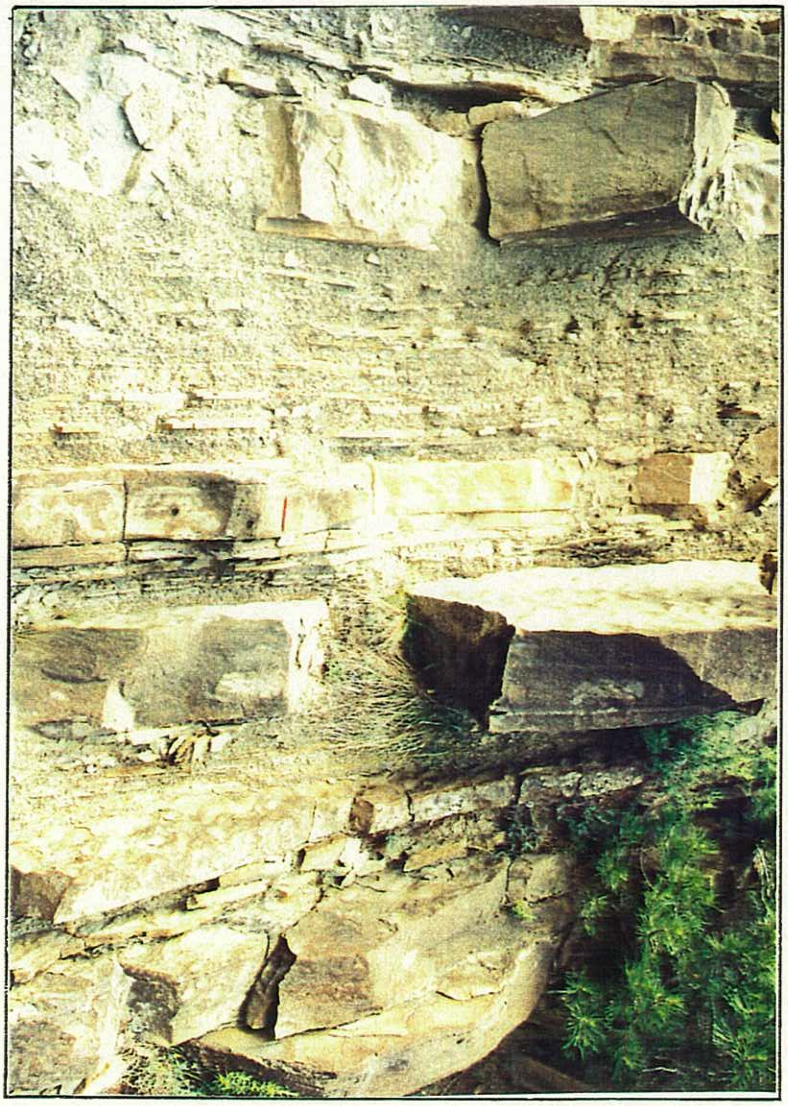


Figure 28. Photograph displaying Bouma A,C,D,& E cycles within a distal turbidite sequence. Photograph is from the Hecho Group, south central Pyrenees, Spain.

Type II systems are almost entirely composed by channellised deposits; decrease of grain size tends to favour the development of associated lobes. Interchannel deposits can consist of crevasse splay and thin interbedded, interchannel turbidites deposited during periods of rapid discharge and levee breaking. Figure 29 displays a crevasse splay deposit associated with a channellised system and Figure 30 displays a photograph of interchannel turbidites. Both photographs were taken in the South Central Pyrenees of the Eocene Hecho Group.

The importance of examining outcrop examples of deep marine clastic deposition is that in the case of the Upper Jurassic of the Barrow Sub-basin, the only continuous rock samples that can be examined are from cores. Consequently, from the understanding of vertical and lateral facies associations in outcrop exposures, a geologist, by analogy, can begin to reliably predict the depositional environments and understand the vertical facies associations observed in cores.

Type III turbidite systems are characterised by small sandstone filled channels that grade vertically and laterally into muddy sequences. The channellised sandstone facies do not extend basinward and are therefore restricted to the inner portions of the system (Mutti, 1985; Damuth et al, 1983). The channel fill sequences are made up of fine to medium grained sandstone beds, that characteristically thin and pinchout towards the margins of the channel. This is shown in Figure 31 which is a photograph of channel margin sediments adjacent to levee deposits within a Type III turbidite system. Type III systems are analogous to modern channel-levee complexes (Mutti and Normark, 1987). Overbank and

Figure 29. Photograph of crevasse splay deposits within an interchannel turbidite system - Mutti Type III channel/levee turbidite. Photograph is of the Hecho Group, south central Pyrenees, Spain. Photograph displays two phases of crevasse splay deposition which are separated by mud drape.

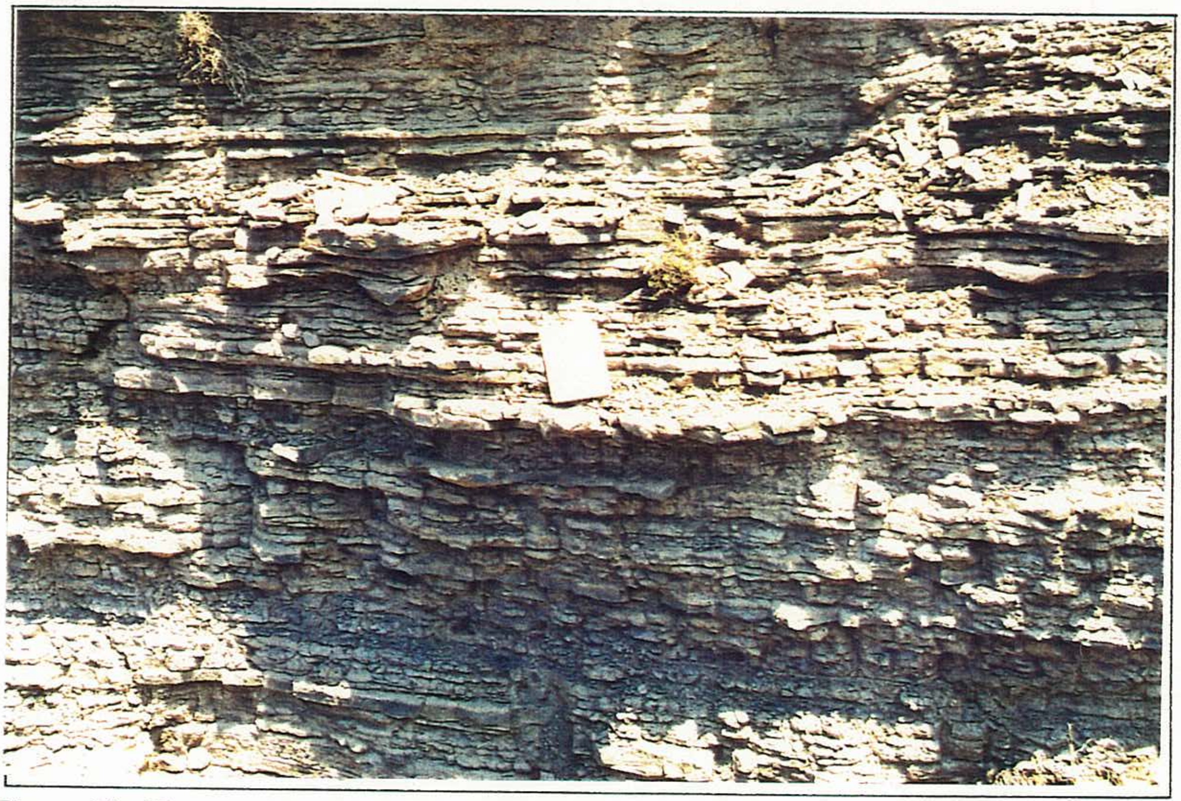


Figure 30. Photograph of interchannel turbidites associated with periods of rapid deposition and breaching of levee margins. Turbidite currents develop on the outer slope of the levee resulting in thinnly interbedded interchannel turbidites. (Hecho Group, south central Pyrenees, Spain.)

Figure 31. Photograph of channel margin sediments adjacent to a levee bank within a Mutti Type III turbidite system.(Hecho Group, south central Pyrenees, Spain.)

interchannel turbidity currents are common in Type III systems.

6 RESULTS: SUMMARY AND DISCUSSION

6.1 CORE LOGGING

6.1.1 Introduction

A total of 337 m of core from the Upper Jurassic penetrated by 14 wells within the Barrow Sub-basin study were logged in detail to evaluate lithology, grain size distribution and sedimentary structures. The aim of the core logging was to evaluate the reservoir quality and facies distribution within the Upper Jurassic interval.

After examination of the core, selected samples were photographed and taken for thin section preparation, and in a few cases, scanning electron microscopy for more detailed evaluation of porosity-occluding cements. Results from these studies were then combined with the wireline logs of the various wells to integrate the facies, reservoir and depositional information with the wireline log and seismic sequence analysis.

A list of cores logged is given in Table II.

6.1.2 Visual Reservoir Characteristics and Facies Subdivision

Seven (7) sandstone facies were recognised whilst logging the core:

1. **Homogenous very fine - fine grained sandstone.**

2. **Very fine - fine grained sandstone with abundant shale clasts.**

3. **Poorly sorted fine - medium grained argillaceous sandstone.**

4. **Poorly sorted, very fine - coarse grained, argillaceous sandstone.**

5. **Well sorted, very fine - fine grained, bioturbated argillaceous sandstone.**

6. **Poorly sorted, very fine grained - cobble sized clasts, matrix supported.**

7. **Well sorted, medium - coarse grained sandstone.**

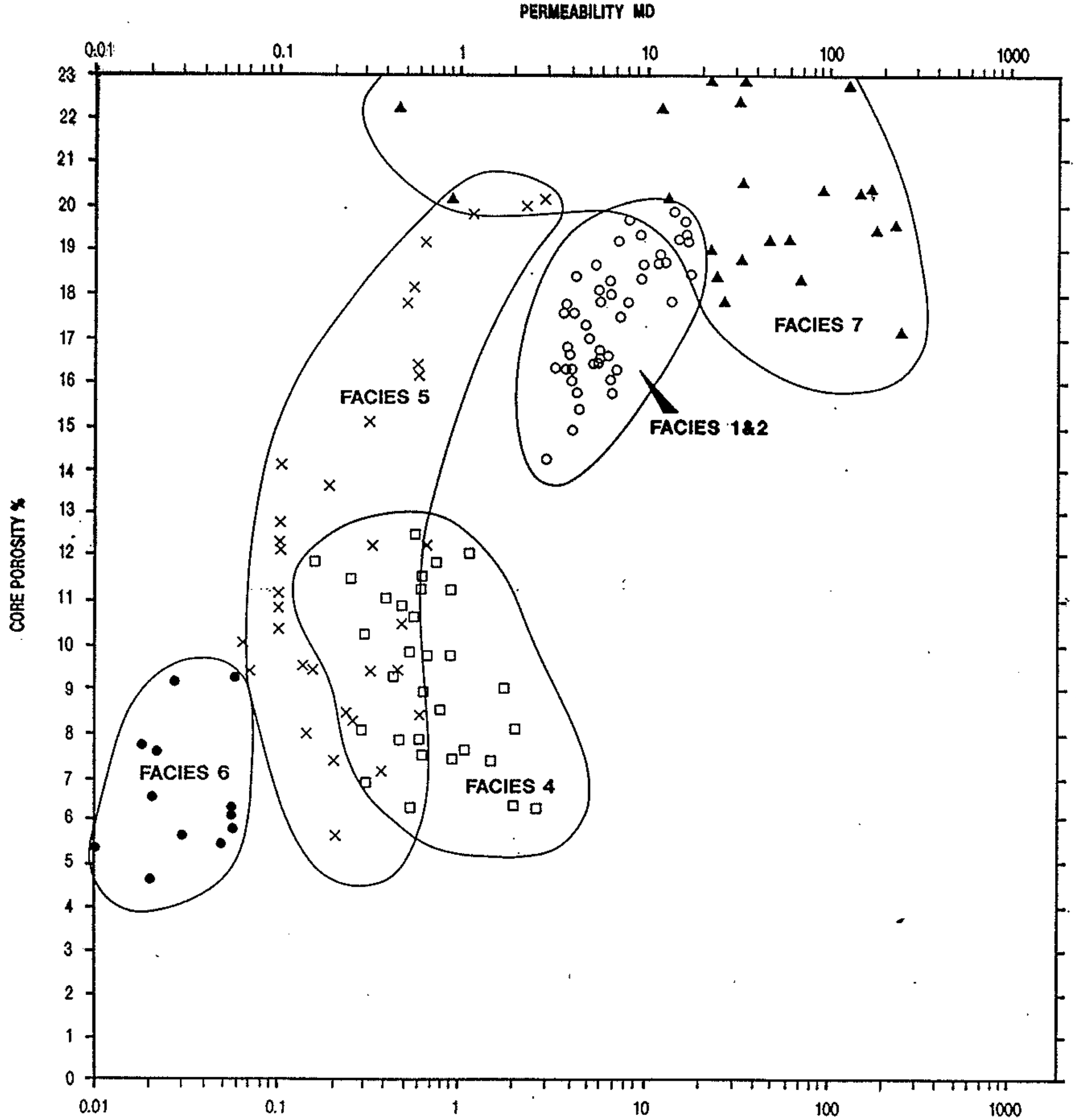
Each facies has unique reservoir characteristics based on available core analysis (Figure 32). A summary of the facies and reservoir characteristics is given in Table IV. The following discusses in more detail each of the sandstone facies recognised and the geographical distribution in the study area.

FACIES 1 homogenous very fine - fine grained sandstone

The type section for Facies 1 and Facies 2 is Bambra-1, Core 2. Lithologically,

POROSITY VERSES PERMEABILITY PLOT FOR UPPER JURASSIC SANDSTONE FACIES

FACIES	LITHOLOGY	ENVIRONMENT OF DEPOSITION
1	homogeneous,vf-f gnd sst	basin floor fan complex
2	vf-fined gnd sst with abdt shale clasts	basin floor fan complex
3	poorly srtd,f-med gnd,arg sst	slope fan complex
4	poorly srtd,vf-crse gnd biot arg sst	slope fan- turbidite
5	well srtd,vf-f gnd,biot arg sst	distal tubidites
6	poorly srtd,vf-boulder, mass flow	mass flow
7	well srtd,med-crse gnd,sst	proximal BFF & interbedded turbidites



LEGEND

○	FACIES 1&2	(Bambra-1 core 2)
□	FACIES 4	(Barrow-25 cores 28,29,30)
×	FACIES 5	(Emma-1 core 3) (Barrow-25 cores 28,29,30)
●	FACIES 6	(South Pepper-1 core 8)
▲	FACIES 7	(Barrow-25 cores 28,29,30)

Figure 32

Facies 1 is an homogeneous, very fine to fine grained, moderately sorted quartzitic sandstone with common siderite nodules, water escape structures, authigenic quartz overgrowths, secondary calcite cement and common detrital glauconite. The quartzitic sandstone has a sucrosic texture and the quartz grains are predominantly clear to milky with frequent conchoidal fracture. Intergranular porosity is typically infilled by authigenic quartz overgrowths and white, authigenic clay matrix. Porosity has generally been totally occluded by the diagenetic processes. A yellowish sulphate stain occurs within isolated zones within which small rhombs of pyrite occur. Figure 33 is a photograph of Facies 1 with a large, well developed, elongate, sideritic nodule. Slight compaction drape has developed over the crest of the nodule evident by the faint orientation of overlying quartz and glauconite grains. Subhorizontal fractures in the sandstone facies suggests a planar alignment of quartz grains which is not clearly observable at core scale. The relative abundance of sideritic calcitic nodules and siderite cement indicates that very early, surface to shallow sub-surface diagenesis had occurred in the Facies 1 sandstones. Johnston and Johnson (1987) suggest that sideritic cementation can occur within a few centimetres of the sediment-water interface as dissolved oxygen from pore water was depleted and sulphate reduction occurred.

The massive, very fine grained sandstone occurs in beds generally 1-2 m thick which are separated by thin (<15 cm) argillaceous, dark grey green - black siltstone grading to claystone beds with thin (<2 mm) lenses of very fine grained sandstone. The top and basal contacts of the siltstone and claystone intervals are

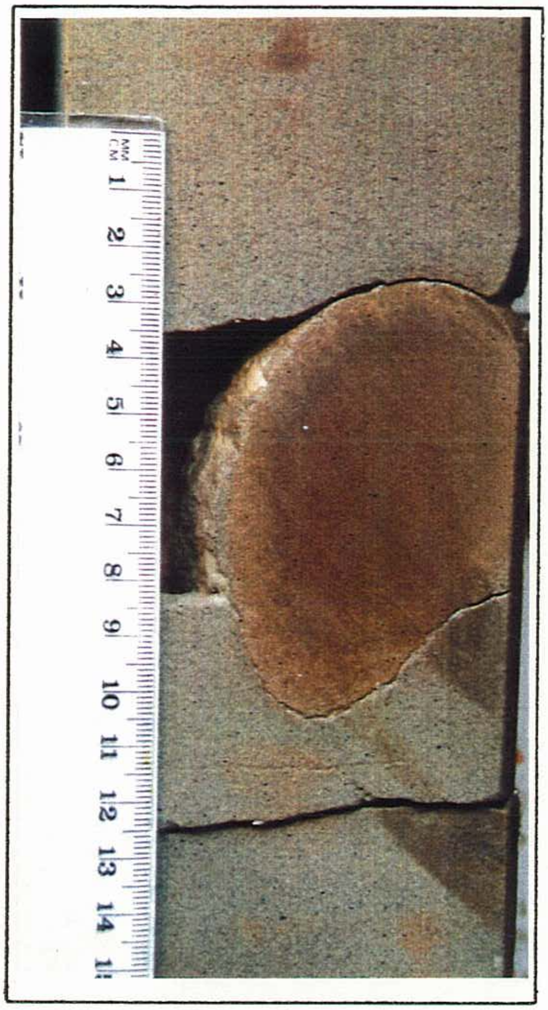


Figure 33. Photo of Bambra-1 core 2, 2722.9 - 2723.1m displaying large siderite nodule within a generally massive fine grained sandstone. Note compaction drape overlying nodule and planar alignment of fractures.

Figure 34. Photo of Bambra-1, core 2, 2713.4-2713.65m displaying sideritised horizontal worm burrows within very weakly planar laminated fine grained sandstone.

sharp with frequent flame structures indicative of dewatering and rapid burial of overlying sandstone facies.

Within the dark grey - black shaly siltstone beds, very fine trace burrows are present (diameter <0.5 mm). These trace burrows have a dendritic type feeding pattern and resemble Chondrites ichnofacies. If this is true then the presence of chondrites suggests that the environment at time of deposition was in a mid - outer shelfal to slope environment.

FACIES 2 very fine - fine grained sandstone with abundant shale clasts

Facies 2 sandstones are similar to Facies 1 apart from the increased abundance of rip-up shale clasts and slight increase in grain size from dominantly very fine to fine grained in Facies 1, to fine to occasionally medium grained in Facies 2 (Figure 35).

The contact with Facies 1 sandstone in Bambra-1 is sharp (Figure 35) and frequently marked by a zone of sideritic cementation <1 cm thick which appears to have developed within the surface of Facies 1 sandstone suggesting episodic deposition, allowing time for siderite cementation to develop between depositional cycles. A relative abundance of generally small (<2.0 mm) shale clasts increases upward in Facies 2 (Figure 35) suggesting the following genesis: i) rip-up of the clasts by turbidity currents from an underlying substratum of soft mud; ii) incorporation of the clasts within the basal, denser portion of a sand-rich turbidity

Figure 35. Bambra-1 core 2, 2716.82-2716.91m. Photograph displays sharp sideritised contact between facies 1 & 2. Core also displays abundance of ripup shale clasts in facies 2. The relative increase of abundance of shale clasts upwards supports relatively long distance fluidised flow regime allowing bouyancy effects to 'float' the shale clasts upwards.The smallness of the shale clasts also supports long distance transport.

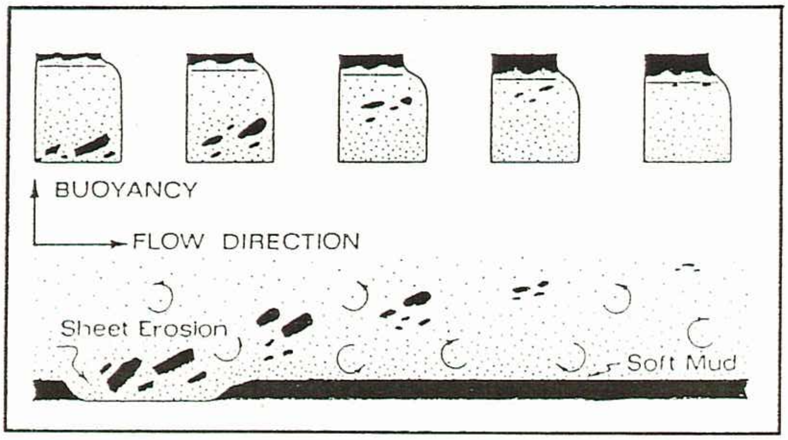


Figure 36. Genesis and occurrences of rip-up clasts in outer fan deposits. (Mutti & Nilsen, 1981)

current; iii) buoyant upward movement of the clasts within the dense basal portion of the current, accompanied by progressive disaggradation and erosion of the clasts; and iv) accumulation of the clasts that are not completely disaggregated at the boundary between the massive Bouma A division and the current laminated Bouma C division present within each cycle; this boundary corresponds to the separation between high density and low density flow conditions within the same current (Figure 35) (Mutti & Nilsen, 1981).

FACIES 3 poorly sorted fine - medium grained argillaceous sandstone

Facies 3 has only been recognised in 1 well, Campbell-1, the most northerly of the 31 wells incorporated in the study. The interval was not cored and sample descriptions and petrography was reliant on two sidewall cores (SWC 6, 2616 m and SWC 7, 2581 m). Lithologically, Facies 3 consists of interbedded sandstones and siltstones. The sandstones are light greyish brown, very fine to coarse grained, poorly sorted, moderately argillaceous with no apparent quartz overgrowths. Calcareous cementation is dominant and "squeezed" detrital glauconite grains are common. Abundant to common medium to very coarse quartz grains occur disseminated throughout the sample. These quartz grains are sub-round - rounded, moderately spherical, frosted to clear and are frequently rimmed by white - brownish clay matrix. The interbedded siltstones are dark brown to brownish grey, blocky to sub-fissile, moderately micaceous and grade to shale in part. Framboidal pyrite is common. Neither SWC 6 (2616 m) or SWC 7 (2581 m) intersected the deeper massive 47 m thick (2617-2664 m) sand unit present in the Campbell-1 well bore. The gamma ray signature of this massive sand unit is blocky (Enclosure III). Sample descriptions from cuttings and SWC 5 2626 m (not available for analysis in this study) indicate that the sandstone is mottled, medium grey - white, dominantly very fine - medium grained, commonly coarse grained, silty and moderately calcareous (Campbell-1 Well Completion Report, 1980) not dissimilar to that described in SWC 6 and 7.

FACIES 4 poorly sorted, very fine - coarse grained argillaceous sandstone

Facies 4 was recognised in numerous cores from Barrow 25, Barrow 1, Emma-1, Elder 1 and Georgette 1. The lithofacies consists of dominantly very fine to fine grained argillaceous sandstone which has been extensively bioturbated generally obliterating any primary sedimentary structures (Figure 37).

The unit is dominantly quartzose with frequent rounded and flattened clasts (up to small pebble size) with occasional belemnites disseminated throughout. The clasts have also been frequently bioturbated. The clasts are typically cemented very fine grained argillaceous sandstones, and shale clasts with frequent large, rounded grains (>1.5 mm) of quartz and feldspar also occurring disseminated throughout the unit. The burrows are rimmed by argillaceous matter and infilled by very fine grained quartzitic sediment. Within the generally massively bioturbated argillaceous sandstone unit are occasional massive, very fine - fine grained sandstone beds generally less than 10 cm thick. These sands are similar to

Figure 37. Photograph displaying facies 4 interbedded with facies 1, Barrow-25, core 29, 6910'-6923'. Photo displays extensive bioturbation, sulphur staining, and sharp contacts with facies 1.

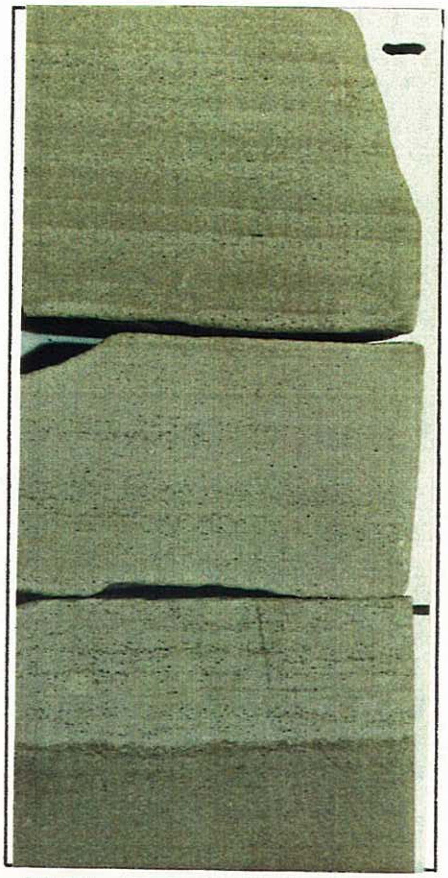


Figure 38. Photograph displaying enlarge view of core 29, 6921'5"-6921'11".Th photo shows the planar lamination, graded bedding and homogeneity of fine grained sandstone facies.

Facies 1 and typically have sharp erosive basal contacts and display weakly developed graded bedding (Figure 38). Where these sandstones lenses are less than 2-4 cm thick, occasional vertical Zoophycos trace burrows and are evident.

Burrows are both oblique and subhorizontal and range in diameter from 1 mm-65 mm. The trace burrows are typical of Zoophycos, Rhizocorallium, and Nereites? Zoophycos and Rhizocorallium are typical of intermediate water depths, sub-tidal/lagoonal - turbiditic associations while Nereites ichnofacies is commonly associated with deep water sediments (Ekdale et al, 1984). The relative abundance of both Zoophycos and Rhizocorallium suggest that the depositional setting was relatively rich in nutrients and the fact that the Zoophycos are seen to bypass thin, relatively clean (nutrient poor) sandstone beds (rare in this facies) is indicative of relatively rapid and episodic deposition rates.

FACIES 5 **well sorted, very fine - fine grained, bioturbated argillaceous sandstone**

Facies 5 is similar to Facies 4 and consists of intensively bioturbated, very fine grained argillaceous sandstones, within which primary sedimentary structures are obliterated (Figure 39). The thickness of the intervals rarely exceeds 15 m. The principal difference between Facies 5 and Facies 4 is the improved sorting, absence of clasts, and lesser abundance of belemnites. Facies 5 has a wavy sub-planar apparent lamination due to the predominance of horizontal burrowing and later compaction effects.

Nereites, Chondrites, Zoophycos and Rhizocorallium (?) trace burrows are present within the unit. The ichnofacies assemblage is indicative of an outer shelfal - slope environment with nutrient rich, disaerobic seabed conditions.

FACIES 6 **poorly sorted, very fine grained - cobble sized, clasts matrix supported**

Facies 6 consists of matrix supported conglomerates and contains boulder sized clasts of reworked bioturbated shelfal sediment with abundant sub-rounded lithic fragments. Boulders are up to 1-3 m in diameter and can be recognised in core as zones of intense soft sediment deformation with sharp contacts at the boundaries. The clast boundaries are frequently rimmed by brown - dark grey argillaceous matrix. Facies 6 is found in wells adjacent to zones of intense block

Figure 39. . Photograph displaying shelly lag deposit within facies 7 overlying erosional contact with underlying facies 5. The shelly lag deposit consists dominantly of small bivalve fragments, crinoid stems, & brachiopod fragments. The nature of the sediments overlying the erosional contact is graded and fines upward into facies 1. The shelly lag overlies the coarsest clastic sediments and is a function of density contrasts suggesting a fluidised flow regime.

faulting, (e.g. South Pepper 1). Interbedded silty claystone intervals frequently show intense slickenslides. The core is intersected by small scale normal faults which post date lithification of the sediments. The faults intersect the core at angles ranging from 30-60°. Five types of clasts were recognised in the unit:

(i) pebble - cobble sized lithic clasts (typically banded irons, cherts, and quartzites).

(ii) pebble - cobble sized cemented very fine - fine grained (occasionally coarse) argillaceous sandstone with common glauconite and variable amounts of argillaceous laminae.

(iii) pebble - cobble sized rounded, elongate highly calcareous clasts with common fractures infilled by calcite cement. The clasts frequently display zones of sulphur staining with an acrid odour.

(iv) pebble sized sideritic claystone clasts with variable amounts of quartz and glauconite.

(v) pebble sized massive dark grey rounded claystone clasts.

FACIES 7 well sorted, medium - coarse grained sandstone

Facies 7 was identified in Barrow-1, Barrow-25 and Perentie-1.

Lithologically, Facies 7 consists of fine - medium, frequently coarse - very coarse grained, poorly - moderately sorted quartzitic sandstones which display silica overgrowths, variable white authigenic clay matrix and calcareous cement. Occasional, pebble sized, rounded lithic (Banded Iron Formation and Chert), quartzitic and claystone clasts occur disseminated throughout the basal intervals of the sandstone beds. The sandstone matrix has variably abundant authigenic white clay. The clasts are well rounded and frequently appear cracked, probably as a result of reworking.

Facies 7 occurs interbedded with Facies 4 and 5 in Barrow-1 and Barrow-25 (Figure 39) and as a massive, generally fining upward sandstone package in Perentie-1. Individual sandstone beds are rarely greater than 5-10 m thick (usually <2 m). The basal contact is erosive and graded bedding is typical. The upper contact is frequently transitional with overlying bioturbated siltstone and very fine grained sandstones. Occasionally within the basal 2-5 cm of the unit, a thin shelly lag deposit develops. This shelly lag (Figures 39 & 40) consists of small bivalve fragments, crinoid stems and brachiopod fragments. The lag occurs immediately above the coarsest grained clastic fraction and below the finer grained sandstone interval which is most likely related to density contrasts within a fluidised depositional regime. In the upper finer grained fraction water escape pillars and bioturbation are evident (Figure 40). Facies 7 has poor - good reservoir characteristics dependent upon the intensity of silica overgrowths and authigenic clay development. The authigenic clay development post dates the silica overgrowths and infills remaining intergranular porosity. Blocky calcitic cement is common in the basal, coarser grained fraction and appears to be an early diagenetic product which has inhibited quartz overgrowths. Also occurring in occasional patches are yellowish sulphate staining and framboidal pyrite clusters. Zones of moderate intergranular porosity are associated with the coarser grained fraction where secondary porosity development associated with calcite cement dissolution is apparent. This was difficult to confirm at hand specimen scale.

6.1.3 Depositional Environment and Reservoir Quality from Core Descriptions

Grainsize distributions, lithology, sedimentary structures and ichnology assemblages indicative of specific depositional settings were identified in all seven facies. These are summarised in Figure 32 and Table IV.

All facies have marine origins as indicated by the abundance of glauconite, presence of belemnites, and the ichnology assemblages. A marine origin is also supported by palynology where dinoflagellates are abundant throughout the Upper Jurassic sediments. A schematic block diagram displaying interpreted depositional environments mostly based on core logging, integrated with the

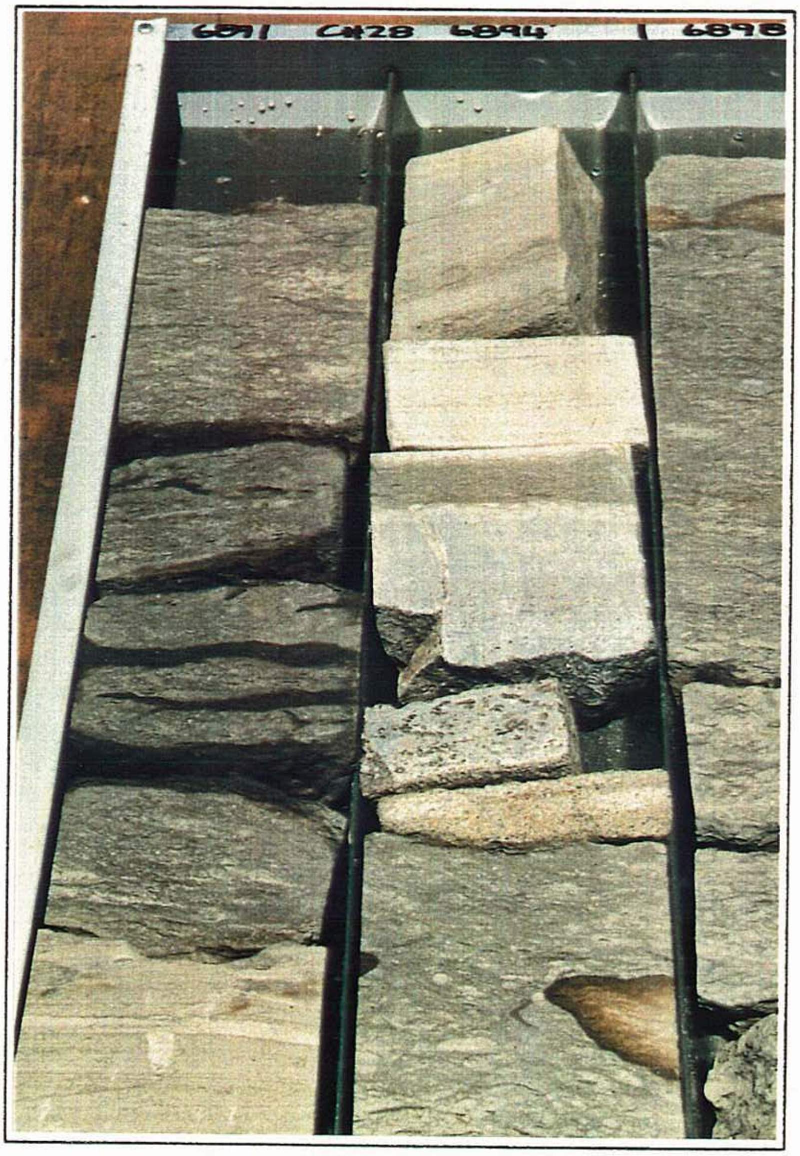


Figure 40. Photograph displaying interbedded relationship of facies 1,4,5,& 7. Note the shelly lag deposit immediately overlying facies 7, vertical escape burrows in facies 1 & intense bioturbation of facies 4 & 5.

TABLE IV
DEPOSITIONAL SETTINGS AND CHARACTERISTICS OF FACIES 1 TO 7

FACIES	LITHOLOGY (IN DECREASING ABUNDANCE)	GRAIN SIZE DISTRIBUTION	SEDIMENTARY STRUCTURES	ICHNOLOGY	DEPOSITIONAL SETTING
1	Quartz, argillaceous matrix (kaolin) siderite, rare feldspar, pyrite detrital glauconite.	Very fine - fine grained occasionally large (up to 7cm) rounded siderite nodules.	Very weak planar lamination indicated by faint orientation of grain axis weakly graded, generally massive.	zoophycas. * chondrites and * helminthoidea	Outer shelfal - slope distal submarine fan lobe setting.
2	Quartz, argillaceous matrix, rip-up shale clasts, siderite, feldspar, detrital glauconite.	Very fine - fine grained occasionally medium grained abundant flattened rip-up shale clasts.	Weak planar lamination, weakly graded, sharp contacts.	Nil.	Rapidly deposited fluidised flow, probably turbiditic, episodic deposition.
3	Quartz, argillaceous matrix. Rare lithics, trace glauconite.	Fine - very coarse. Poorly sorted.	Bimodal quartz grain size distribution.	Nil observable (no core).	Outer shelfal - slope? Channel/levee slope fan deposit.
4	Argillaceous matrix. Quartz, lithics, shale clasts, glauconite, feldspar, pyrite, siderite.	Very fine - fine grained with occasional pebble sized flattened clasts.	Bioturbation has obliterated primary sedimentary structures. Horizontal burrowing & compaction has led to wavy horizontal laminae.	zoophycas rhizocorallium chondrites, * nereites (?) * helminthoidea	Deep marine outer shelfal - slope, episodic deposition.
5	Argillaceous matrix, quartz, mica, glauconite, feldspar, pyrite.	Very fine - fine grained.	As for Facies 4.	zoophycas, rhizocorallium, * chondrites, nereites? * helminthoidea	Outer shelfal - slope episodic deposition, anoxic - sub-aerobic.
6	Shale, argillaceous sandstone clasts. Argillaceous matrix, siderite.	Very fine - boulder sized clasts.	Soft sediment deformation slumping, slickenslide.	zoophycas.	Mass flow, adjacent to fault scarps.
7	Quartz, lithics (BIF, chert), argillaceous matrix, feldspars.	Fine - very coarse occasional pebble size rounded clasts.	Graded bedding water escape structures.	* chondrites * nereites helminthoidea	Turbiditic deposition in slope - bathyl.

* Occur in thin interbedded silty shales.

sequence analysis results (Section 6.4) is given as Figure 41.

Facies 1 and 2 were likely deposited in an outer submarine fan setting due to the dominantly homogeneous sandstone package with the presence of small rip-up shale clasts concentrated near the top of the sandstone beds. The abundance of clasts near the top of the sandstone section is a result of buoyant upward movement of the clasts within the dense basal portion of the current, accompanied by progressive disaggradation and erosion of the clasts (Figure 36). Proximal outer fan lobe sandstones are as a result characterised by abundant mudstone clasts at any level within the Bouma A division. Distal lobe sandstones are characterised by fewer mudstone clasts that are typically smaller and concentrated near the top of the Bouma A division immediately underlying the current laminated Bouma C division (Mutti and Nilsen, 1981). Facies 1 and 2 correspond more closely to the distal lobe sandstone facies under that classification. This is also supported by the relatively thinly bedded nature of the sandstones making up the gross sandstone sequence and episodic deposition indicated by the presence of sideritic cement bands frequently marking bed boundaries (e.g. Figure 35). Bouma C and E facies, indicative of periods of quiescence and non deposition are present in thin (< 10 cm) beds. These silty claystones have nereites ichnology assemblages, indicative of deep marine, outer shelf - bathyal settings.

Due to the lack of available core indicative of Facies 3, a reliable depositional environment interpretation is difficult. Based on the two available sidewall cores

DISPLAYING UPPER JURASSIC FACIES DISTRIBUTION BASED ON CORE DESCRIPTIONS

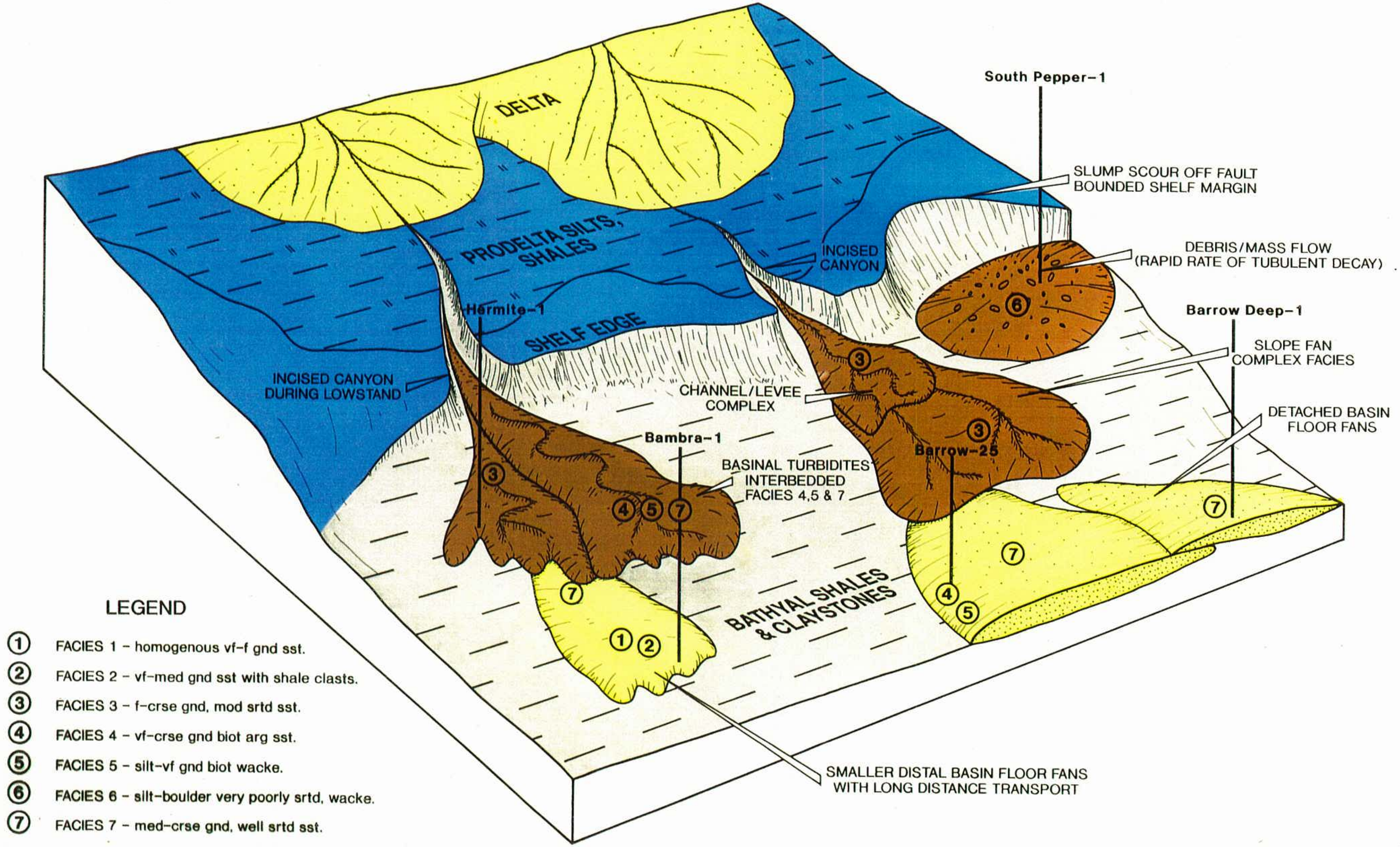


Figure 41

Author : K.Wulff

it is likely that Facies 3 was deposited in an mid - outer shelfal channellised or reworked shelfal deposit due to the poorly sorted nature and frequent large rip-up shale clasts. The abundance of detrital glauconite, variable grain shape, size and coating (frosted or smooth) supports reworking and sediment bypass into an allochthonous setting. This supports a channellised or proximal fan lobe type depositional setting.

Facies 4, 5 and 7 occur interbedded with each other and collectively are indicative of episodic turbiditic deposition with Facies 4 representing periods of quiescence and low depositional energy; Facies 5 being rapid sedimentation followed by extensive periods of non deposition and Facies 7 representing high energy, rapid deposition associated with slow rate of turbulent decay. Periods of quiescence are indicated by the intense bioturbation. The presence of shelly lag material occurring above the basal erosive contact and coarser grained clastic fraction indicates that the turbidity current responsible for deposition was of long enough duration (i.e. low rate of turbulence decay) to allow the buoyant upward movement of the clasts within the basal portion of the current. This suggest a long slope with little change in gradient.

Facies 6 is typical of a high rate of turbulence decay (Figure 41) which occurs when mass flow deposits travelling down a slope reach a major change in gradient resulting in a rapid decrease in fluid strength and rapid deposition of the mass flow sediments en masse (Mutti & Normark, 1987). Facies 6 is the result of slumping off active fault blocks and redeposition at the foot of the slope

(Figure 41). The semiconsolidated state of the clasts at time of slumping suggests the reworked material had been deposited for a moderate period of time prior to the slumping and reworking.

A core porosity verses permeability plot is given as Figure 32. This plot clearly displays the different reservoir characteristics of the seven facies recognised whilst logging the core. The dominantly medium grained sandstone of Facies 7 is the only unit which displays moderate - good reservoir characteristics (ø 18-23%, K 0.5-230 mD). The porosity development is probably associated with carbonate dissolution of the early diagenetic blocky calcite cement which impeded compaction effects of the framework grains. Facies 7 would have had primary porosities in excess of 30%.

Facies 1 and 2 display moderate - good core porosity (14-20%) but poor permeability (2-16 mD). Silica overgrowths and authigenic clays occlude porosity and restrict permeability in Facies 1 and 2. The homogeneous nature of the sandstones is reflected by the relatively bunched population of measured core porosities and permeabilities.

Facies 4, 5 and 6 display very poor reservoir characteristics (ø 4.5-19%, K 0.01-2.1 mD). The variable porosity distribution in Facies 4 is associated with the very poorly sorted nature however, detrital clay matrix in all three facies inhibits permeability. The abundance of detrital clay in Facies 4 and 5 is related to the distal depositional setting and relatively low depositional energy. In

Facies 6, the detrital clay is related to the rapid rate of turbulent decay effectively 'freezing' the mass flow deposit before sorting could take place.

6.2 PETROGRAPHY AND SCANNING ELECTRON MICROSCOPY

6.2.1 Introduction

Core samples were selected for petrographic analysis to evaluate the diagenetic history, mineralogy, grain size distribution, and textural characteristics typical of the seven sandstone facies recognised whilst logging the core (Section 6.1, page 36). Forty seven (47) thin sections were cut and studied, twenty (20) of which were evaluated in detail (Appendix II). The twenty thin sections studied in detail were considered a fair representation of the facies distribution identified.

The following discusses the mineralogy, textural relationships, depositional setting and diagenetic history of the samples. Samples were selected for detailed diagenetic studies using the scanning electron microscope. Discussions of these results are incorporated in the diagenetic history section (Section 6.2.3, page 65).

6.2.2 Mineralogy, Texture and Depositional Environment

The mineralogy of the sandstones varies considerably and ranges from sub-greywackes to feldspathic quartzites. Textural characteristics are also highly varied and are reflected in the degree of sorting, maturity of the sediments and relative abundance of detrital clay.

FACIES 1 AND 2

Facies 1 and 2 are discussed together because the only observable petrographic difference is the slightly higher abundance of lithics and small scale clasts in Facies 2. Facies 2 also has a marginally greater mean grain size than Facies 1, from 0.1-0.25 mm to 0.15-0.4 mm (i.e. very fine - fine to fine - medium grained).

Mineralogy

Facies 1 and 2 were evaluated using petrographic slides from 2716.75 m, 2721.19 m, 2722.05 m and 2723.82 m cut from Bambra-1, Core-2 (Appendix II). The framework composition of Facies 1 and 2 is dominantly quartzitic (60-70%), common feldspar (5-10%), siderite (trace-10%) with trace-5% detrital glauconite and clays (muscovite and biotite), lithics (predominantly chert) and rare organic matter. Authigenic kaolinite (trace-10%) and rare secondary sparry calcite cement infills remaining pore space (Figure 42). The feldspar is dominantly plagioclase and microcline. Dissolution of feldspar is apparent along cleavage plains resulting in the generation of authigenic kaolinite.

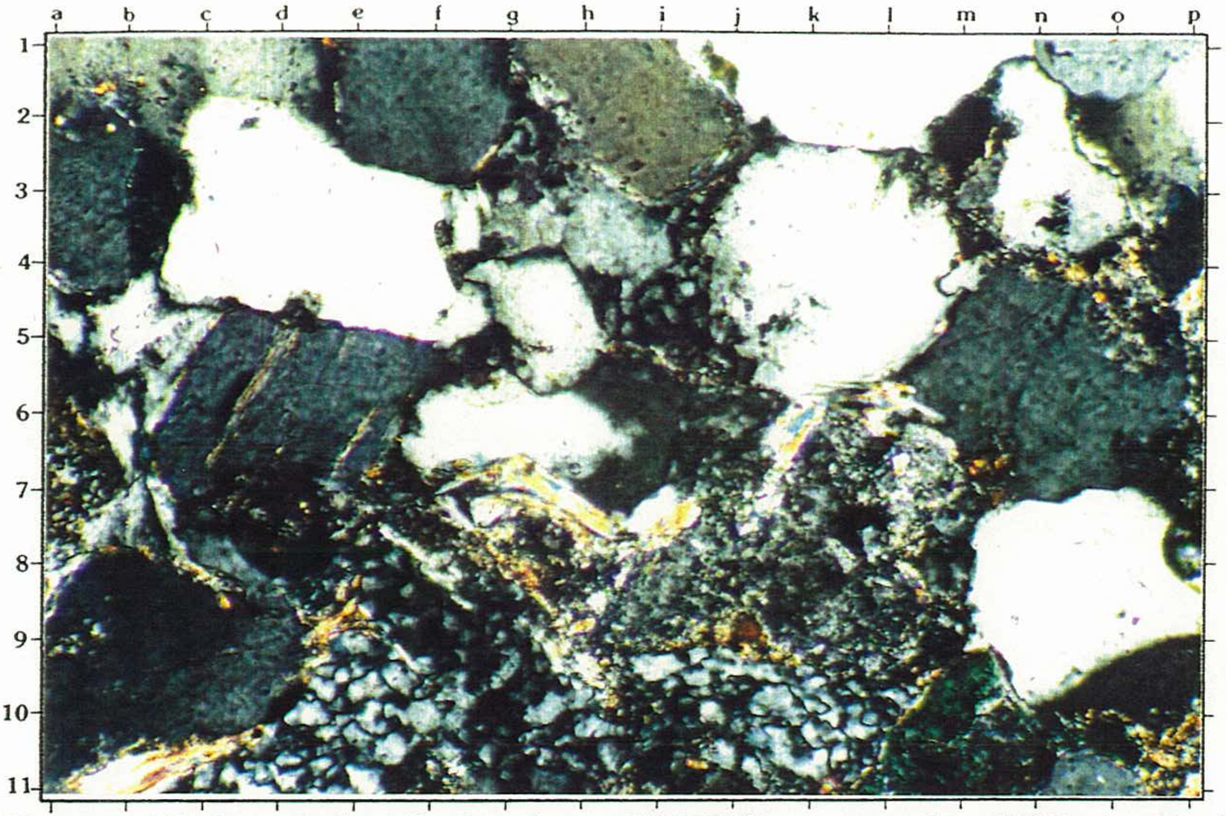
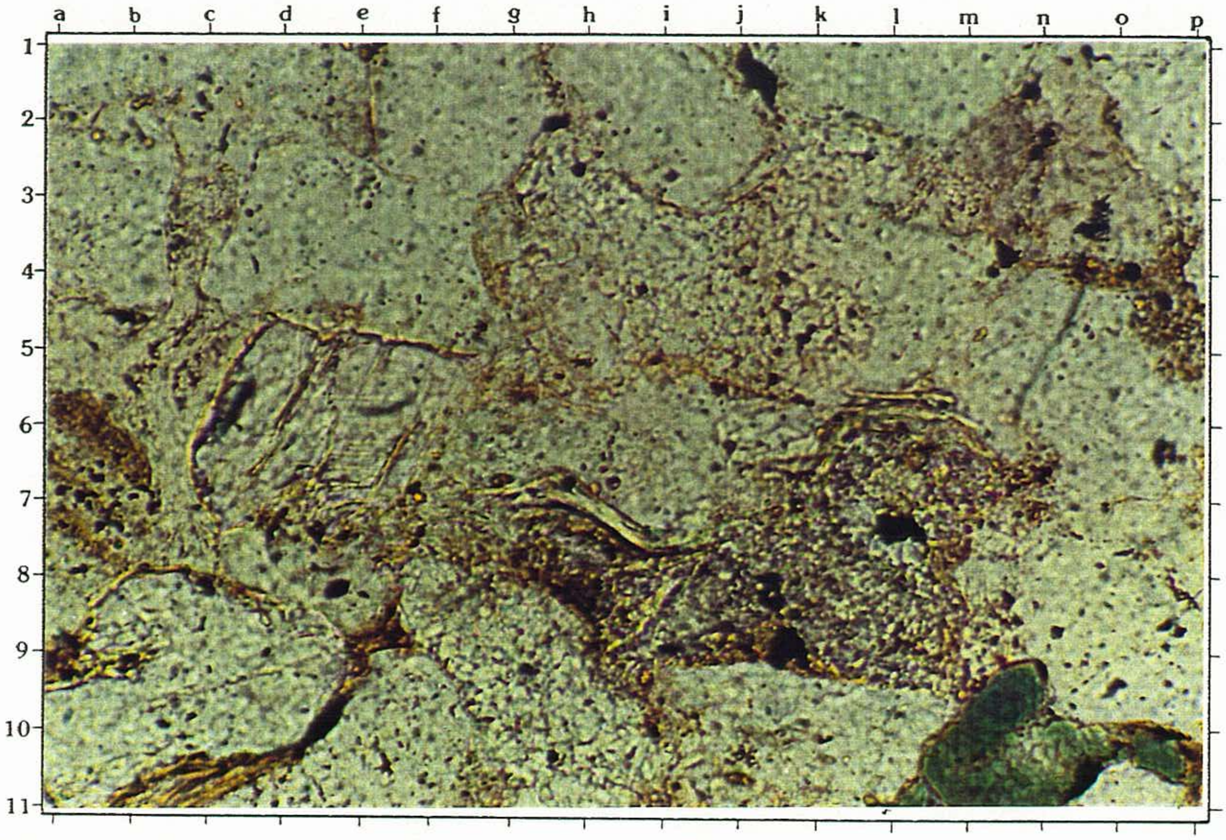


Figure42.Petrographic photograph of Bambra-1, core 2,2722.05m, cross-polars, 200X magnification ield of view = 0.55mm).Photograph displays contorted moscovite crystals(h8), sericitization of feldspar ong cleavage planes(c6), euhedral quartz grains and authigenic quartz overgrowths(e2,l2), triple point ontacts indicative of pressure solution(n1,c5), intergranular calcite cement.The rock is framework upported with minor intergranular clays (authigenic kaolinite & siderite).



igure43.Petrographic photograph of Bambra-1, core 2, 2722.05m, plane polars, 200X magnification, field of view = 0.55mm) Dissolution of feldspars(plagioclase) is observable at k8 and sericitisation along cleavage planes is clearly definable at c6. Glauconite is also present ,n10. The sample displays no observable intergranular porosity.

Texture

The samples are moderately sorted and grain size of the framework grains ranges from 0.1-0.4 mm. Mean grain size is 0.15-0.25 mm. Authigenic, syntaxial quartz overgrowths result in frequent occurrence of triple point boundaries (Figure 42). Grain to grain contacts are generally planar and definable.

A minor degree of compaction has occurred evident by contorted muscovite and biotite crystals (Figure 43). However, intense early sideritic cement and quartz overgrowths generally inhibited compaction effects (Figure 44). Common globular organic matter displays no extensive flattening, supporting an early cementation phase preventing extensive compaction. The original shape of the quartz grains was sub-rounded to rounded, elongate with moderate sphericity as indicated by the occasionally faint rim of the detrital grain boundary marked by very small siderite? crystals and dark brown clay rims (Figure 43). Detrital clays are generally absent hence clay rims on the quartz grain boundaries most likely represent staining from a earlier depositional setting. The relative abundance of siderite, and glauconite is highly variable within the samples.

Glauconite occurs in two forms within the samples, detrital and faecal glauconite. The detrital glauconite occurs generally disseminated throughout the framework grains while the smaller faecal (?) glauconite is associated with the argillaceous and organic rich bands which form wavy, laminae within the quartzite. These zones are also associated with abundant siderite cement which suggests that these

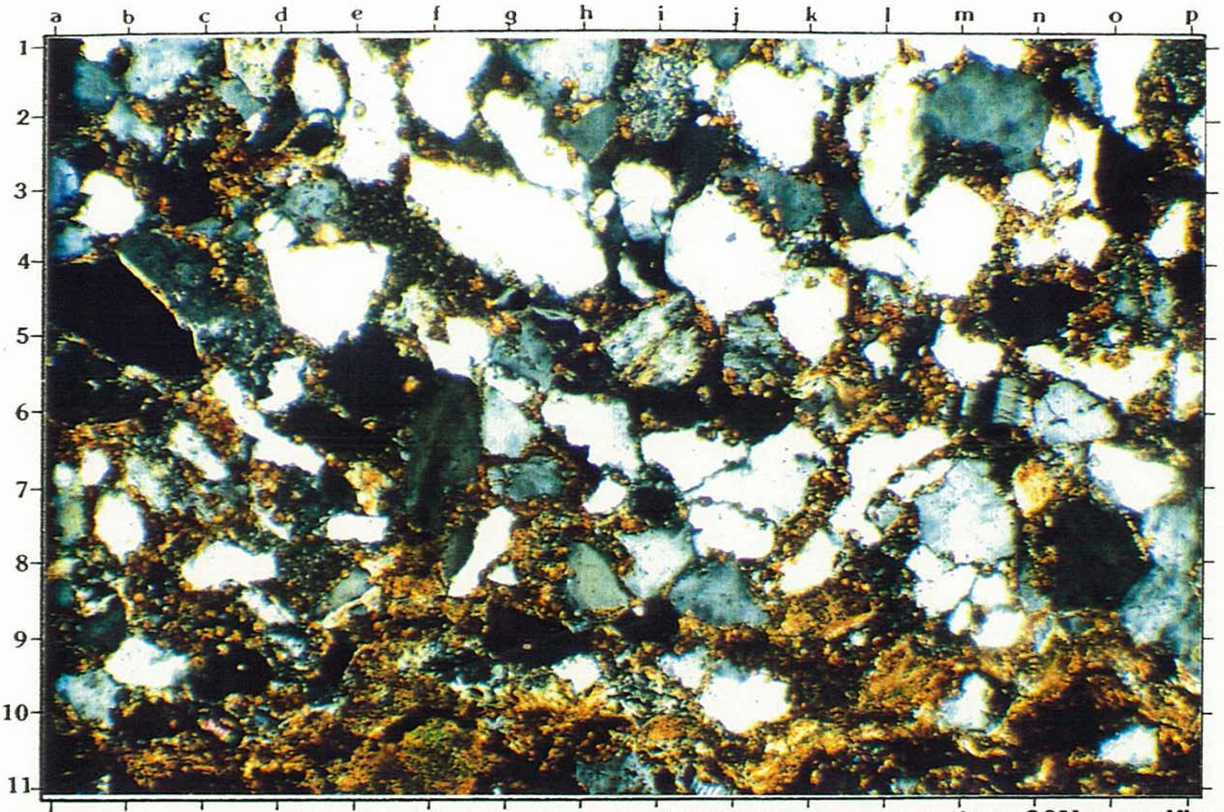


Figure 44. Petrographic photograph of Bambra-1, core 2, 2721.19m, cross-polars, 80X magnification (field of view = 1.375mm). Photograph displays intense siderite cementation and relative lack of detrital clays within a well sorted, fine grained, feldspathic quartzite. The small(<0.02mm) siderite crystals rim the quartz grains and freqently occur as inclusions within the authigenic quartz overgrowths(i7,e3).The framework quartz & feldspar grains frequently show sutured grain contacts indicative of pressure solution & the feldspar (plagioclase(h6) & microcline(m6)) display dissolution to authigenic kaolinite.

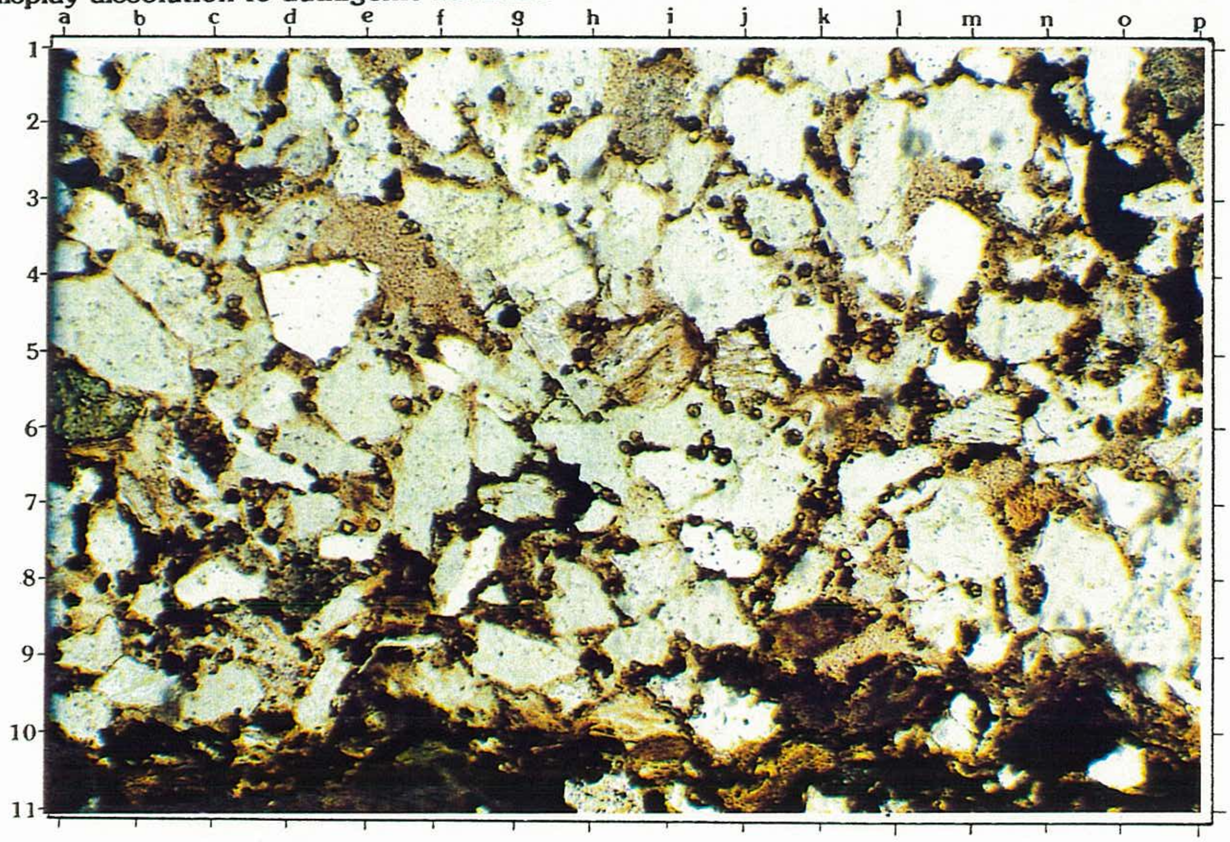


Figure 45. Photograph of the same sample as Figure 44 under plane polarised light.

layers represent periods of non deposition within the episodic depositional setting.

The textural maturity of Facies 1 and 2 is high due to general abundance of detrital quartz, lack of detrital clay, relative abundance of authigenic clays and frequent dissolution of feldspars.

Diagenesis

The following outlines the diagenetic history with increasing burial depth that modified the porosity and permeability of Facies 1.

(i) Sideritic cementation
(ii) Authigenic silica overgrowths
(iii) Dissolution of feldspars
(iv) Authigenic kaolinite formation
(v) Microsparry - sparry calcite cementation.

(i) Siderite Cementation

Siderite has formed as the earliest diagenetic cement and studies (Johnston and Johnson, 1987; Moraes, 1989) indicate that siderite cementation begins in the surface to shallow sub-surface (within a few centimetres of the sediment/water interface). This siderite cement is shown on Figures 46 and 47. Small siderite rhombs can be seen to rim detrital quartz grains. Siderite cementation was also

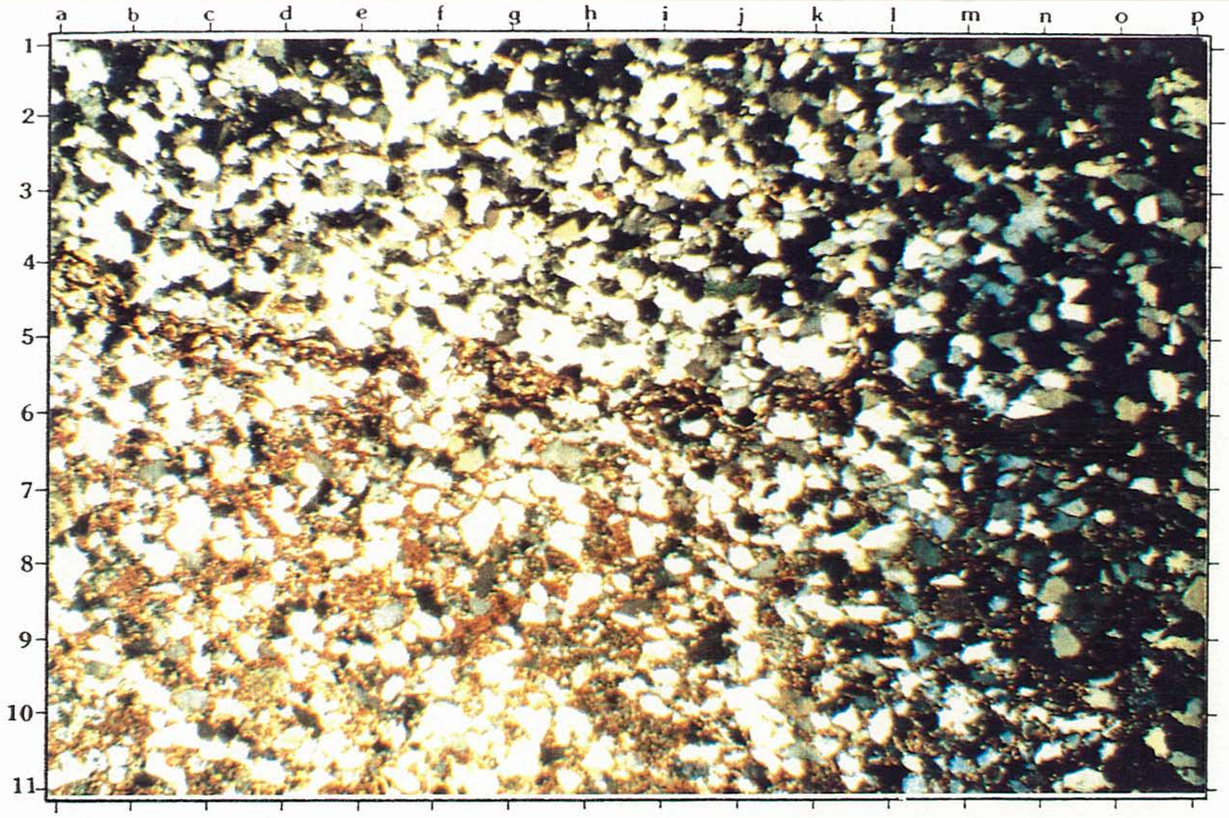
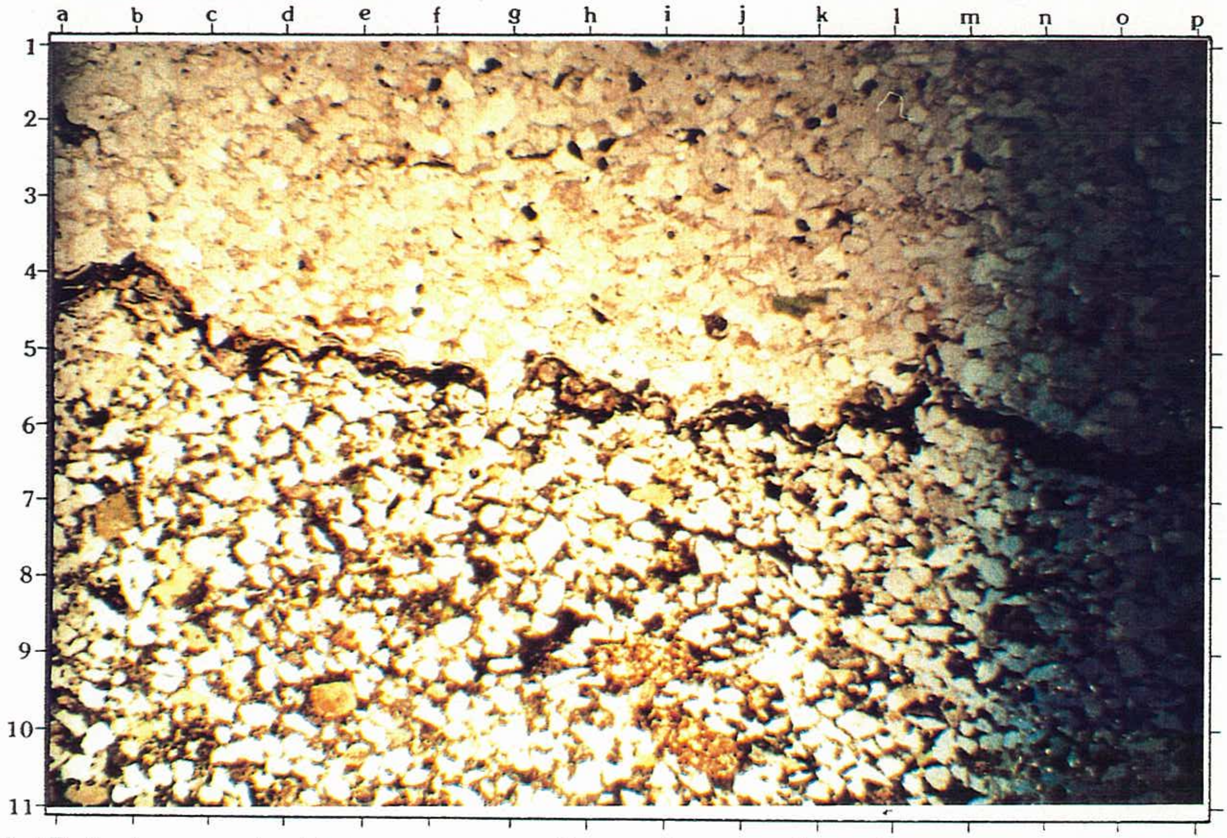


Figure46.Petrographic photograph of Bambra-1, core 2, 2723.82m, cross-polars, 20X mag
Field of view = 5.5mm.

Figure47. Petrographic photograph of Bambra-1, core 2, 2723.82m, plane-polars, 20X mag,
Field of view = 5.5mm.



ures 46 & 47 display a contact between a generally massive, very fine - fine grained (0.15 - 0.25mm) uartzitic sandstone (facies 1) and underlying sideritic cemented very fine - fine grained sandstone. depositional hiatus occurred between the two beds allowing concentration of early diagenetic iderite cement to precipitate at, or near the sediment/water interface.

occurring penecontemporaneously with syntaxial quartz overgrowths. This is observed where the siderite rhombs occur as inclusions within the syntaxial quartz overgrowths.

(ii) Authigenic Silica Overgrowths

The quartz overgrowths frequently display euhedral crystal faces (Figure 48). The silica overgrowths have a smooth, non corroded appearance. The relative abundance of quartz triple points, smooth grain contacts and relatively non compacted appearance suggests that the authigenic quartz overgrowths developed early enough to form a rigid framework inhibiting significant compaction.

(iii) Dissolution of Feldspars

The occasional detrital plagioclase and microcline grains frequently display dissolution along cleavage plains and conversion to kaolinite and sericite as shown on Figure 42.

(iv) Authigenic Kaolinite Formation

Booklets of small, hexagonal plates of kaolinite infill intergranular porosity generally occluding remaining poor space. The authigenic kaolinite development post dates the silica overgrowths as shown on Figure 48.

Figure 48.

Bambra #2 Core 2 2722.5m Photo displays early diagenetic syntaxial quartz overgrowths displaying euhedral crystal faces. Remaining inter-crystalline porosity is infilled by later booklets of authigenic kaolinite.

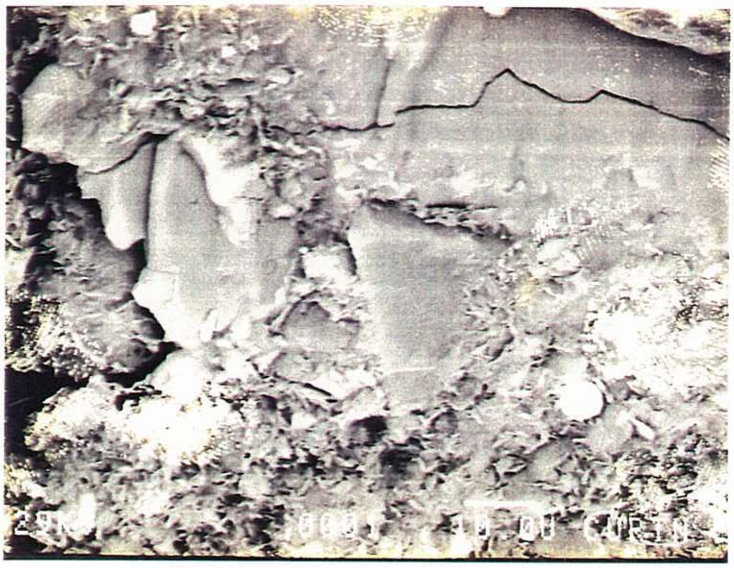


Figure 49.

Barrow 25 Core 30 2117.5m (6948ft) Photo displays early diagenetic syntaxial quartz overgrowths wi
interstital late diagenetic illite. One quartz grain displays large open fracture and the quartz overgrowth
frequently display a minor degree of corrosion.

(v) Calcareous Cementation

Following authigenic clay formation, any remaining void space has been infilled by calcareous cement. This last phase of porosity occlusion is probably a deep burial effect. Precipitation of calcite cement in sandstones frequently increases with depth due to the decline in calcite solubility with increased pressures. Even though the solubility increases with higher hydrostatic pressures, the net effect is a decline in solubility of calcite (Johnston and Johnson, 1987; Blatt, 1979).

Depositional Environment

The presence of glauconite scattered throughout the samples indicates a marine origin. When combined with the moderately sorted, fine grained quartzitic nature and minor detrital clay, it supports deposition in a moderate energy environment. Winnowing or non deposition of detrital clays indicates deposition in either an shelfal, above wave base setting or within a turbiditic system. The presence of dewatering structures (dish structures) in the core supports rapid deposition suggesting a turbiditic style of sedimentation.

FACIES 3

Lithologic and diagenetic discussions of Facies 3 are based on thin sections from Campbell-1, SWC 6 (2616 m) and SWC 7 (2581 m).

Mineralogy

Facies 3 is a poorly sorted, very fine to coarse grained (0.04-2 mm) argillaceous sandstone (sub-greywacke). Quartz is the dominant framework grain (50-60%) and occurs both as large (1-2 mm) rounded, moderately spherical grains and small (<0.05 mm) sub-rounded - sub-angular grains within the argillaceous matrix (Figures 50 & 51). The samples display a moderate abundance of medium - coarse grained feldspar (predominantly plagioclase and microcline) 5% and rounded chert 5-10%. The matrix consists of very fine grained quartz, and detrital clays. The clays are most likely kaolinite and sericite? and rim the larger quartz grains preventing syntaxial authigenic quartz overgrowths. Microsparry calcite has occasionally replaced the detrital clays (Figure 50). Calcite and authigenic clay appear to corrode quartz and feldspar boundaries which are in general curvilinear and clearly definable. Rare detrital medium grained glauconite appear squeezed and have been replaced by microsparry calcite? Opaque rounded globules of organic matter or bitumen occur disseminated throughout.

Texture

The rock is poorly sorted. There are few grain - grain contacts and the larger quartz, feldspar and chert grains frequently appear floating in a very fine grained quartzitic argillaceous matrix. The grain size distribution of the quartz grains is bimodal. The larger grains (1-2.5 mm) occur as rounded and spherical while the

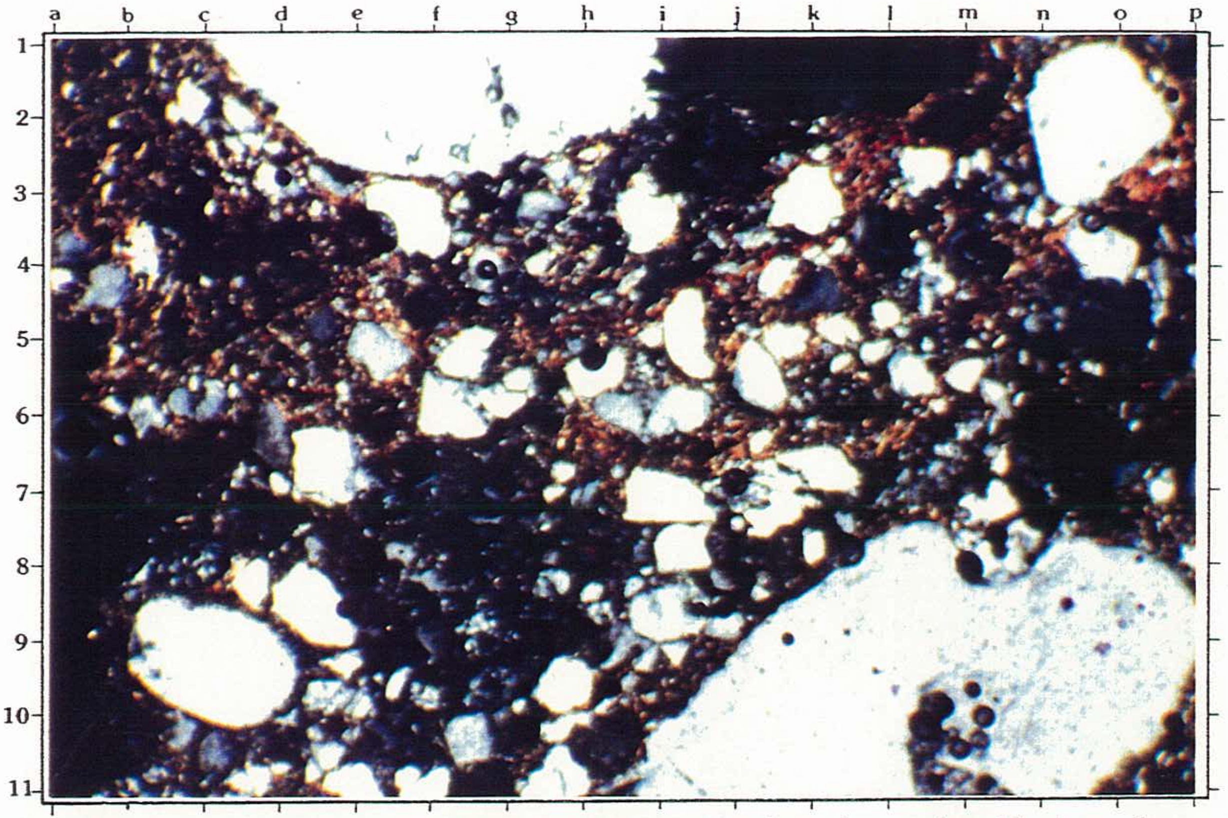


Figure 50. Campbell-1, SWC-7, (2581m), 50X magnification, plane polars. Photograph displays bimodal grainsize distribution and relatively poorly sorted nature.

Figure 51. Campbell-1, SWC-7, (2581m), 50X magnification, plane polars. The large quartz grains display corrosion at the grain boundaries and replacement by argillaceous (kaolinite & illite?) matrix

smaller grained fraction (<0.05 mm) are angular - sub-rounded with moderate - low sphericity (Figure 50). The larger quartz grains are also frequently recrystallised with wavy extinction under cross-polars while the smaller grains have sharp extinction and display no indications of recrystallisation prior to deposition. A single burrow? (<0.5 mm diameter) infilled by microsparry calcite occurs generally planar to the weak alignment of the long axis of the larger grains.

Diagenesis

The detrital clay matrix has generally inhibited syntaxial quartz overgrowths. The detrital clays are the major porosity occluding constituent. Early diagenetic microsparry calcite infilled any remaining void space as evident by the infilling of a small burrow. The quartz boundaries are occasionally corroded and replaced by authigenic clays and calcite (Figure 51). The samples display no visible intergranular porosity. The diagenetic sequence for Facies 3 sandstones is:

i early siderite and microsparry calcite.

ii dissolution of feldspars and kaolinite generation.

iii corrosion of quartz boundaries by authigenetic clay and calcite.

Depositional Environment

The bimodal nature of the grains, generally matrix supported texture and rounded shape of the larger grains suggests that sedimentation was the result of reworking and mixing. Deposition occurred in a density flow type setting. This can occur during periods of lowstand introducing fluviatile sediments onto marine shelfal areas, reworking a mixing due to channel incision and final deposition as a slope fan, basin floor fan or channellised deposit. A second depositional setting may be reworking and mixing of shelfal and near shore sediments with outer shelfal marine sediments during periods of major storm activity.

FACIES 4

Lithologic and diagenetic discussions on Facies 4 are based on petrographic samples from Barrow-1, core-28 (6829'); Barrow-1, core-27 (6822'); Barrow-25, core-22 (6707'); Barrow-25, core-23 (6759'); and Emma-1, core-3 (2187.05 m).

Mineralogy

Facies 4 is a very poorly sorted bioturbated argillaceous sandstone (sub-greywacke). Grain size varies from very fine (<0.04 mm) to coarse, occasionally very coarse (2 mm). The unit is lithologically similar to Facies 3 apart from the increased abundance of detrital glauconite (5-10%) chert and feldspar, plagioclase and microcline (5%). Quartz occurs as large, rounded grains, up to 2 mm (20-30%) with minor corroded boundaries and very fine - medium grained sub-rounded - sub-angular quartz (10-20%). The matrix consists of high birefringent clays which are partially replaced by microsparry calcite cement (Figure 52). Dissolution of the feldspars along cleavage planes is moderately advanced. Sericitisation of the detrital glauconite is also common. Burrows from 0.1-0.5 mm in diameter are generally infilled by clays and calcite cement. A large (1.8 mm), rounded clast of cemented pyrite rhombi occurs within the unit. It is probable that the pyrite is authigenic in origin and replaces clasts of unknown original constituents. Rare (<2%) small, highly birefringent laths of muscovite and biotite occur within the matrix. Opaque, irregular shaped organic matter? occurs disseminated throughout the unit.

Texture

The rock is poorly sorted and dominantly matrix supported. Where quartz grain - grain contacts are present, dissolution has occurred indicating pressure solution. Original grain boundaries are marked by fluid inclusions? and occasional clay rims. The detrital clay has predominantly inhibited syntaxial silica overgrowths, however they are occasionally present, albeit poorly developed. There is a very weakly developed planar alignment of grains. As is the case in Facies 3, the larger quartz grains frequently display recrystallisation and wavy extinction while the fine grained crystals display sharper extinction indicating that at some point in history the larger quartz grains have experienced higher pressures and temperatures.

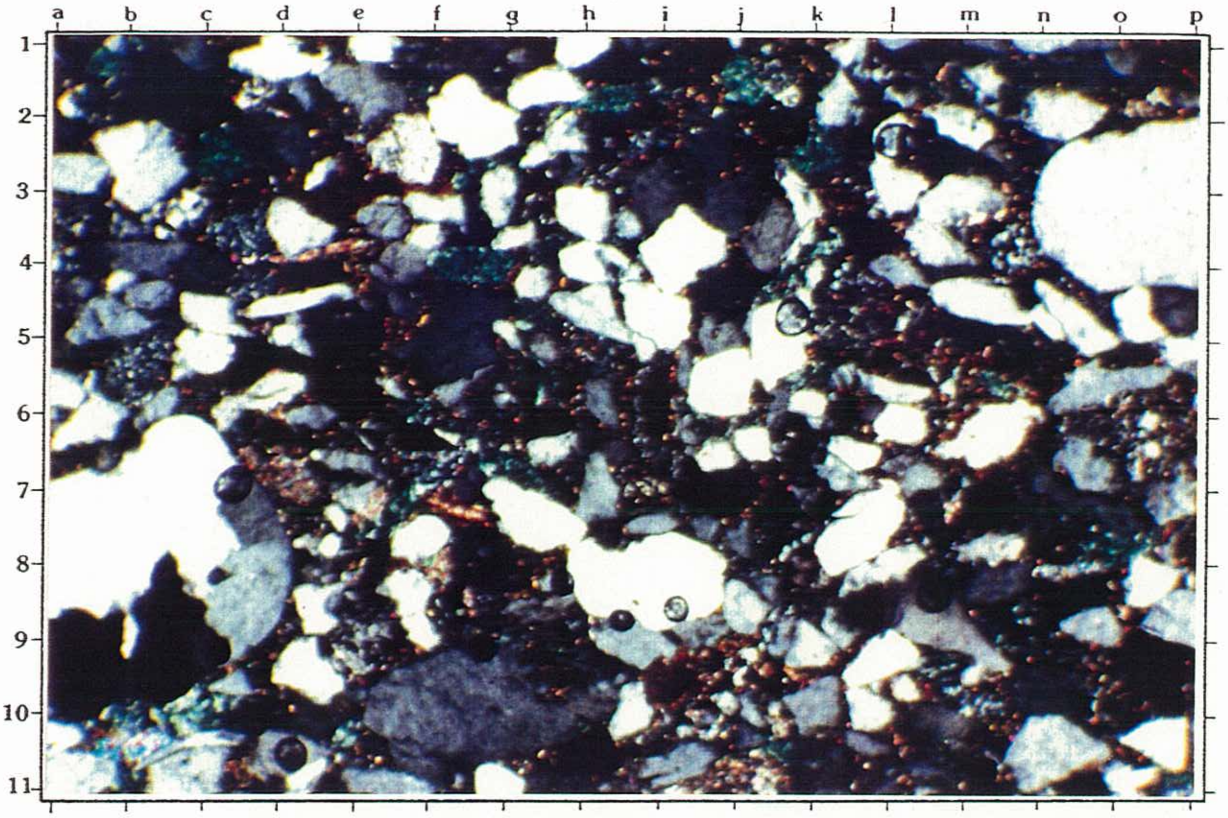


Figure 52. Petrographic photograph of Barrow-1, 6829ft, 50X magnification, cross polars. Sample displays relatively poor sorting and bimodal quartz grainsize distibution. Sample contains abundant argillaceous matrix which has impeded authigenic quartz overgrowths.

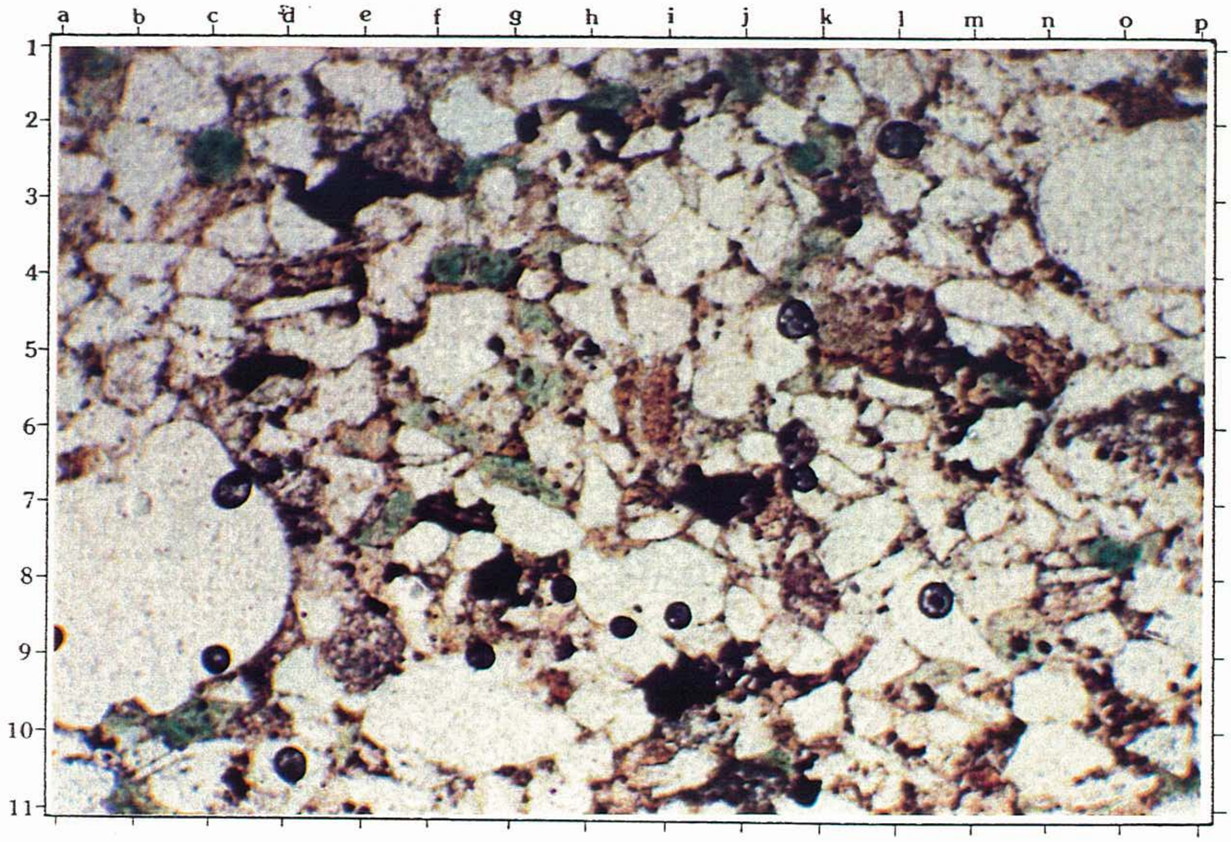


Figure 53. Petrographic photograph of Barrow-1, 6829ft, 50X magnification, plane polars. Sample displays poor sorting, angular-subangular fine grained quartz (0.2-0.4mm) and rounded, coarse (0.8-1.5mm) quartz which displays frequent recrystallisation suggesting a metamorphic provenance. Note the abundance of glauconite(f6).

Diagenesis

Detrital clay matrix has restricted authigenic syntaxial quartz overgrowths. Where present, the overgrowths are poorly developed but appear to be an early diagenetic process. Dissolution of feldspar along cleavage plains is evident and authigenic kaolinite generation is common. Detrital quartz grains show a range of surface features varying from smooth unaltered grain boundaries to pressure dissolved contacts where quartz grains are in contact. Poorly developed corrosion of quartz boundaries by authigenic clays (Figure 49) is present and the pressure solution boundaries between quartz grains suggests that the rock has undergone deep burial.

Depositional Environment

The presence of glauconite and trace burrows indicates a marine depositional environment which when combined with the poorly sorted nature of the grains and bimodal quartz fabric suggest deposition in a rapid, relative high energy fluidised flow regime with rapid decay of turbulence within the basal portion of the current. This environment may indicate mass flow or proximal submarine fan deposition.

FACIES 5

Lithologic and diagenetic discussions in Facies 5 are based on petrographic descriptions on samples from Barrow-25, core-21, 6699'6" (2042 m); Barrow-25, core-29 6921'3" (2109.6 m); Barrow-1, core-27 6822' (2079.3 m); Hermite-1, core-1, 4809' (1465.8 m).

Mineralogy

Facies 5 is a very fine grained argillaceous sandstone (quartz wacke) which consists of moderately well sorted, rounded to sub-angular, very fine (0.1-0.2 mm) quartz (50-60%), feldspar (5%) and chert (trace-5%) detrital grains with highly birefringent argillaceous matrix (20%) (Figures 54 & 56). The argillaceous matrix has been partially replaced by microsparry calcite cement (10-15%) (Figure 57). Accessory minerals include glauconite (trace) muscovite (<5%) and biotite (trace). Trace burrows (<0.15 mm in diameter) frequently occur within the samples and are generally infilled by the argillaceous matrix. Occasional, opaque, globular clusters occur within the samples. A single recrystallised foraminifera occurrence was identified in sample from Barrow-25, 6699'6" (2042 m).

Texture

Facies 5 is moderately well sorted, dominantly grain supported with no preferred orientation of grain axes. The quartz boundaries frequently display corrosion associated with the calcite cement which replaces the detrital clay matrix in part. Elongate tabular lathes (0.2-0.3 mm long) of muscovite occur randomly orientated

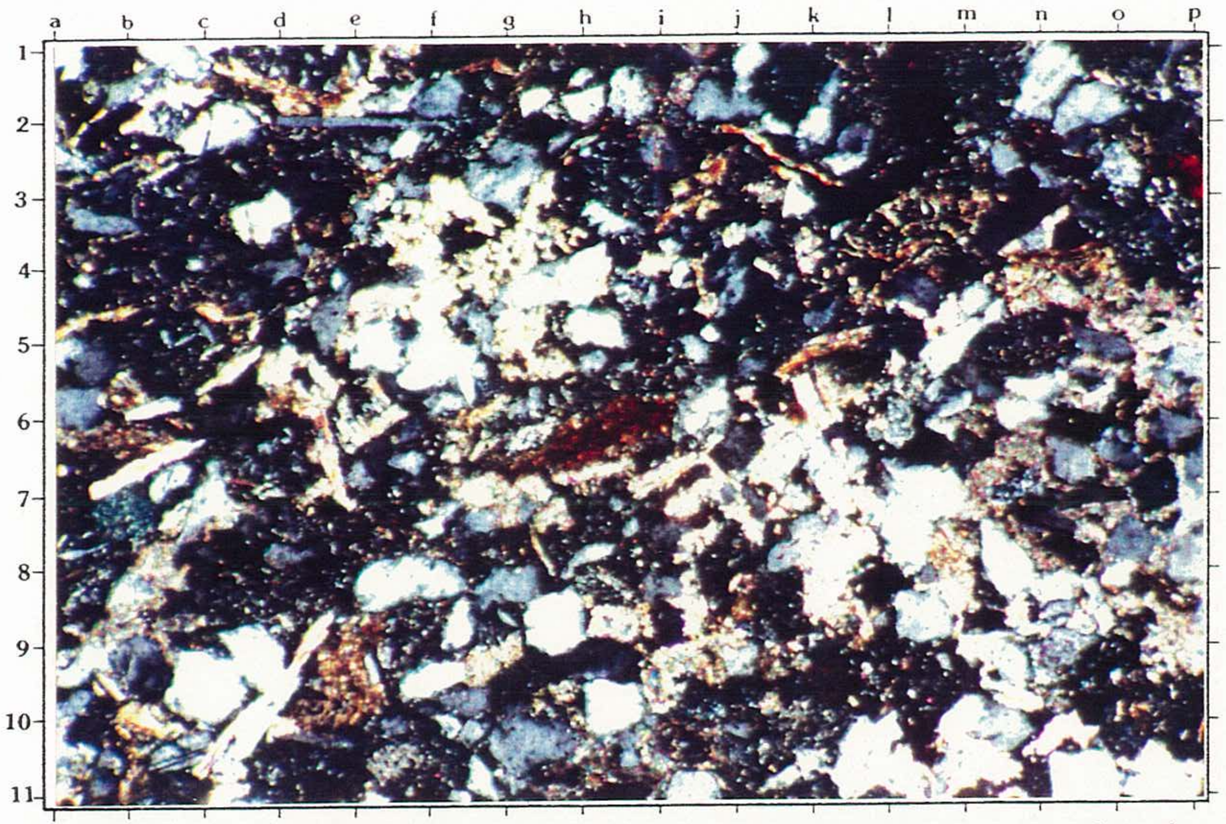


Figure 54. Barrow 25, 6699'6",80X magnification. Photograph displays cross-polars view of Facies 5 with abundant randomally orientated muscovite laths and, recrystallised microsparry calcitic matrix replacing original detrital clays, Quartz grains are very fine grained,(0.01-0.05mm) and display no evidence of authigenic quartz overgrowths.

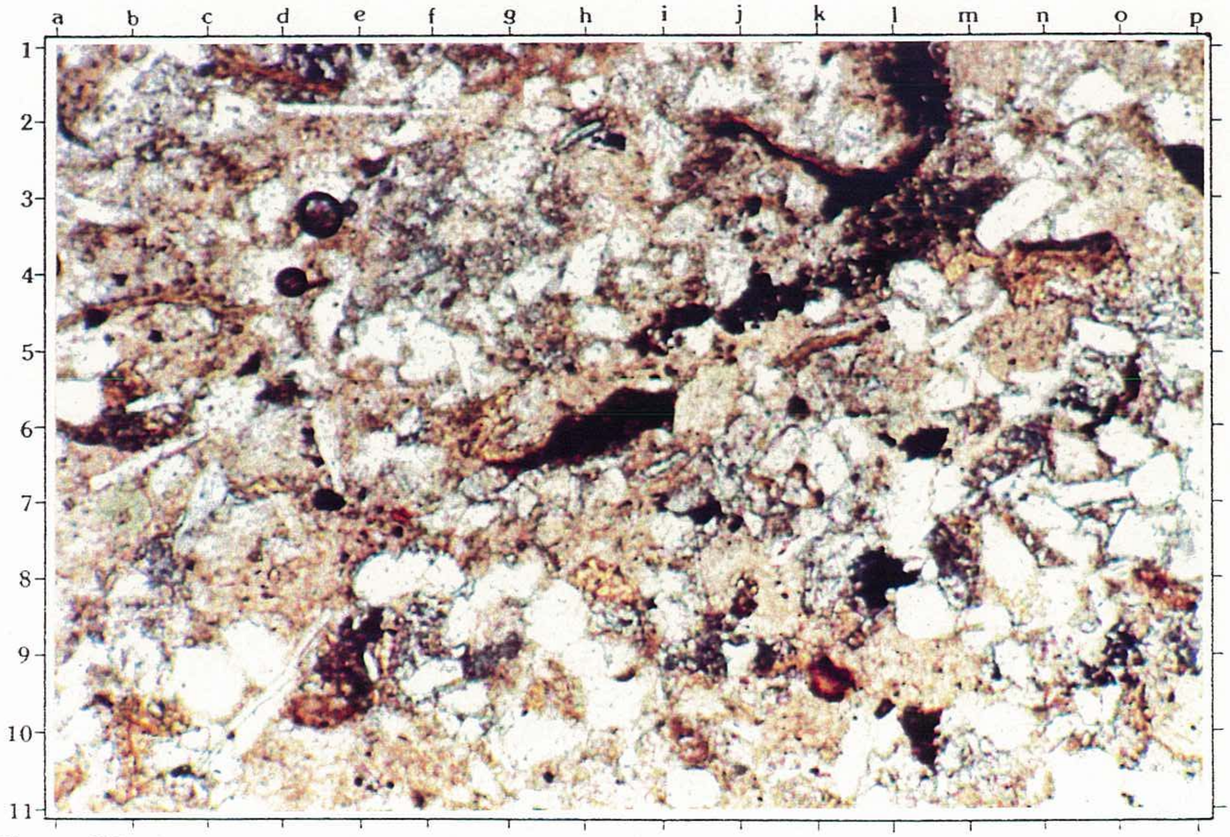


Figure 55. Barrow 25,6699'6", 80X magnification. Photograph displays plane polarised view of figure 54. Photograph shows extensive calcitic matrix infilling randomally oriented trace burrows. The burrowing has the effect of concentrating the quartz grains in 'clusters'.

throughout the samples (Figures 54 & 55).

Diagenesis

The detrital clay matrix has generally inhibited syntaxial quartz overgrowths. The most clearly observable diagenetic effect is the partial replacement of the argillaceous matrix by microsparry calcite cement which has also corroded quartz grains. The microsparry calcite cement is most abundant in Hermite-1 (1465.8 m) (Figures 56 & 57). Pressure solution is evident in samples from Barrow-1 and Barrow-25 where quartz grains display curvilinear and sutured grain contacts.

Depositional Environment

A marine depositional setting is indicated by the rare glauconite and the presence of a single recrystallised foraminifera fragment. The very fine grained and argillaceous nature suggests below wave base depositional conditions. The moderate degree of sorting yet random orientation of grain axis may suggest that deposition may represent a distal turbidite facies deposited as a result of rapid turbulence decay of an already weak turbidity current.

FACIES 6

No petrography was carried out on Facies 6 due to the lack of framework grains

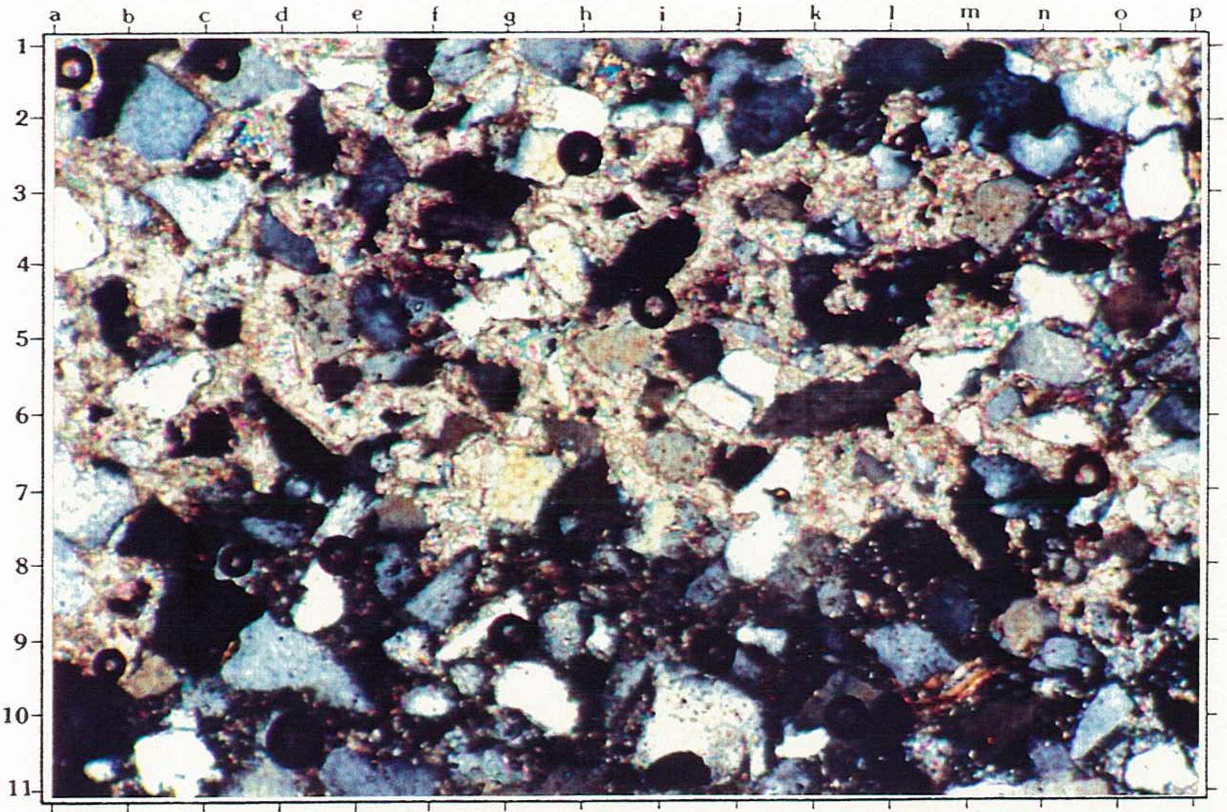


Figure 56. Hermite 1, 1465.8m, 80X magnification. This photograph displays cross-polars view of Facies 5 with calcitic matrix supporting very fine grained (0.02–0.04mm), sub-angular quartz grains. Quartz boundaries show a moderate degree of corrosion and absence of authigenic quartz overgrowths and feldspars.

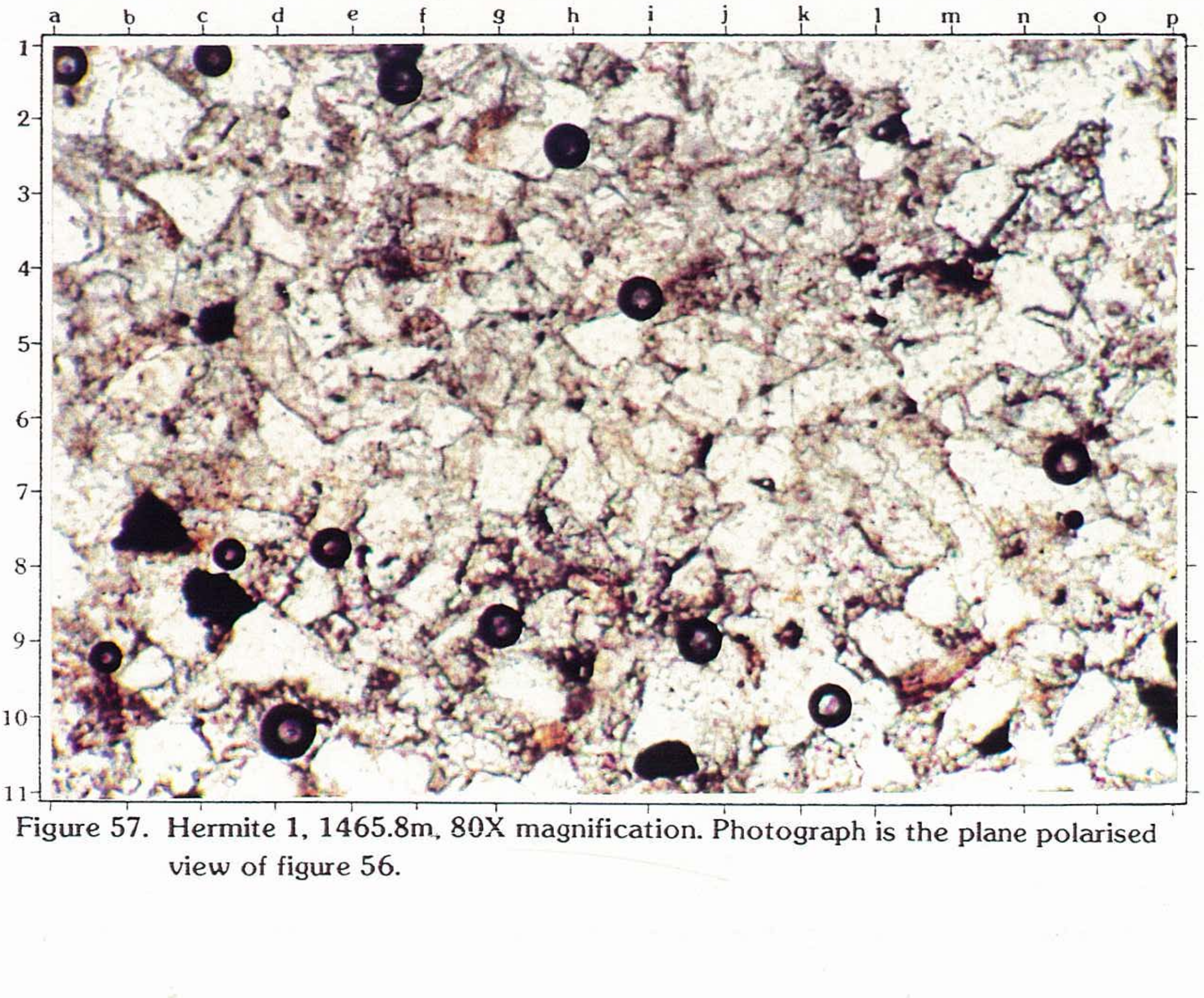


Figure 57. Hermite 1, 1465.8m, 80X magnification. Photograph is the plane polarised view of figure 56.

and predominantly reworked shelfal pebble to boulder sized clasts dominating the lithotypes within the unit. The facies displays no reservoir characteristics (Figure 32) and minimal depositional environment information can be obtained from thin section analyses.

FACIES 7

Mineralogy

Facies 7 is a orthoquartzite consisting of 80-90% moderately - well sorted, fine - medium (0.15-0.5 mm) occasionally coarse quartz which contains extensive syntaxial silica overgrowths. Intergranular porosity is infilled by blocky sparry calcite cement. Quartz is the dominant framework grain with chert and feldspar (plagioclase and microcline) in moderate amounts, <5% and 5-10% respectively (Figures 58, 59, 60 & 61).

Authigenic clays (kaolinite) have developed along cleavage plains within the feldspar due to dissolution. Facies 7 is generally devoid of detrital clays. Rare unaltered, rounded detrital glauconite grains occur within the framework grains. The quartz contains abundant dark, high birefringent very small (<0.04 mm) inclusions and the original grain boundaries are frequently marked by fluid inclusions.

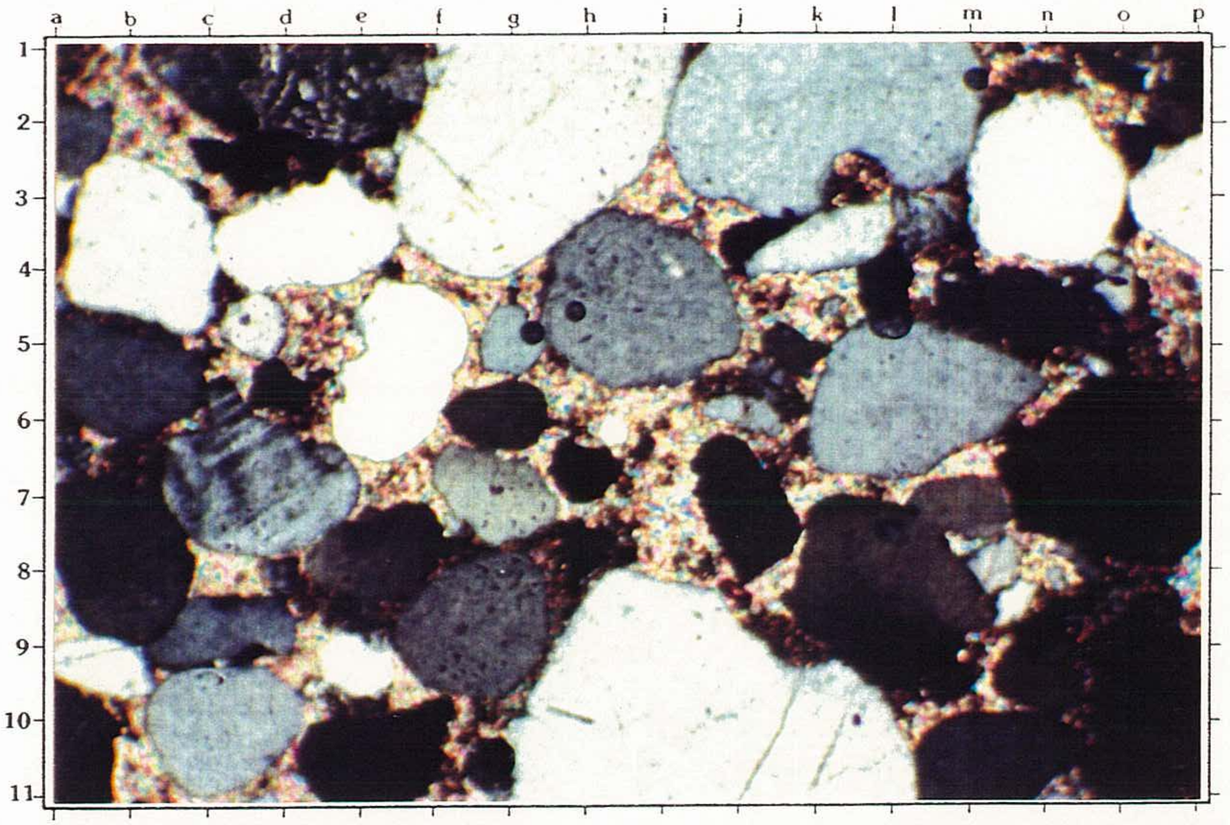


Figure 58. Barrow 25, 6905', 50X magnification photograph of Facies 7 sandstone under cross-polars. Photo displays calcitic cemented, well rounded , medium - coarse grained quartz and feldspar grains. Quartz grains display no evidence of authigenic quartz overgrowths suggesting early diagenetic calcite cement inhibiting overgrowth development.

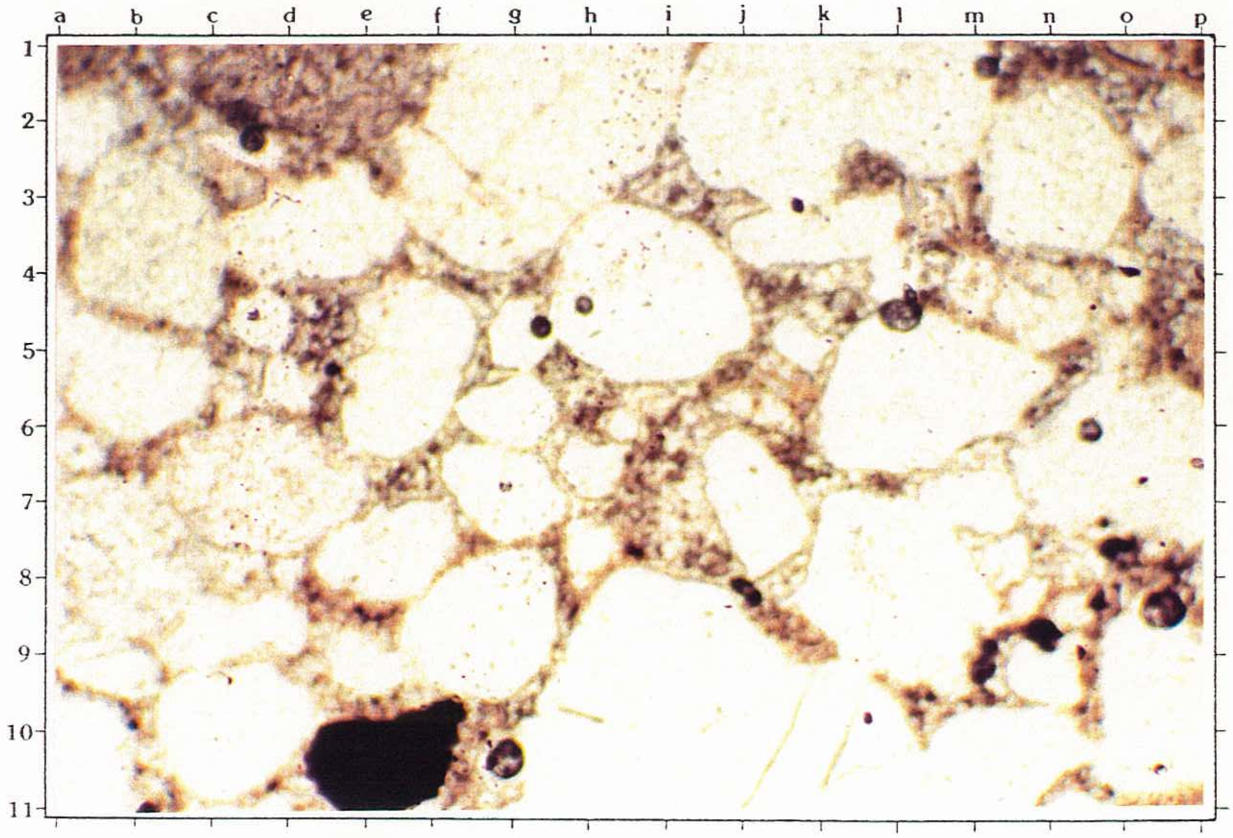


Figure 59. Barrow 25,6905',50X magnification photograph of Facies 7 sandstones under planepolarised light. Quartz grains display a minor degree of corrosion and replacement by the calcitic matrix.

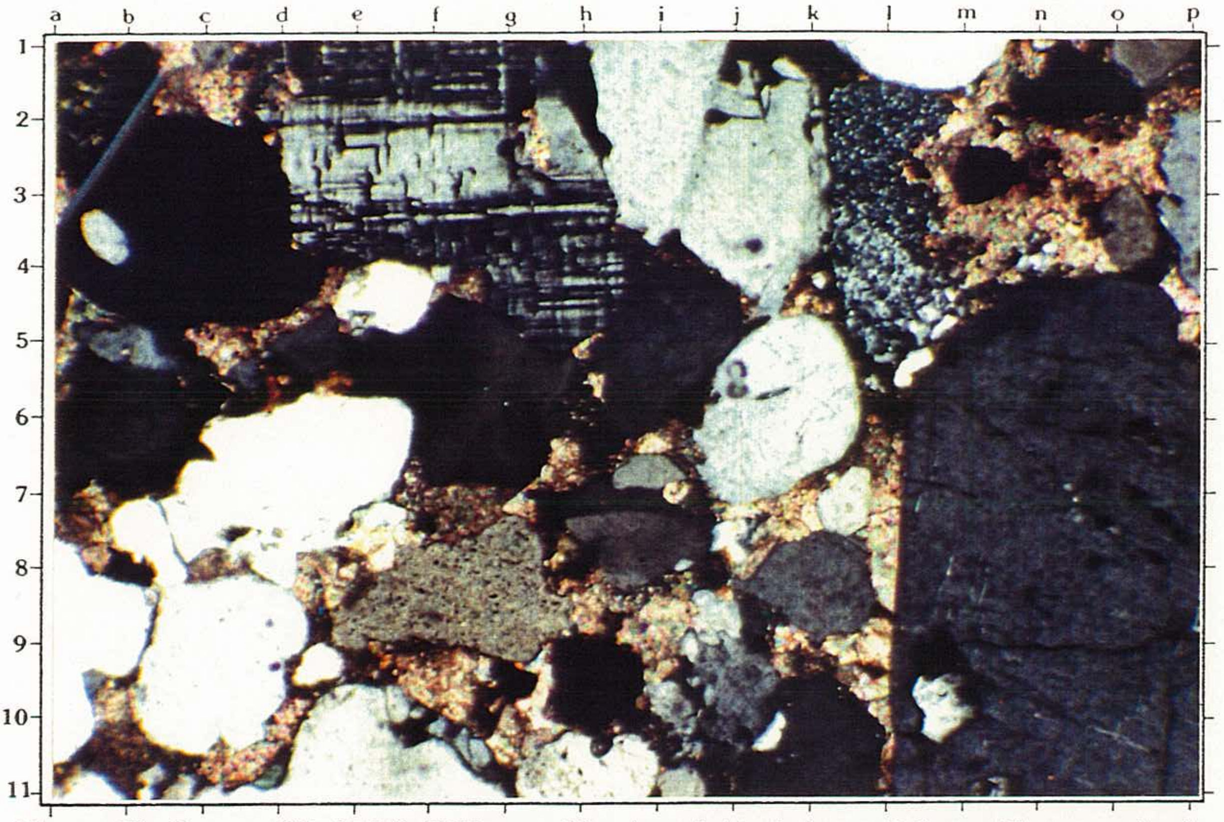


Figure 60. Barrow 25, 6794', 50X magnification, field of view - 2.2mm. Photograph of Facies 7 sandstone under cross-polars. Photo displays coarse grained, sub-rounded -rounded, moderately-poorly sorted nature of sandtone facies. Framework grains consist dominantly of quartz with subordinate feldspar (microcline(e3) & plagioclase), chert(l2) & glauconite(f8).Intergranular porosity has been infilled by microsparry calcitic cement and quartz grains display moderate degree of quartz overgrowths(e6).

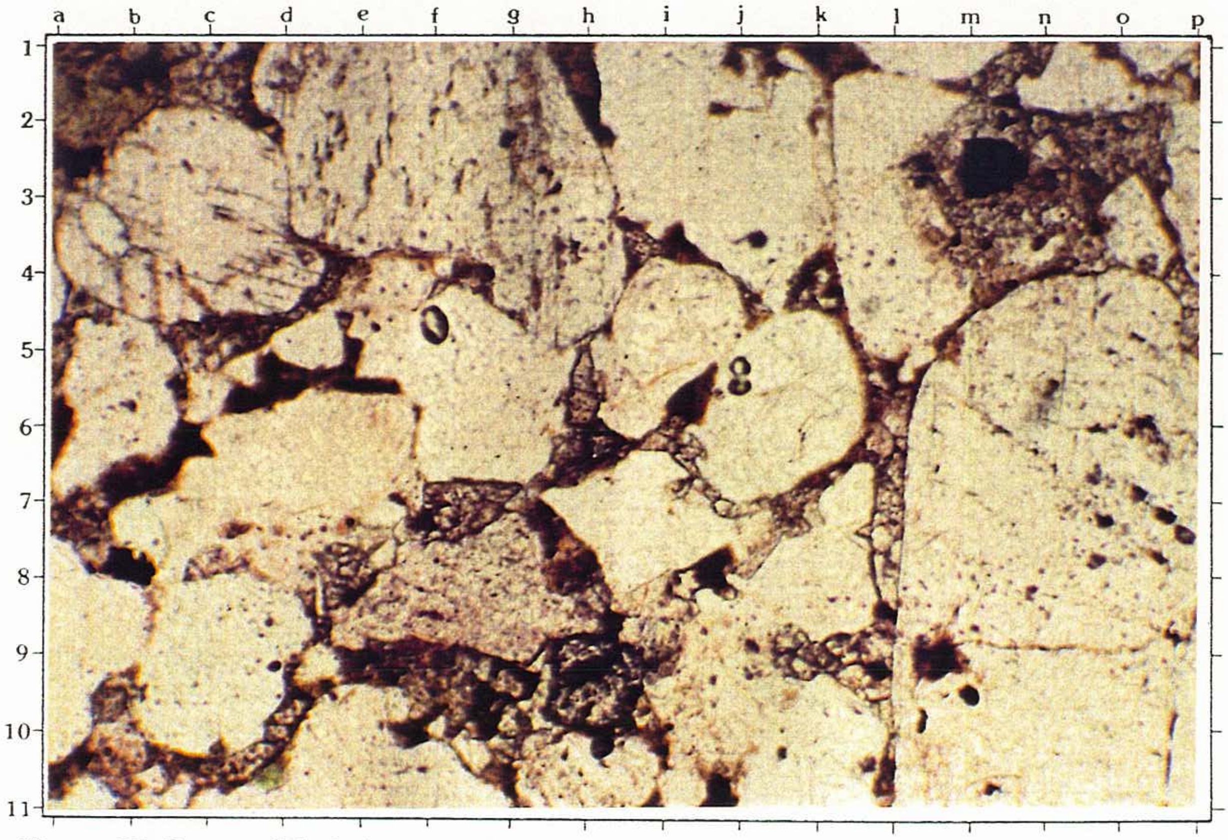


Figure 61. Barrow 25, 6794', 50X magnification, field of view - 2.2mm. Photograph of figure 60 under plane polarised light.

Texture

Facies 7 is moderately - well sorted. The absence of detrital clays and the development of extensive syntaxial silica overgrowths indicates that the primary porosity of the sandstone would have been very high (>30%). Grain to grain contacts are curvilinear to sutured indicating pressure solution. The lack of detrital clays makes identification of original grain boundaries difficult and there is no obvious preferred orientation of grains. Sparry calcite cement has infilled remaining pore space post syntaxial overgrowth resulting in generally <15% observed intergranular porosity. The quartz grains generally have wavy extinction under cross-polars.

Diagenesis

Primary porosity within the Facies 7 sandstones would have been high (20-25%).

The first pervasive cementation episode was the early precipitation of syntaxial overgrowths on the surface of detrital quartz grains. Early diagenetic blocky calcite cement infilled remaining pore space and appears to have replaced the earlier syntaxial overgrowths in some cases.

Minor authigenic kaolinite possibly related to the dissolution of feldspars is apparent, however has not significant reduced intergranular porosity. Early diagenetic carbonate cement appears to have been leached out in some samples, probably due to migration of acidic pore fluids and that secondary porosity is partially infilled by authigenic kaolinite.

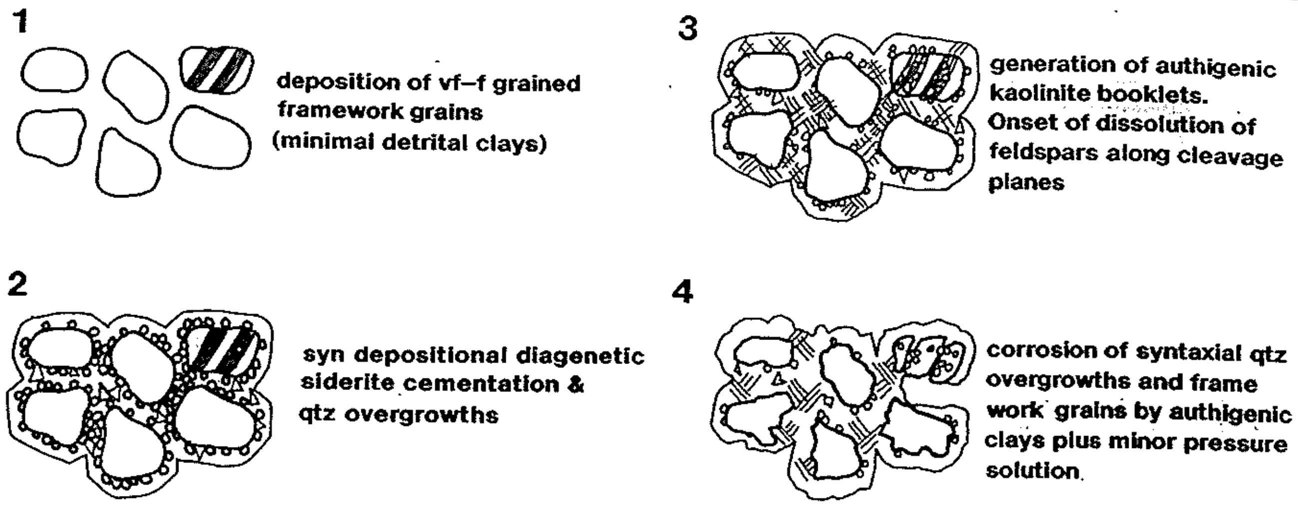
Depositional Environment

The presence of glauconite disseminated throughout the sandstone supports a marine origin. When combined with good sorting, lack of detrital clays and dominantly medium grained nature suggest deposition in a moderately high energy environment. Two such marine conditions are either above wave base, near shore - beach facies or deep marine turbiditic depositional system. The interbedded nature of this sandstone facies with Facies 4 and 5, and deep marine ichnology assemblage supports the latter, turbiditic mode of deposition.

6.2.3 Reservoir Characteristics

Diagenetic Summary

Upper Jurassic sandstones have undergone a complex history of physical and chemical changes during burial. Porosity-occluding diagenetic processes include syntaxial quartz overgrowths, carbonate cementation, authigenic clays, siderite cementation, compaction, pressure solution, and dissolution of feldspars. The relative paragenetic sequence established by Petrography and scanning Electron Microscopy for the seven recognised sandstone facies are summarised on Figures 62 to 64.



1 deposition of vf–f grained framework grains (minimal detrital clays)

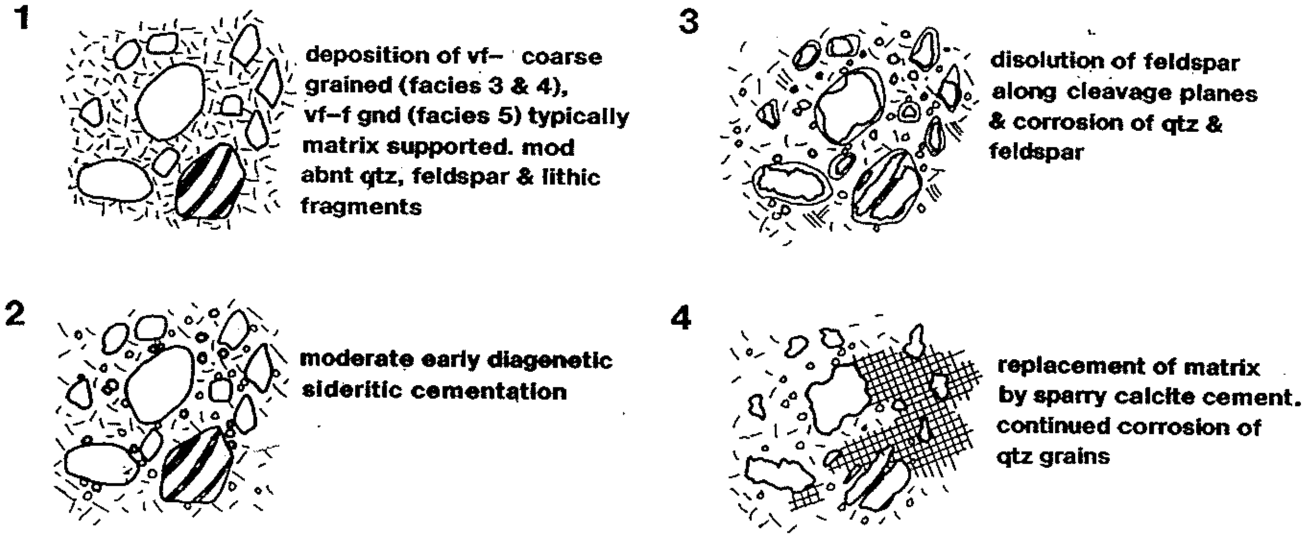
2 syn depositional diagenetic siderite cementation & qtz overgrowths

3 generation of authigenic kaolinite booklets. Onset of dissolution of feldspars along cleavage planes

4 corrosion of syntaxial qtz overgrowths and frame work grains by authigenic clays plus minor pressure solution.

FACIES 1&2 DIAGENETIC SEQUENCE

Figure 62.



1 deposition of vf– coarse grained (facies 3 & 4), vf–f gnd (facies 5) typically matrix supported. mod abnt qtz, feldspar & lithic fragments

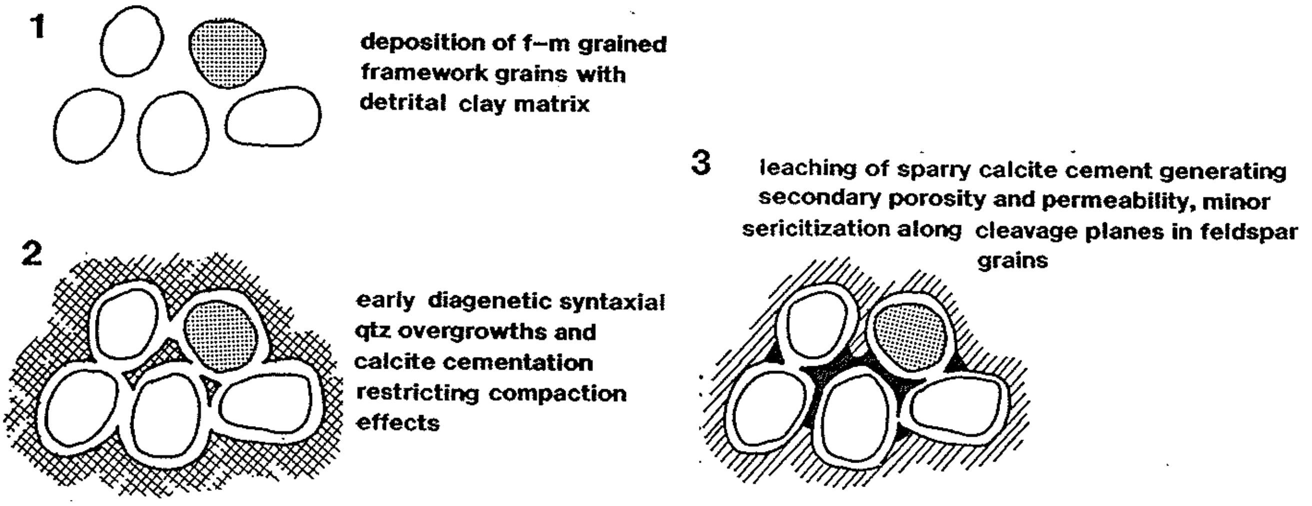
2 moderate early diagenetic sideritic cementation

3 disolution of feldspar along cleavage planes & corrosion of qtz & feldspar

4 replacement of matrix by sparry calcite cement. continued corrosion of qtz grains

FACIES 3,4&5 DIAGENETIC SEQUENCE

Figure 63.



1 deposition of f–m grained framework grains with detrital clay matrix

2 early diagenetic syntaxial qtz overgrowths and calcite cementation restricting compaction effects

3 leaching of sparry calcite cement generating secondary porosity and permeability, minor sericitization along cleavage planes in feldspar grains

FACIES 7 DIAGENETIC SEQUENCE

Figure 64.

DIAGENETIC SEQUENCE OF UPPER JURASSIC SANDSTONES BARROW SUB–BASIN NORTHWEST SHELF, AUSTRALIA

Porosity and permeability is only preserved in Facies 7 (Figure 64), within thin, interbedded (<5 m thick) medium - occasionally coarse grained quartz - sub-arkosic arenites identified in cores from Barrow-1, Barrow-25 and Perentie-1. Early syntaxial quartz overgrowths and blocky calcite cementation has inhibited significant compaction effects. Secondary porosity associated with carbonate dissolution at greater depths of burial has resulted in good intergranular (>17%) porosity and moderate permeability (11-230 mD) (Figure 32). The early carbonate cement inhibited significant intergranular porosity occlusion by early diagenetic syntaxial quartz overgrowths. Facies 7 sandstones have generally minimal detrital clay matrix.

Relatively rapid burial in the depositional setting probably restricted siderite cementation which usually occurs at or near the sediment water interface.

In contrast, within the remaining facies, porosity occlusion due to extensive syntaxial quartz overgrowths, early diagenetic siderite cement, authigenic kaolinite, and carbonate cement is extensive. Only Facies 1 and 2 have permeabilities in excess of 5 mD but are generally less than 20 mD. Porosity occlusion due to syntaxial authigenic quartz overgrowths and late diagenetic authigenic clays has occurred in Facies 1 and 2 resulting in moderately high porosities 14-20% but low permeabilities. The remaining four facies (Facies 3, 4, 5, and 6) all have a high abundance of detrital clay matrix which has generally inhibited authigenic, syntaxial quartz overgrowths but has generally restricted permeability. The schematic paragenetic sequence Surdam et al (1989)

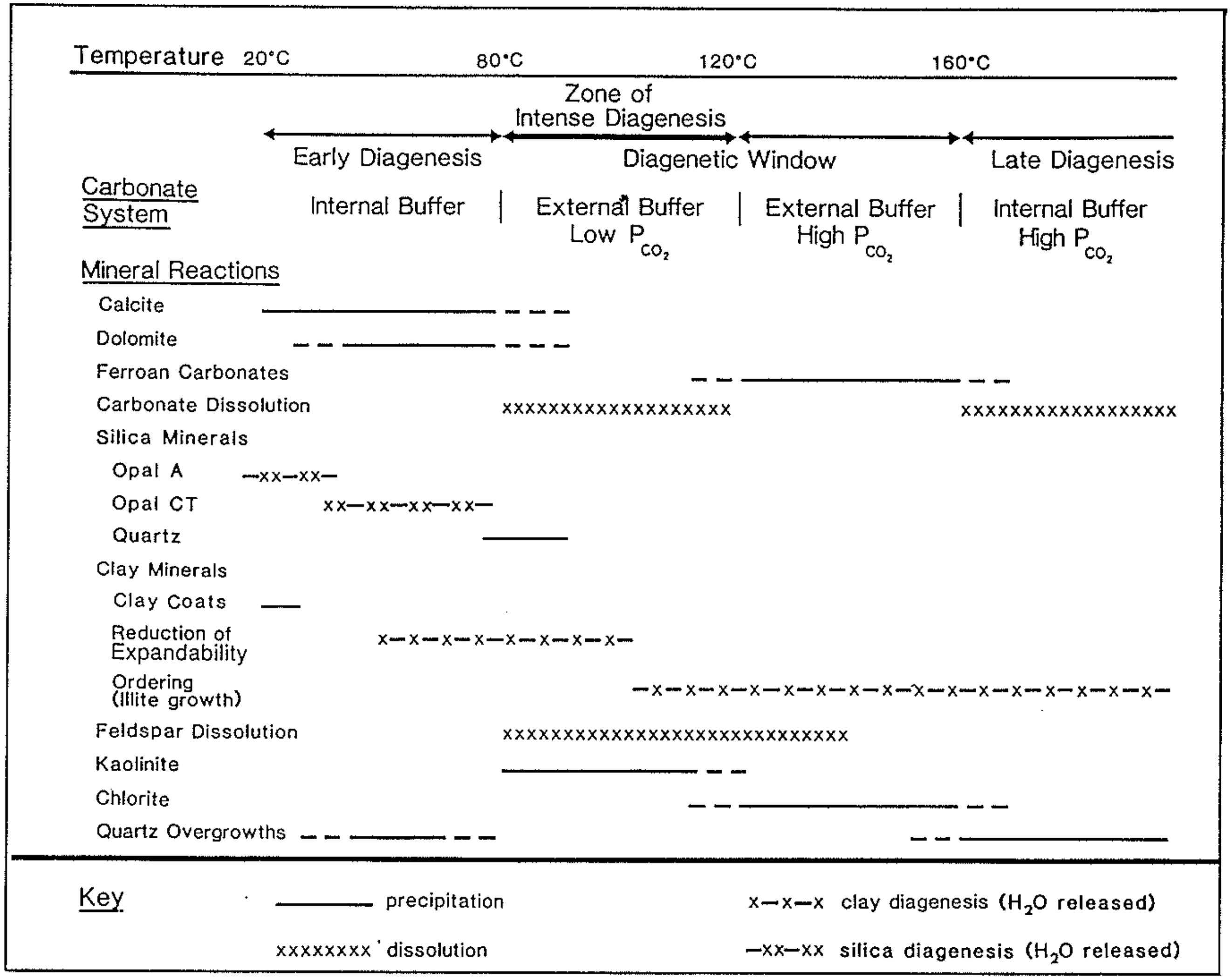


Figure 65. Schematic paragenetic sequence derived from commonly observed diagenetic reactions. (Surdam et al, 1989)

(Figure 65) derived from commonly observed diagenetic reactions supports the diagenetic history proposed for the Upper Jurassic sandstone facies in this study. Quartz overgrowths and calcite or dolomite cementation can be early diagenetic events, i.e. 20-80° C temperatures. Carbonate dissolution (decarbonatisation), feldspar dissolution and authigenic kaolinite formation are within the zone of intense diagenesis (80-120° C). Late stage diagenetic effects (>120° C) are reappearance of quartz overgrowths and carbonate dissolution and the generation of illite precipitation. More detailed SEM and XRD work needs to be done on the argillaceous samples to evaluate the abundance of illite.

6.3 LITHOSTRATIGRAPHY

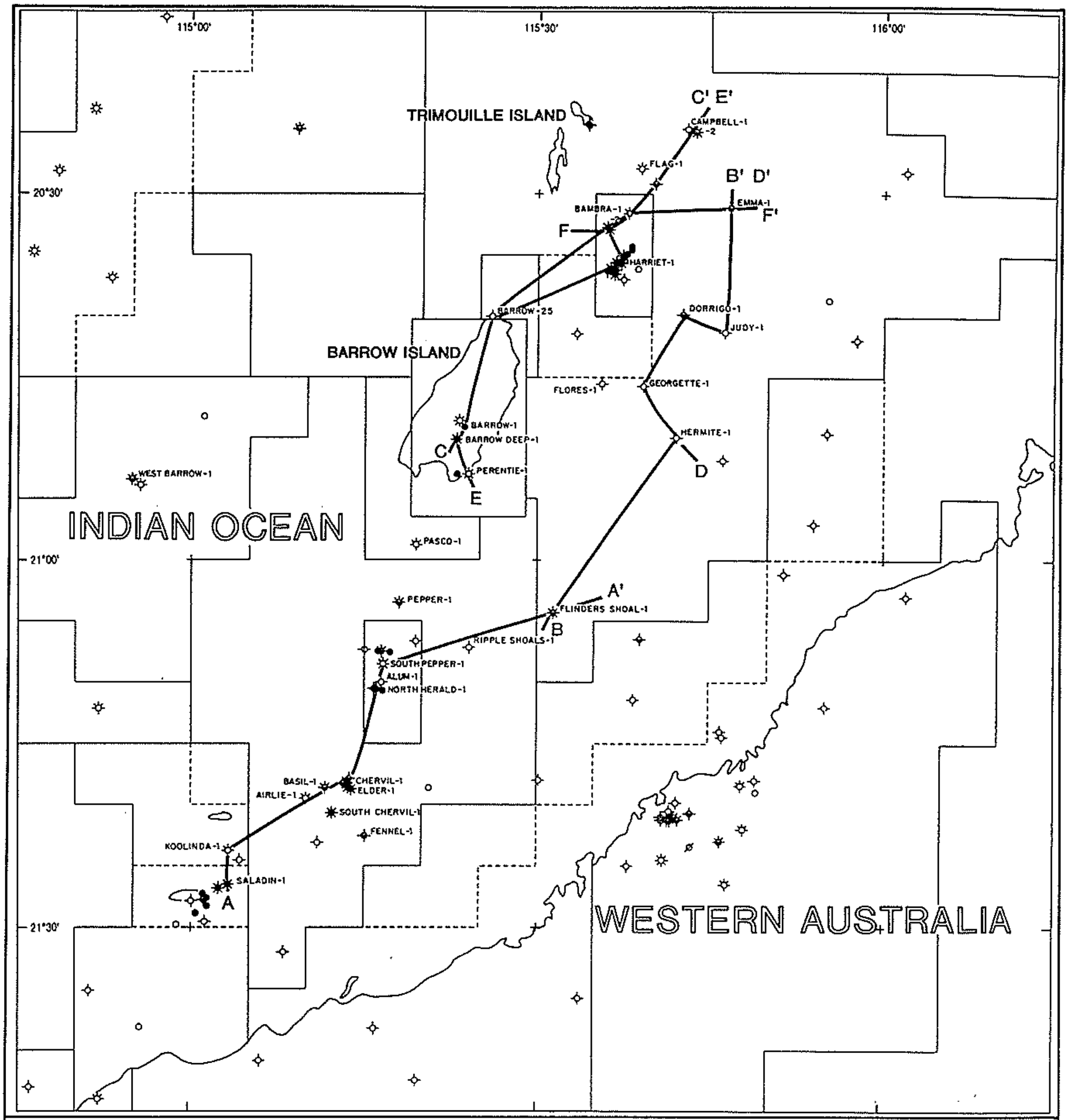
6.3.1 Introduction

This section forms the basis from which the sequence analyses interpretation (Section 6.4, page 82) was developed. Difficulty was experienced in reliably correlating individual facies between wells on the basis of wireline log character, sparse and relatively poorly controlled biostratigraphy and lithologic descriptions from cores and cuttings. This lithostratigraphy section has been included to display the comparison in results between a lithostratigraphic and a sequence analyses approach (Section 6.4). No seismic was incorporated into this early stage of the project and the results provided a guide for the sequence analysis. The sequence analyses section (6.4) integrated geologic and geophysical facets to develop a basin history explaining the relationship between tectonism and eustacy and their control on facies distribution.

Three regional cross sections integrating 20 wells (Figure 66) were generated on which basic data (biostratigraphy and core locations) were plotted (Enclosures II, III and IV). The aim of the lithostratigraphic cross sections was to evaluate the applicability of correlating individual facies trends observed from core descriptions and wireline log character.

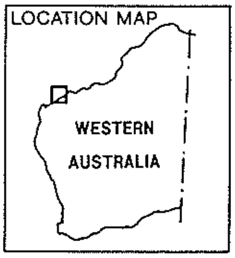
Due to the lack of well control drilling deep enough to penetrate the intra-Callovian unconformity in the southern study area, little is known of the facies distribution and the extent to which intra-Callovian tectonism has controlled sedimentation in the area. In the northern half of the study area both the Base Cretaceous and intra-Callovian unconformities are identifiable from the moderate well control allowing elucidation of the entire Upper Jurassic interval. Due to the sparsity of wells and lack of lithological variation in the southern study area, the Base Cretaceous unconformity was more difficult to discern.

The following discusses the three individual cross sections with regard to the reliability of facies correlations, age dates and missing sections associated with intra Upper Jurassic tectonism. In general, four regional depositional units (cycles) were recognised. The oldest, (Unit 1) is of Callovian age and was recognised in Section B-B'. The second, (Unit 2) is of Oxfordian - lower Kimmeridgian age and was recognised on all three cross sections. A regional unconformity of Kimmeridgian age separates Units 2 and 3. Unit 3 is generally a



LOCATION OF CROSS-SECTIONS

A-A'	*Saladin 1 – Flinders Shoal 1 lithostratigraphic*
B-B'	*Flinders Shoal 1 – Emma 1 lithostratigraphic*
C-C'	*Barrow Deep 1 – Campbell 2 lithostratigraphic*
D-D'	*Hermite 1 – Emma 1 sequence analysis*
E-E'	*Perentie 1 – Campbell 2 sequence analysis*
F-F'	*Bambra 2 – Emma 1 sequence analysis*



Location of Cross-sections
Eastern Barrow Sub-basin
Study Area

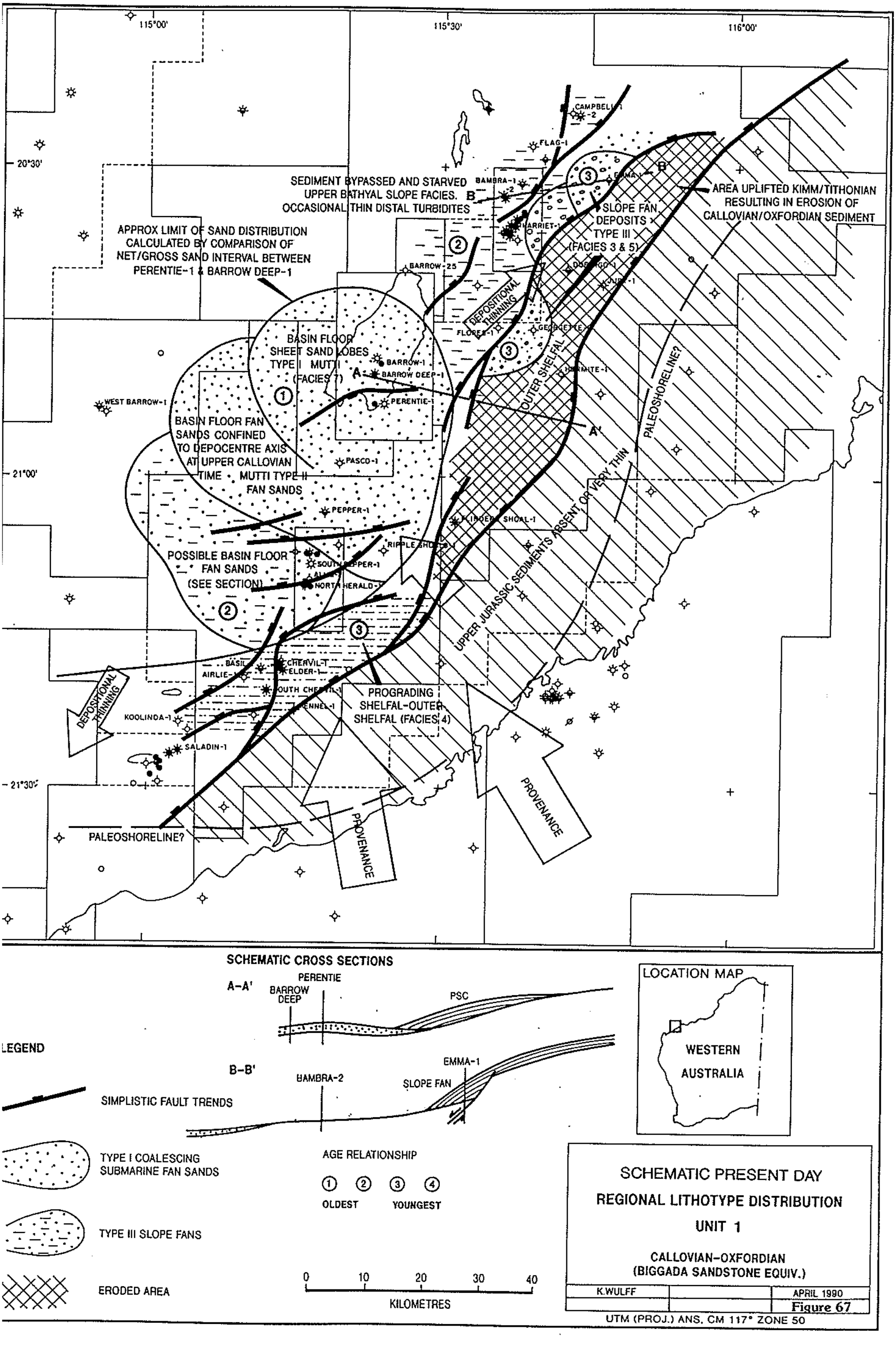
author : K.W.	drafted : K.W.	date : October 1990
		Figure 66

UTM (PROJ.) ANS. CM 117° ZONE 50

fining upward clastics unit with small scale coarsening upward cycles which in turn is unconformably overlain by a mid-upper Tithonian generally coarsening upward unit (Unit 4). This unit marks a return to a higher energy depositional conditions. The following discusses the results of the three lithostratigraphic cross sections and summarises the distribution and facies of the four depositional units recognised. Figures 67, 68, 69 and 70 are paleogeography maps of Units 1 to 4 respectively and summarise the environmental interpretations based on lithostratigraphy. These figures are schematic and were generated during the early stages of the project. These have been included for comparison with figures 84, 88 and 91 which are facies distribution maps generated from the sequence analysis of the Upper Jurassic using seismic, wireline logs, core and biostratigraphy. In contrast, figures 67, 68, 69 and 70 are poorly controlled and based only on wireline log correlation.

6.3.2 Southern Barrow Sub-basin (Cross-section A-A', Enclosure II)

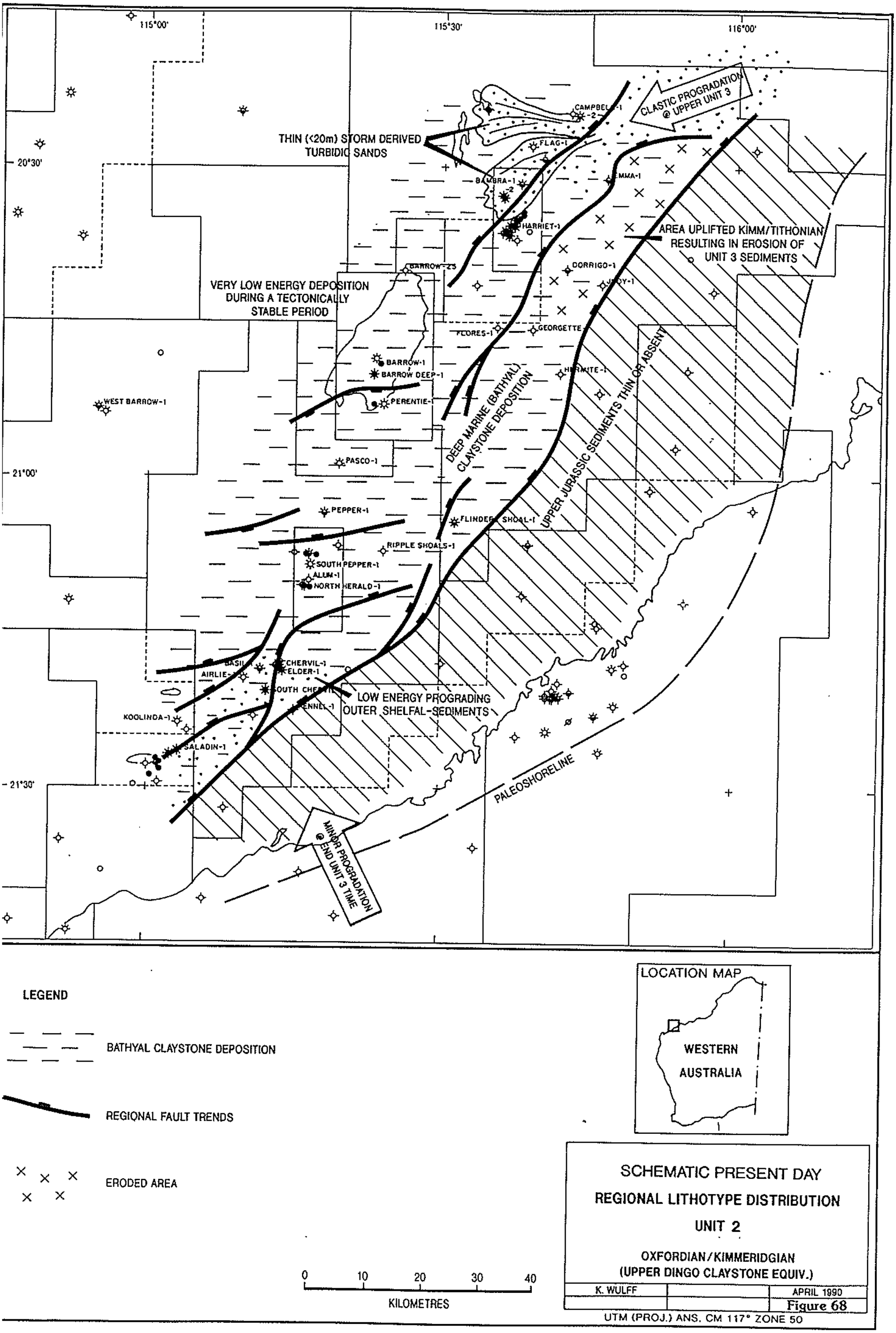
A gamma - sonic cross section at 1:2,000 vertical scale and 1:100,000 horizontal scale was generated to evaluate the lateral correlatability of lithostratigraphic units in the south of the study area. This cross section incorporated Saladin-1, Koolinda-1, Basil-1, Elder-1, Alum-1, South Pepper-1 and Flinders Shoal-1. Few wells penetrated the entire Upper Jurassic interval in the southern Barrow Sub-basin. Only Elder-1 and Flinders Shoal-1, (Enclosure II) drilled deep enough to intersect the intra-Callovian unconformity. Based on biostratigraphy, the tectonically active nature of the Upper Jurassic period is evident by the absence of



SCHEMATIC PRESENT DAY
REGIONAL LITHOTYPE DISTRIBUTION
UNIT 1

CALLOVIAN–OXFORDIAN
(BIGGADA SANDSTONE EQUIV.)

Figure 67



SCHEMATIC PRESENT DAY

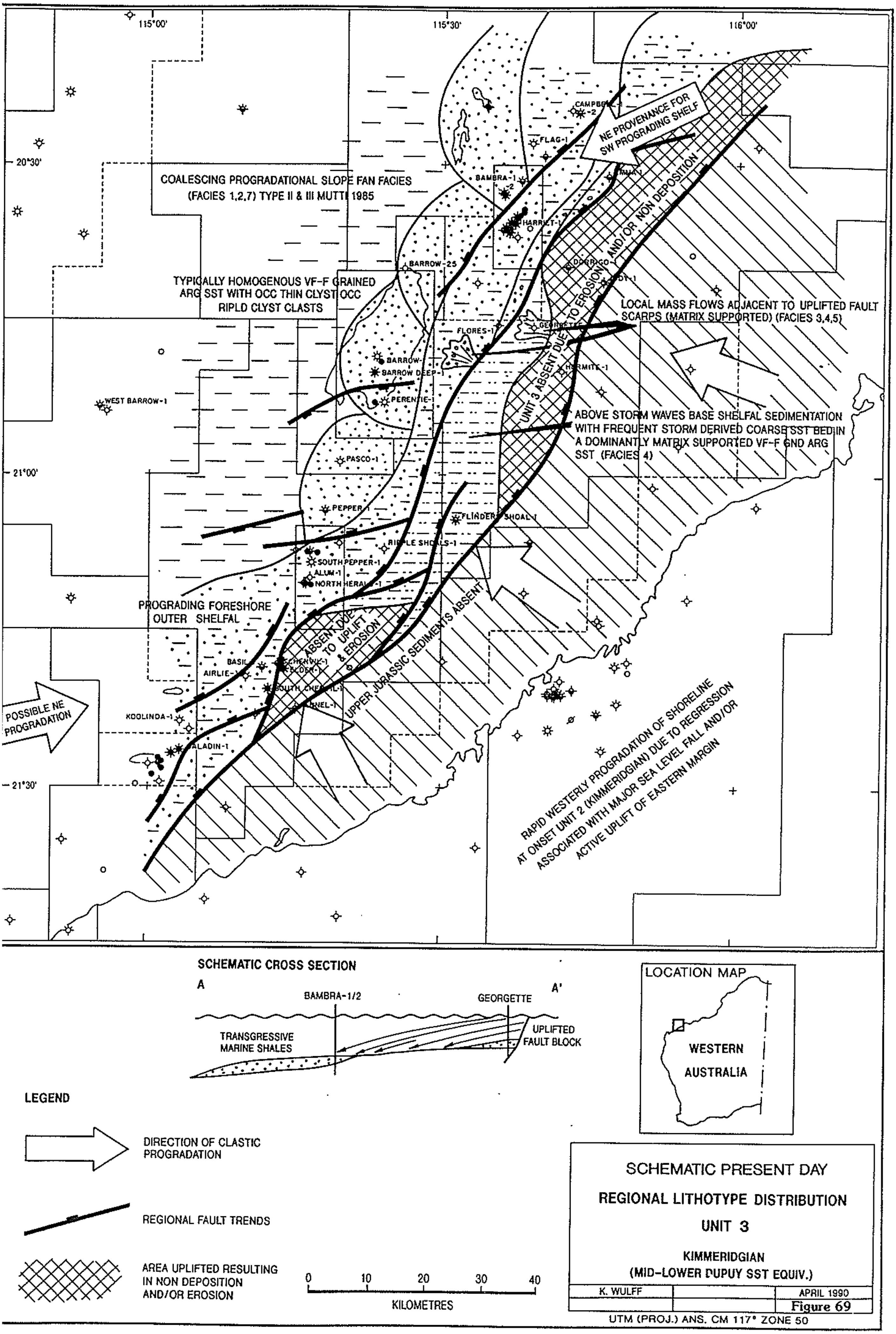
REGIONAL LITHOTYPE DISTRIBUTION

UNIT 2

OXFORDIAN/KIMMERIDGIAN
(UPPER DINGO CLAYSTONE EQUIV.)

K. WULFF		APRIL 1990
		Figure 68

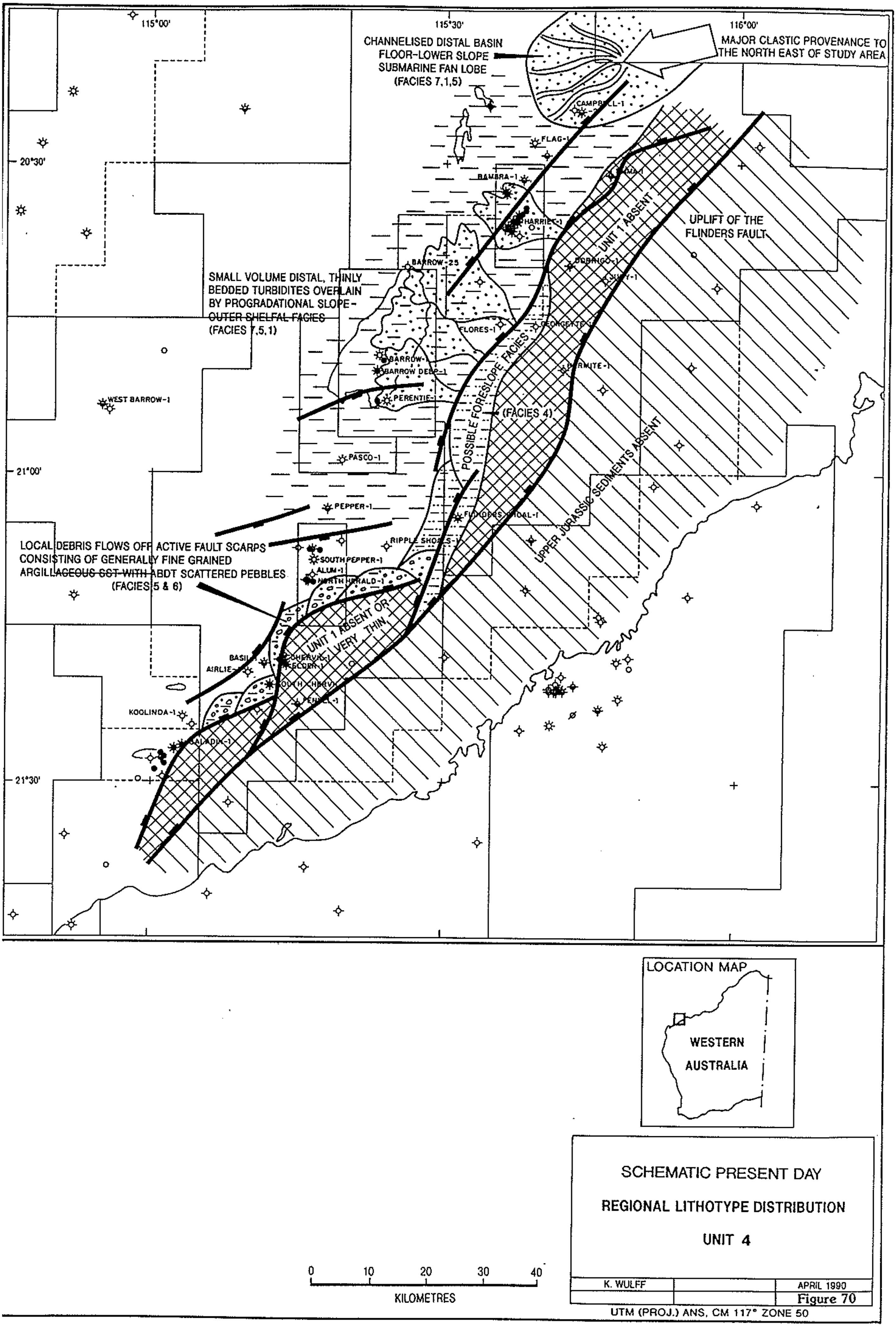
UTM (PROJ.) ANS. CM 117° ZONE 50



SCHEMATIC PRESENT DAY
REGIONAL LITHOTYPE DISTRIBUTION
UNIT 3
KIMMERIDGIAN
(MID-LOWER DUPUY SST EQUIV.)

K. WULFF		APRIL 1990
		Figure 69

UTM (PROJ.) ANS. CM 117° ZONE 50



SCHEMATIC PRESENT DAY

REGIONAL LITHOTYPE DISTRIBUTION

UNIT 4

K. WULFF		APRIL 1990
		Figure 70

UTM (PROJ.) ANS, CM 117° ZONE 50

biostratigraphical zonations within the interval, an example being the absence of the D.jurassicum (Portlandian) - D.swanense (Kimmeridgian) interval in Elder-1. This interval equates to ~12 mya of missing section. The presence of a relatively thick section of Callovian - Oxfordian sediment (~200 m) suggests that the Elder-1 locality was a relative topographic low immediately post Callovian time which was subjected to periods of isostatic adjustment and uplift ultimately culminating in deposition of thin Tithonian interval (29 m). This interpretation is supported by the dipmeter, electric logs and biostratigraphy which suggest that at least two unconformities exist within the Upper Jurassic interval in the Elder-1 borehole, at 1388 mKb and 1448 mKb (Figure 71).

Unit 2 (Oxfordian - Lower Kimmeridgian) was recognised in the Saladin-1 - Flinders Shoal-1 cross section (Enclosure II). This unit is equivalent to the Upper Dingo Claystone in accepted Carnarvon Basin nomenclature and lies within the W.clathrata - R.aemula dinoflagellate zones. Unit 2 consists of massive claystone grading in part to silty shale with minor thin argillaceous sandstone lenses. On Section A-A', Koolinda-1, Elder-1 and Flinders Shoal-1 intersected the Upper Dingo Claystone (Unit 2). In Elder-1 the total thickness of Unit 2 is 190 m which may be further subdivided into the Upper Dingo Claystone (97 m) and the underlying Biggada Sandstone age equivalent (93 m). W.digitata dinoflagellates (Biggada age equivalent) were recognised in Elder-1. Core 2 (1536.2-1543.05 m) was cut within this interval and contains dominantly very fine - fine grained argillaceous sandstone (quartz wacke) with poor - moderate sorting, and occasional medium - coarse, floating quartz grains. Due to the abundant

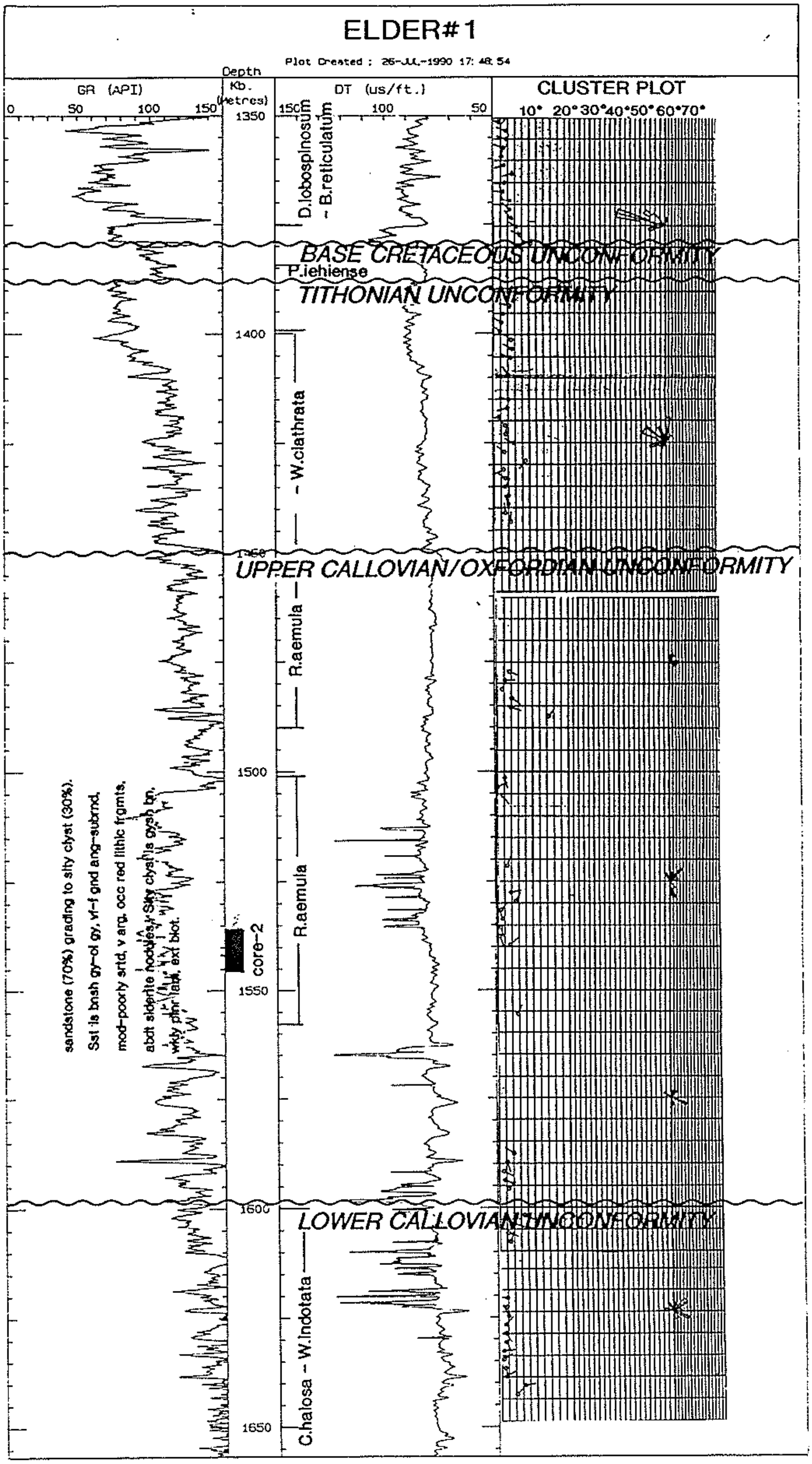


Figure 71 Gamma ray–sonic trace plot of the Upper Jurassic Interval in Elder–1

argillaceous matrix the core displayed no visible intergranular porosity.

Unit 3 unconformably overlies Unit 2 and is of Kimmeridgian - mid Tithonian age. This unit lies within the D.swanense - O.montgomeryi dinoflagellate zones. An unconformity at base D.swanense can be correlated basin-wide and marks a period of significant faulting and relative sea level fall related to the uplift of the Peedamullah Shelf. Unit 3 consists of a series of small scale coarsening upward cycles which grade upward into claystone and siltstone with minor very fine - fine grained argillaceous sandstone (Figure 69). In the basal section of Unit 3 immediately overlying the unconformity, the unit consists of argillaceous sandstones which are very fine - fine grained, poorly - moderately sorted, abundant argillaceous matrix with occasional medium - coarse quartz grains.

On Section A-A', Unit 4 is not as clearly lithologically definable as Sections B-B' and C-C'. Unit 4 has been tentatively correlated and is of mid - upper Tithonian age. Unit 4 unconformably overlies Unit 3 and lies within the P.iehiense - O.montgomeryi dinoflagellate zones.

On Section A-A' Unit 4 marks a change from dominantly claystones with minor siltstone and sandstone to a generally coarsening upward, argillaceous, very fine - fine to occasional coarse grained sandstone (quartz wacke) (Figure 70). The mid Tithonian unconformity represents a period of faulting and uplift initiating relative lowstand conditions. This is suggested by Elder-1, where the Tithonian Unit 4 interval unconformably overlies Oxfordian - Callovian sediments (Unit 2). The

Kimmeridgian, Unit 3 sediments are absent (Figure 71).

A change in sedimentation styles and provenance direction between the Upper Jurassic and Lower Cretaceous in the south of the study area is not obvious. Intermixing of sedimentation directions from the east and the south was likely during the latest Jurassic and earliest Cretaceous. This is evident in South Pepper-1, Core 8 (2361.5-2379.8 m log depth) which displays massive slumped boulders and rounded lithic fragments indicative of mass flow deposition and soft sediment deformation suggesting local slumping and scouring of uplifted or shelfal fault blocks. This core occurs approximately 80 m above the interpreted base Cretaceous unconformity within sediments of Berriasian age based on biostratigraphy. The mass flow deposits can be tentatively recognised in Elder-1, Alum-1 and South Pepper-1 (Enclosure II). Within the basal Barrow Group, a bentonite marker has been tentatively correlated in five of the seven wells within the prodelta shale interval immediately overlying the Berriasian mass flow deposits (where present). The thickness of prodelta shales in the basal group separating the base Cretaceous unconformity from the Barrow delta bottomsets varies between 20 m at Flinders Shoal-1 to 520 m in Basil-1.

6.3.3 Eastern Barrow Sub-basin (Cross-section B-B', Enclosure III)

Cross section B - B' (Enclosure III) is a south - north cross section incorporating six wells (Flinders Shoal-1, Hermite-1, Georgette-1, Judy-1, Dorrigo-1 and Emma-1) on the eastern flank of the Barrow Sub-basin. Based on the wireline log character, lateral facies variations are marked and thickness of units based on biostratigraphy is highly variable. Hermite-1, Georgette-1, Judy-1, Dorrigo-1 and Emma-1 all contain moderately thick Oxfordian/Callovian intervals (Unit 1 and Unit 2) and very thin or absent Kimmeridgian and Tithonian age sediments (Units 3 & 4). Only Georgette-1 and Flinders Shoal-1 contain Units 3 and 4, (Kimmeridgian and Tithonian age sediments) indicative of isostatic adjustment of fault blocks during the Upper Jurassic interval. Significant post Callovian / Oxfordian uplift has occurred resulting in non deposition and erosion at Judy-1, Dorrigo-1 and Hermite-1.

Unit 1 (Biggada Sandstone equivalent) is only recognisable on the basis of log character in Emma-1 and Georgette-1. Lithologically the unit consists of poorly sorted, generally very fine - fine grained argillaceous sandstone (quartz wacke) with occasional coarse grained quartz and lithic fragments (Figure 67). The argillaceous sandstone is interbedded with olive grey - medium grey sandy siltstone which contains frequent calcisiltite clasts up to 2 cm. Both the argillaceous sandstone and siltstone are planar laminated and frequently bioturbated. Very poorly sorted beds generally less than 1.5 m thick consisting of coarse - very coarse rounded quartz and lithic grains within an argillaceous matrix also occur within the overall unit. Basal contacts are sharp and are indicative of short periods of rapid deposition. In Emma-1 numerous small scale fining upward cycles (<5-10 m) can be recognised on dipmeter and core. Unit 1 (Biggada Sandstone equivalent) equates to Facies 4 (Section 6.1.2, page 36) and has poor reservoir characteristics. Depositional environment proposed for Unit 1 in Georgette-1 and Emma-1 is a slope fan, channel/levee turbidite complex (Type III, Mutti, 1985) (Figure 67). The thinly bedded and muddy character combined with the presence of slumping, graded bedding, and sharp basal contacts recognised in cores from both Emma-1 and Georgette-1, support Mutti Type III classification.

Unit 2 Oxfordian - Callovian Upper Dingo Claystone equivalent sediments are present in all six wells. Lithologically this unit consists of medium - dark grey claystones which grade up into silty claystones with thin interbeds (<1 m) of very fine grained argillaceous sandstone and siltstone. Although in Dorrigo-1 and Judy-1 the W.digitata - R.aemula zone has tentatively been referred to as Unit 2, (Upper Dingo Claystone equivalent) however lithofacies correlations between these and adjacent wells are highly dubious on the basis of wireline log character. These units may prove to be more analogous to Unit 1 (Figure 68).

Unit 3 has only been recognised in Georgette-1 and Flinders Shoal-1 and marks a rapid change from the underlying claystone facies of the Upper Dingo Claystone to very fine - fine, occasionally medium to coarse grained, generally massive sandstone facies which equates to the Dupuy Sandstone. Unit 3 lies within the O.montgomeryi - D.swanense dinoflagellate zones. This unit contains coarsening up cycles (50-150 m) within an overall fining upward unit which suggest initial regressive conditions and progradation within a dominantly transgressive marine environment (Figure 69). The dominantly fine - very fine, with occasional coarse - very coarse grained sandstones combined with the coarsening up cycles and presence of glauconite suggests deposition in an outer shelfal - shelfal marine environment with periodic storm derived sandstones introducing coarser grained sediment into the system. The general abundance of argillaceous matrix suggests deposition at or just below wave base. The contact with the underlying Unit 2 (Upper Dingo Claystone) is very sharp and erosive suggesting a rapid fall in sea level associated with a eustatic sea level fluctuation or as a result of tectonic uplift and tectonism along the Flinders Fault zone.

Unit 4 is only recognised in Georgette-1, Emma-1 and Flinders Shoal-1 and is a maximum of 103 m thick in Georgette-1 (Enclosure III). This unit is of Tithonian age (O.montgomeryi - P.iehiense) and consists of a generally coarsening upward, very fine - fine grained argillaceous sandstone with occasional coarse grained quartz fragments. The basal contact with Unit 3 is sharp and generally erosive (Flinders Shoal-1 and Emma-1) and is clearly definable on wireline logs. The return to higher energy conditions and erosive basal contact with the underlying Unit 3 suggests a return to regressive conditions associated with a rapid fall in sea level. Initial deposition in the Emma-1 and Flinders Shoal-1 areas most likely occurred in an outer shelfal to slope turbidite channel/levee type system whilst deposition at Georgette-1 was progradational and occurred in an outer shelfal grading to inner shelfal environment (Figure 70). The abundance of detrital argillaceous matrix in all three wells restricts the reservoir characteristics of the sandstones in Unit 4. The sandstones in Unit 4 are comparable to Facies 1 and 4 as described in Section 6.1.2, page 36.

6.3.4 Central Barrow Sub-basin (Cross-section C-C', Enclosure IV)

Cross section C - C' is orientated south to north and incorporates seven wells (Barrow Deep-1, Barrow-25, Harriet-1, Bambra-2, Bambra-1, Campbell-1 and Campbell-2) within the central area of the Barrow Sub-basin. Only four of the seven wells (Barrow Deep-1, Bambra-2, Bambra-1 and Flag-1) intersected a complete or near complete Upper Jurassic study interval. These four wells provide valuable information for the facies distribution of Upper Jurassic sediments within the central Barrow Sub-basin.

On the basis of wireline log character, lithofacies and dipmeter motifs (structural and stratigraphic) the Upper Jurassic (intra-Callovian - base Cretaceous) may be subdivided into four units.

The basal Unit 1 equates to the Upper Callovian Biggada Sandstone Equivalent and is best developed in Perentie-1 (3549-3900+ m) and Barrow Deep-1 (3226-3650 m).

In Perentie-1 and Barrow Deep-1 Unit 1 consists of blocky sandstone beds up to 15-20 m thick with interbedded massive claystones ranging from 1-50 m (Enclosure IV). The relative variability in net sandstone thickness yet obvious correlations attests to the lateral extensiveness of these sands and suggests that Perentie-1 is slightly more proximal than Barrow Deep-1 due to the relative increase in sandstone thickness. Lithologically these sands are predominantly medium grained, frequently ranging to granular, well - moderately sorted, subround - rounded, with fair visible intergranular porosity. The presence of dish structures observed in Perentie-1 core 2 and the medium grained, frequently granular nature of the sandstones suggests deposition in large volume, sand laden turbidity currents and most likely equate to Mutti's Type I turbidite system (Figures 25 & 67). The grainsize distribution and blocky sandstone nature are indicative of rapidly deposited Bouma A facies sandstones. The water escape features (dish structures) observed in Perentie-1 support rapid deposition of the sandstones.

In Bambra-2 the intra-Callovian unconformity has tentatively been interpreted at 3798 mRKB. Immediately overlying the unconformity are thinly bedded, very fine grained argillaceous sandstones and silty claystones. This facies has been interpreted as distal turbidites within a depositional setting (Figure 67).

Unit 2 conformably overlies Unit 1 and is equivalent to the Upper Dingo Claystone. This unit lies within the W.clathrata - W.spectabilis dinoflagellate zones and consists of massive medium - dark grey claystones and siltstones. Thin (<30 m), laterally extensive, fine grained, argillaceous sandstone beds are present within this unit and most likely represent storm-derived turbiditic sandstones or may be associated with minor eustatic sea level fluctuations. These thin sandstone beds lie immediately above the transition from a general fining upward to a coarsening upward sequence. This marks a change from transgressive to regressive and progradational sedimentation. Unit 2 was deposited in a deep marine (bathyal) environment (Figure 68) and kerogenous shales within this unit constitute excellent source rocks (Volkman et al, 1983).

In the northern study area, progradation of clastic facies is observable in the upper section of Unit 2 as observed in Flag-1, Bambra-1, Bambra-2. This suggests that towards the end of Unit 2 time a transition from bathyal to outer shelfal deposition had occurred making an increase in the rate of progradational sedimentation. Lithofacies within this progradational assemblage are a transition from dark grey, silty claystones at the base to interbedded, very fine grained argillaceous sandstones, siltstones and minor claystones to fine grained argillaceous sandstones at the top of the sequence. Thin beds (<3 m) of fine - medium grained sandstones occur throughout the coarsening upward sequence probably mark periods of storm activity or sediment instability closer to the shelf edge. This is supported by core 4 in Flag-1 (2993.1-3000.5 m) which contains clean, fine - medium grained sandstone beds less than 30 cm thick interbedded with intensely bioturbated grey fine grained, argillaceous sandstones and siltstones.

Reservoir quality sandstones are generally lacking in Unit 2, however, the thin sandstone beds observed in Bambra-2, Bambra-1 and Flag-1 may thicken and clean up in a more proximal location to provenance. This is discussed in greater detail in Section 6.4, page 82.

Unit 3 is of Kimmeridgian age and lies within O.montgomeryi / M.perforans to base D.swanense dinoflagellate zones. As shown on Enclosure IV, the base of Unit 3 is identified by a marked coarsening upward sequence which can be correlated on a regional scale. Unit 3 is approximately 250-300 m thick in the depocentre axis and has a variable facies assemblage. In the north of the study area the upper section of Unit 3 has been eroded by a major unconformity of upper Tithonian age. This has resulted in approximately 100-150 m of missing section in Campbell-1 and 2 equating to a period of 5-10 my.

Elsewhere in the study area, Unit 3 marks a rapid transition to clastic sedimentation. In the Bambra area Unit 3 is characterised by two coarsening upward cycles (Enclosure IV). Core 2 in Bambra-1 (2713-2730 m) consists dominantly of massive very fine - fine grained, moderately argillaceous sandstone with thin interbeds of micaceous, subfissile claystone (Figure 69). Ichnology assemblages typical of an outer shelfal depositional environment occur within the core (Section 6.1.2, page 36). Overlying the coarsening upward cycles is a generally fining up transgressive cycle. This interval has been eroded in Campbell-1 and 2 and is missing in Bambra-1 due to faulting. Lithologically this upper interval of Unit 3 consists of finely interbedded very fine grained argillaceous sandstone and silty claystone. The claystone facies is the dominant lithotype in the upper interval.

South of Barrow Island, the base of Unit 3 is not as clearly definable as it is on the Flinders Fault Terrace (Enclosure III) or in the north of the study area. As displayed at Perentie-1 (2736 m) and Barrow Deep-1 (2550 m) (Enclosure IV) the base of Unit 3 is marked by a relatively rapid, upward coarsening in grainsize from silty dark grey claystones of the upper section of Unit 2 (Upper Dingo Claystone) to very fine grained bioturbated argillaceous sandstones of basal Unit 3 (Dupuy Sandstone Equivalent). The dominant lithotype of Unit 3 in Barrow Deep-1 and Perentie-1, based on cutting descriptions and wireline logs, is very fine grained argillaceous and glauconitic sandstones. Poorly defined coarsening upward trends, <25 m thick, indicate weak progradational cycles. Thin interbedded argillaceous sands (<5 m thick) in the upper section of Unit 3 may mark periods of storm activity or sediment instability further up on the shelf.

The upper boundary of Unit 3 is marked by an unconformity separating the finer grained argillaceous facies of upper Unit 3 from the coarser grained clastics of Unit 4.

Unit 4 is a Tithonian age sequence which lies within the P.iehiense - O.montgomeryi dinoflagellate zone. Facies variations are highly variable and range from coarse grained proximal turbidites and basin floor fan facies in Campbell-1, 2, and Harriet-1 to distal, thinly interbedded turbiditic fan lobes in Barrow-25, Barrow Deep-1, Bambra-1, Bambra-2 and Flag-1 (Figure 69). Overlying this basal turbiditic facies is a regionally coarsening up sequence marking a period of progradation. Facies and ichnology assemblages identified in Barrow-25 (cores 21-31), and Barrow-1 (cores 21-37), suggest a transition from thinly bedded turbiditic facies to outer shelfal - slope deposition. These sediments consist of interbedded bioturbated argillaceous, very fine - fine grained sandstone and silty claystone. Thin beds of very poorly sorted coarse grained sandstone with abundant pebble sized lithic fragments in the unit suggests periodic turbiditic cycles throughout Unit 4. The thinly bedded nature of these sandstones and abundant argillaceous matrix suggests deposition in a distal turbiditic deposition setting. In the north of the study area, a relatively thick (~50 m) basal Unit 4 sand package is recognisable in Campbell-1 and 2. This sand package is not correlatable to the south of the Campbell wells but can be correlated to a massive 300 m thick sand package of the same age in Rosemary-1, 80 km north of Campbell-2. This suggests that the main provenance for the massive sand facies overlying the Kimmeridgian unconformity in the northern half of the study area is to the northeast (Figure 70).

Active clastic sedimentation was developed on the eastern margin of the Barrow Sub-basin prior to the rapid regression and subsequent turbidite deposition. This is indicated by the medium grained (occasionally coarse) sandstone facies intersected in Harriet-1 (2442-2455 m), and Bambra-2 (2645-2665 m) and the thinly bedded (<5 m) medium - coarse grained turbidites in Barrow-25 (2100-2150 m) and Barrow-1 (2000-2390 m).

Reservoir quality sandstones exist in Unit 4 in Campbell-1 and 2, Harriet-1 with minor potential in Bambra-2, Barrow-25 and Barrow-1 within the coarser grained, thinly bedded turbiditic sandstones (Figure 70). The presence of massive, fine - coarse grained sandstone beds (Facies 7, Section 6.1, page 36) in Unit 4 renders the unit prospective for reservoir development. However, the lack of a thick overlying transgressive shale interval and rapid coarsening upward cycles overlying the more proximal turbidite or fan complexes downgrades the sealing propensity. The more distal, thinly interbedded turbidite facies intersected at Barrow-25 and Barrow-1 may provide a series of stacked reservoir objectives.

Recovery of 950 BOPD from a thin Tithonian age turbidite sand in Barrow 1 from DST supports the sealing propensity of the overlying thinly bedded, albeit laterally extensive, shales deposited following the turbidite deposition.

6.4 SEQUENCE ANALYSES AND CONTROLS ON SEDIMENTATION

6.4.1 Introduction

This section proposes depositional models based on sequence analyses of wireline logs, well data (cores, biostratigraphy, etc.) and seismic. This section utilises the results from the lithostratigraphic correlations (Section 6.3) and integrated seismic data and sequence stratigraphy principles to elucidate the complex relationship between tectonism, sea level fluctuations and facies distribution. The regional seismic coverage used in this study (~1800 km) is not sufficient to reliably resolve in detail the sequence analyses in what is a complex, tectonically active depositional setting.

Due to the post depositional uplift and erosion of shelfal sediments, equivalent to the transgressive and highstand systems tracts of the Upper Jurassic depositional sequences, conclusive models explaining the relationship between tectonism and eustasy and control on sediment distribution could not be established.

The models proposed in this section form the basis from which further detailed sequence stratigraphic studies may be initiated.

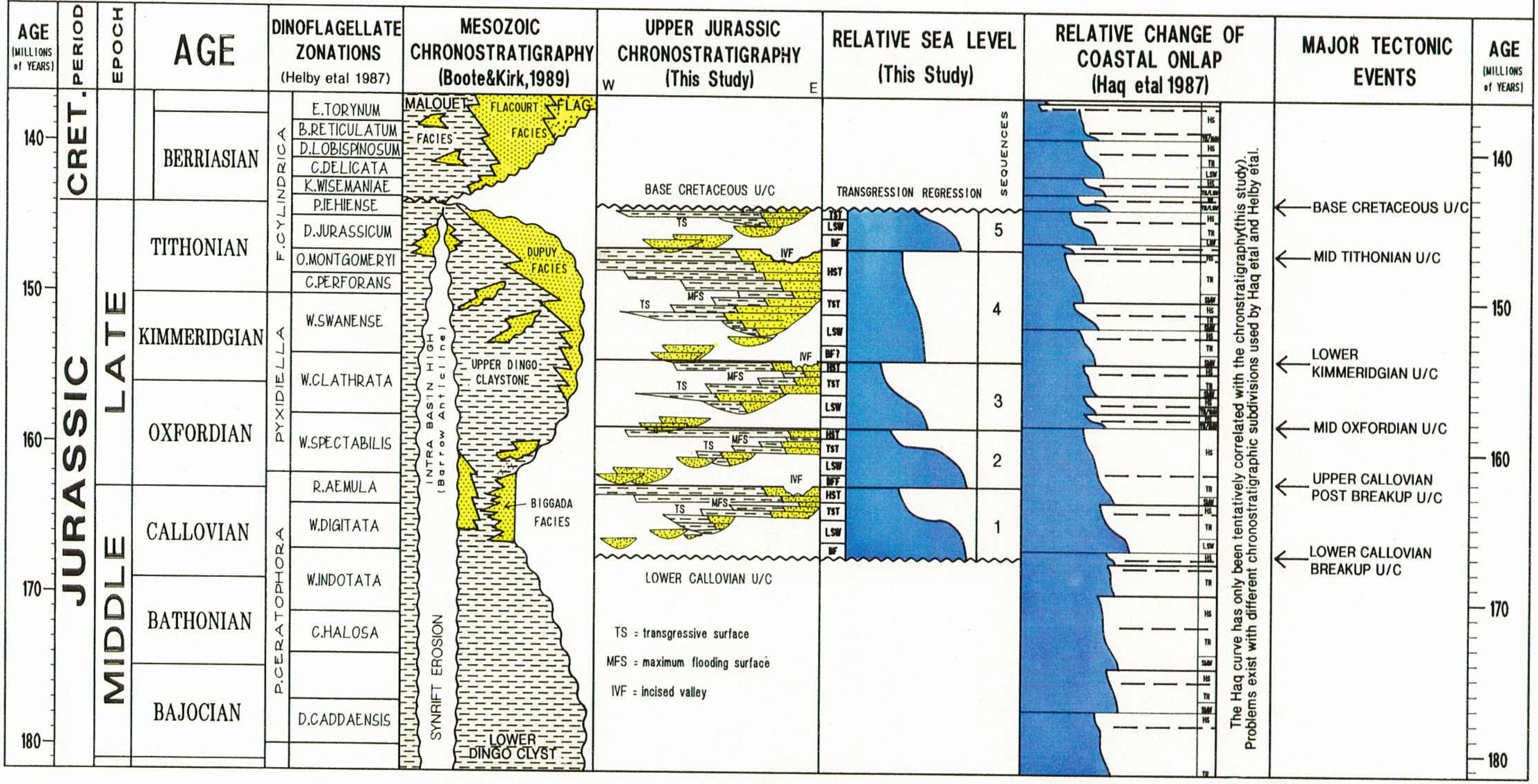
6.4.2 Results and Discussion

Five depositional sequences have been recognised within the Callovian - Base Cretaceous sedimentary section in the eastern Barrow Sub-basin. These depositional sequences are summarised on Figures 72 & 73.

The Lower - Mid Callovian sequence (Sequence 1) (W.digitata - R.aemula dinoflagellate zone) has been intersected in wells drilled on the eastern flank of the Barrow Sub-basin. This sequence has previously been referred to as the Biggada Sandstone Equivalent. This is dealt with in greater detail in Section 6.4.2.1, page 85. This sequence marks the first period of deposition following the onset of major rifting (termed Callovian breakup unconformity by most Carnarvon Basin authors). Tectonism and sediment supply are the major controlling factors for facies distribution in Sequence 1.

The second depositional sequence present is of Upper Callovian - Mid Oxfordian age and falls within the R.aemula - W.spectabilis dinoflagellate zones. This sequence is recognised in wells within the central Barrow Sub-basin and on the

JURASSIC - EARLY CRETACEOUS CHRONOSTRATIGRAPHY



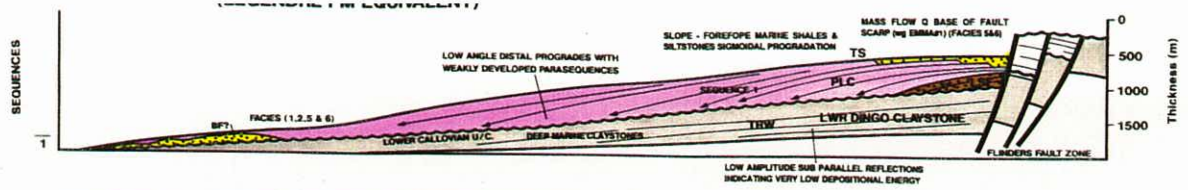
TS : transgressive surface

MFS : maximum flooding surface

IVF : incised valley

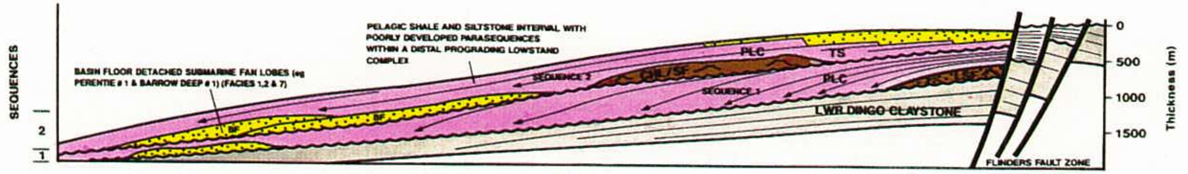
The Haq curve has only been tentatively correlated with the chronstratigraphy(this study).
Problems exist with different chronostratigraphic subdivisions used by Haq etal and Helby etal.

Figure 72



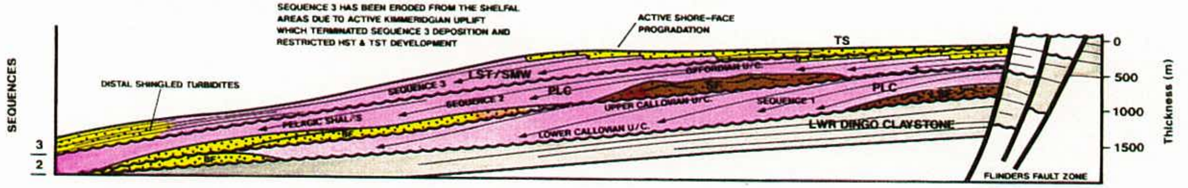
HIGHSTAND & TRANSGRESSIVE SYSTEM TRACT SHELFAL & SHOREFACE SEDIMENTS ARE ABSENT IN THE STUDY AREA DUE TO UPLIFT & EROSION OF THE PEEDAMULLAH SHELF & FLINDERS FAULT TERRRACE BETWEEN CALLOVIAN & BASE CRETACEOUS TIMES.

SEQUENCE 2 **UPPER CALLOVIAN–LOWER OXFORDIAN (R.aemula–W.spectabilis)**
(BIGGADA – UPPER DINGO CLAYSTONE EQUIVALENT)



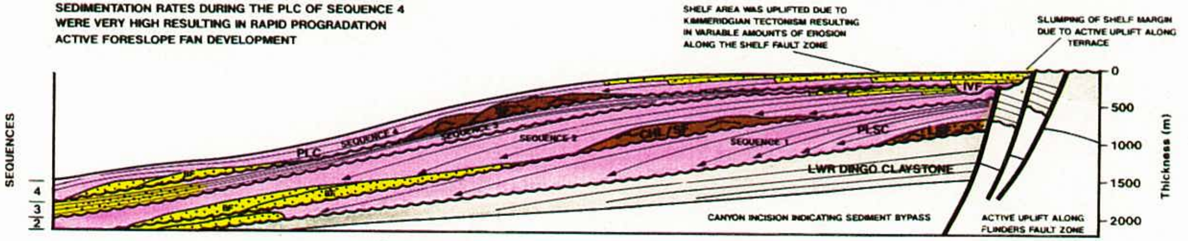
SEQUENCE 3 **MID OXFORDIAN–LOWER KIMMERIDGIAN (W.spectabilis–W.clathrata)**

SEQUENCE 3 IS POORLY DEVELOPED AND IS ONLY RECOGNISED WITHIN THE BASIN DEPOCENTRE



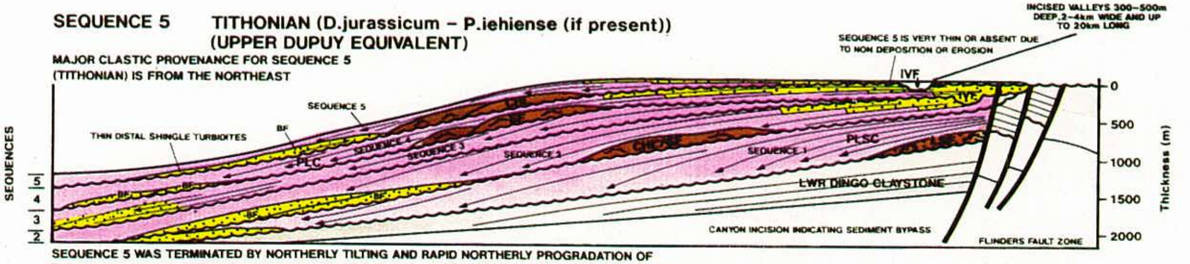
SEQUENCE 4 **LOWER KIMMERIDGIAN – MIDDLE TITHONIAN (Base D.swanense – O.montgomeryi / D.jurassicum**
(DUPUY EQUIVALENT)

SEDIMENTATION RATES DURING THE PLC OF SEQUENCE 4 WERE VERY HIGH RESULTING IN RAPID PROGRADATION ACTIVE FORESLOPE FAN DEVELOPMENT



SEQUENCE 5 **TITHONIAN (D.jurassicum – P.iehiense (if present))**
(UPPER DUPUY EQUIVALENT)

MAJOR CLASTIC PROVENANCE FOR SEQUENCE 5 (TITHONIAN) IS FROM THE NORTHEAST



SEQUENCE 5 WAS TERMINATED BY NORTHERLY TILTING AND RAPID NORTHERLY PROGRADATION OF THE BARROW GROUP DELTAIC SYSTEM FROM THE SOUTH DOWN THE AXIS OF THE BARROW SUB-BASIN. UPLIFT OF THE BARROW ANTICLINE BEGAN AS EARLY AS THE TITHONIAN

LEGEND

(FACIES 5 & 6) LITHOFACIES (SECTION 6.12)

LSF	LOW SLOPE FAN (MASS FLOW)
TRW	TRANSGRESSIVE – REGRESSIVE WEDGE
PLC	PROGRADING LOWSTAND COMPLEX
LST	LOWSTAND SYSTEM TRACT
TST	TRANSGRESSIVE SYSTEM TRACT
TS	TRANSGRESSIVE SURFACE
HST	HIGHSTAND SYSTEM TRACT
CH–L	CHANNEL LEVEE DEPOSITS / SLOPE FAN
MFS	MAXIMUM FLOODING SURFACE
⇇	DOWNLAP
⇉	ONLAP
〰	SEQUENCE BOUNDARY
IVF	INCISED VALLEY FILL
BF	BASIN FLOOR FAN SAND

VERTICAL EXAGERATION 2.5x

SCHEMATIC DEPOSITIONAL HISTORY OF THE CALLOVIAN – TITHONIAN MEGA–SEQUENCE PRESENT WEST OF THE PEEDAMULLAH SHELF

K.WULFF JULY 1990

Figure 73

eastern flanks of the Sub-basin. Tectonism along the Flinders Fault zone and adjacent terrace areas during the Kimmeridgian, Tithonian and Valanginian has resulted in significant erosion of Sequence 2 from uplifted areas. This sequence marks a major period of sediment bypass of the shelf areas and deposition of massive, detached, submarine basin floor fan sands in the subsiding depocentre axes.

Sequence 2 equates to the Biggada and overlying Upper Dingo Claystone Formations of the accepted Carnarvon Basin Formation name nomenclature (Figure 72).

The third depositional sequence recognised in the study area is of Mid Oxfordian - Mid Kimmeridgian age (upper W.spectabilis - base D.swanense). This sequence is marked by a relatively poorly developed lowstand systems tract which grades upward into a well developed transgressive/regressive wedge. No massive basin floor fan sands have been intersected downlapping onto the Mid Oxfordian unconformity. Sequence 3 equates to the Upper Dingo Claystone grading to Lower Dupuy Sandstone in accepted Carnarvon Basin formation name nomenclature.

The fourth depositional sequence recognised is of Mid Kimmeridgian - Mid Tithonian age and lies within the base D.swanense - O.montgomeryi dinoflagellate zones. This sequence is identified in wells in the central Barrow Sub-basin and along the eastern flank. Erosion and/or non-deposition of

Sequence 4 sediments has occurred on uplifted fault blocks along the eastern flank of the Barrow Sub-basin. Sequence 4 equates to the lower to mid Dupuy Formation and is time equivalent to the massive Kimmeridgian prograding clastic influx in the Dampier Sub-basin to the north.

The fifth depositional sequence recognised in the study area is of upper Tithonian age and lies within the P.iehiense (if present) - base D.jurassicum / upper O.montgomeryi dinoflagellate zones. This depositional sequence has been recognised throughout the study area but has been eroded on the eastern flanks of the Barrow Sub-basin due to post Tithonian uplift along the Flinders Fault zone and adjacent Peedamullah Shelf. Sequence 5 is marked by an active period of tectonism and sediment bypass indicated by canyon incision. (Figures 73 & 78). Tithonian uplift of the shelfal areas resulted in major erosion of Kimmeridgian - Callovian sediments from exposed areas. This sequence is incomplete and relatively short-lived due to the inception of Barrow Group deltaic sedimentation from the south associated with regional northerly tilting and uplift of the southern Carnarvon Basin during the earliest Cretaceous (Section 4.1, page 12). Sequence 5 equates to the uppermost Dupuy Formation.

6.4.2.1 Sequence 1, Callovian (W.digitata - R.aemula)

Sequence 1 has been recognised in Georgette-1, Emma-1, Hermite-1, Judy-1 and Dorrigo-1 on the eastern flank of the Barrow Sub-basin (Enclosure V). This sequence of Callovian age has previously been assigned to the Biggada Formation. The results of this study however have discerned two unconformities within the Callovian - Lower Oxfordian interval.

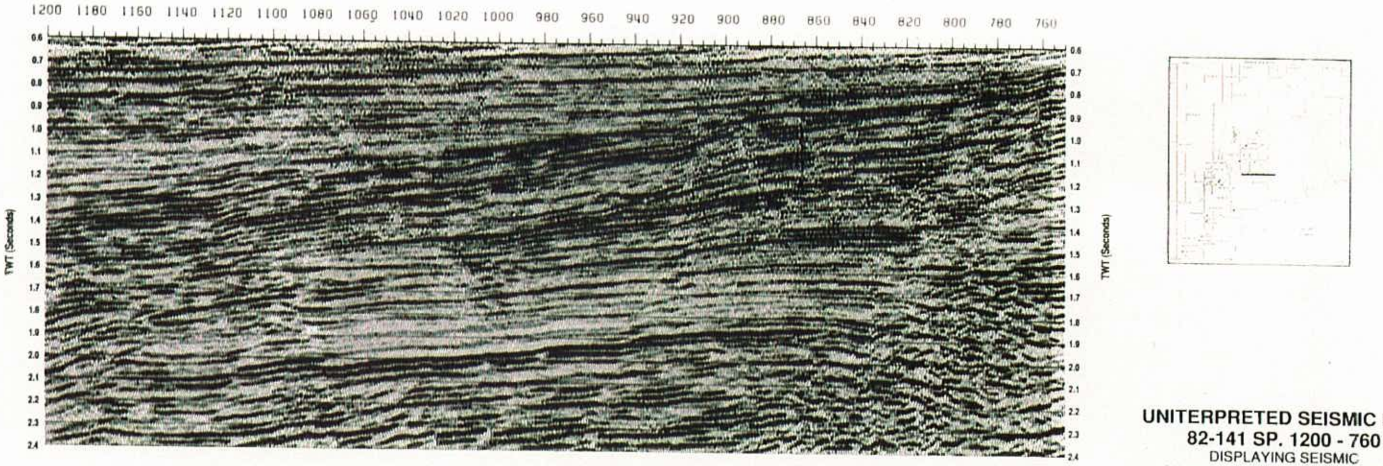
Biggada Sandstone sediments intersected along the eastern basin margin (Emma-1, Georgette-1, Dorrigo-1, Judy-1) are not time or facies equivalent to the younger, previously assigned Biggada sediments intersected within the basin depocentre, (Perentie-1, Barrow Deep-1 and Bambra-2). Biostratigraphy and sequence analysis support the basin margin sediments to be older, Callovian slope fan and outer shelfal facies while the massive sandstones intersected within the central depocentre are younger, Sequence 2, Oxfordian age detached submarine fan deposits overlying the Upper Callovian / Lower Oxfordian unconformity (Enclosures V & VI, Figures 72 & 75).

Figure 73 displays the development of Sequence 1. Post Callovian uplift has resulted in the erosion of Sequence 1 sediments along the Flinders Fault Terrace and Peedamullah Shelf. Only the basinal facies are preserved within the study area west of the Peedamullah Shelf and consist of argillaceous sandstones and siltstones of the lowstand slope fans (Mutti type III channel/levee deposits) and pelagic shales and siltstones of the overlying distal prograding lowstand systems tract and transgressive regressive wedge. The slope fans have been intersected in Emma-1 (Figure 76) and Georgette-1 (Figure 77). Based on core descriptions (Section 6.1, page 36) the slope fans consist of poorly sorted, argillaceous, very fine to medium grained sandstones (Facies 3 and 5, Section 6.1.2, page 36) interbedded with the bioturbated siltstone and shale beds. The argillaceous sandstones have minimal reservoir potential as shown on Figure 32.

The lowstand deposits of Sequence 1 display downlap in the distal portions of the fan and onlap onto the bounding topographical high). The interval reflection characteristics of these fans are poorly defined, low amplitude, discontinuous reflections with an upper high amplitude correlatable stratal surface (Figures 75 & 79). This stratal surface is downlapped by the distal margins of the overlying progradational lowstand wedge. Emma-1 and Georgette-1 differ in that the complex intersected at Emma-1 occurs at the base of an active fault margin while the Georgette-1 fan complex is infilling a topographic low on the margin of the basin. The facies and age of sediments intersected in the two wells are however similar, suggesting a common provenance. The generally fine grained and argillaceous nature of the sediments suggests an outer shelfal, low energy provenance.

Figure 76 displays the Gamma-Sonic wireline log and dipmeter characteristics of the slope fan deposit in Emma-1. This figure indicates that there were two major periods of slope fan deposition with an intervening period of quiescence marked by massive shale and siltstone deposition. The dipmeter discerns the boundary between the slope fan and overlying shale sediments as a rapid transition from high angle (30-40°) dominantly westerly dips to low angle (5-7°) westerly dips. The final overlying slope fan deposition marks a return to high angle (8-25°) dips. The slope fan deposits may have well developed channel/levee systems as

LINE 82-141 SP 1200 to 750

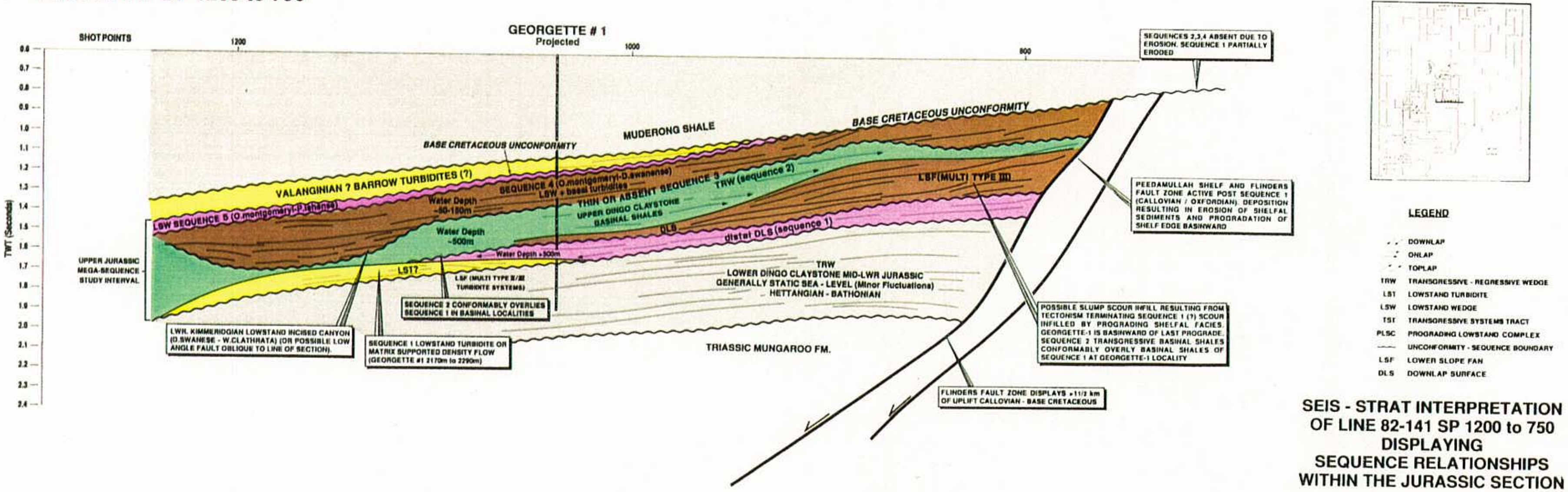


UNITERPRETED SEISMIC LINE
82-141 SP. 1200 - 760
DISPLAYING SEISMIC
CHARACTERISTICS OF JURASSIC /
CRETACEOUS SEDIMENTS ON THE
EASTERN MARGIN OF THE BARROW
SUB - BASIN

K WULFF JULY 1990

Figure 74

LINE 82-141 SP 1200 to 750



SEQUENCES 2,3,4 ABSENT DUE TO EROSION. SEQUENCE 1 PARTIALLY ERODED

PEEDAMULLAH SHELF AND FLINDERS FAULT ZONE ACTIVE POST SEQUENCE 1 (CALLOVIAN / OXFORDIAN). DEPOSITION RESULTING IN EROSION OF SHELFAL SEDIMENTS AND PROGRADATION OF SHELF EDGE BASINWARD

POSSIBLE SLUMP SCOUR INFILL RESULTING FROM TECTONISM TERMINATING SEQUENCE 1 (?) SCOUR INFILLED BY PROGRADING SHELFAL FACIES. GEORGETTE-1 IS BASINWARD OF LAST PROGRADE. SEQUENCE 2 TRANSGRESSIVE BASINAL SHALES CONFORMABLY OVERLY BASINAL SHALES OF SEQUENCE 1 AT GEORGETTE-1 LOCALITY

FLINDERS FAULT ZONE DISPLAYS ≈11/2 km OF UPLIFT CALLOVIAN - BASE CRETACEOUS

SEQUENCE 2 CONFORMABLY OVERLIES SEQUENCE 1 IN BASINAL LOCALITIES

LWR. KIMMERIDGIAN LOWSTAND INCISED CANYON (D.SWANESE - W.CLATHRATA) (OR POSSIBLE LOW ANGLE FAULT OBLIQUE TO LINE OF SECTION).

SEQUENCE 1 LOWSTAND TURBIDITE OR MATRIX SUPPORTED DENSITY FLOW (GEORGETTE #1 2170m to 2290m)

SEIS - STRAT INTERPRETATION
OF LINE 82-141 SP 1200 to 750
DISPLAYING
SEQUENCE RELATIONSHIPS
WITHIN THE JURASSIC SECTION

K WULFF JULY 1990

Figure 75

suggested by constantly opposing dip motifs and presence of shell fragments and coarse grained quartz and lithic grains in core-3 indicative of lag deposit within a channel axis.

Overlying the fan complexes intersected in Georgette-1 and Emma-1 are massive, soft, dispersive olive grey claystones. Drape over the Emma-1 fan complex is recognisable on the dipmeter (Figure 76). No shale drape is discernible overlying the Georgette-1 fan complex (Figure 77) due to the fan infilling a topographic low rather than being a moundform as at Emma-1. These basinal marine shales are the facies equivalent of the pelagic distal prograding lowstand complex and transgressive/regressive wedge. Both the Georgette-1 and Emma-1 slope fans are located distal of the last definable downlap of the westerly prograding lowstand / slope fan complex as shown in Figures 75 & 79 and Enclosures V & VIII.

The Sequence 1 shale and siltstone interval intersected in Dorrigo-1, Judy-1 and Hermite-1 was deposited under low energy, tectonically quiescent conditions prior to the main period of uplift along the Flinders Fault Zone and Peedamullah Shelf in the Upper Callovian. These sediments are seen on seismic to have apparent toplap indicative of truncation. Internal seismic reflection characteristics of the shaly interval include very low angle ($<1^\circ$), low amplitude, discontinuous progrades downlapping onto the lower Callovian sequence boundary (Figure 80). This downlap surface is recognisable immediately adjacent to the Flinders Fault Zone but loses definition into the basinal axis. The low amplitude, low angle nature of the progrades and shale/siltstone lithology suggest deposition as part of

EMMA-1

GAMMA/SONIC/DIPMETER PLOT DISPLAYING LOG CHARACTERISTICS OF THE CALLOVIAN SEQUENCE 1

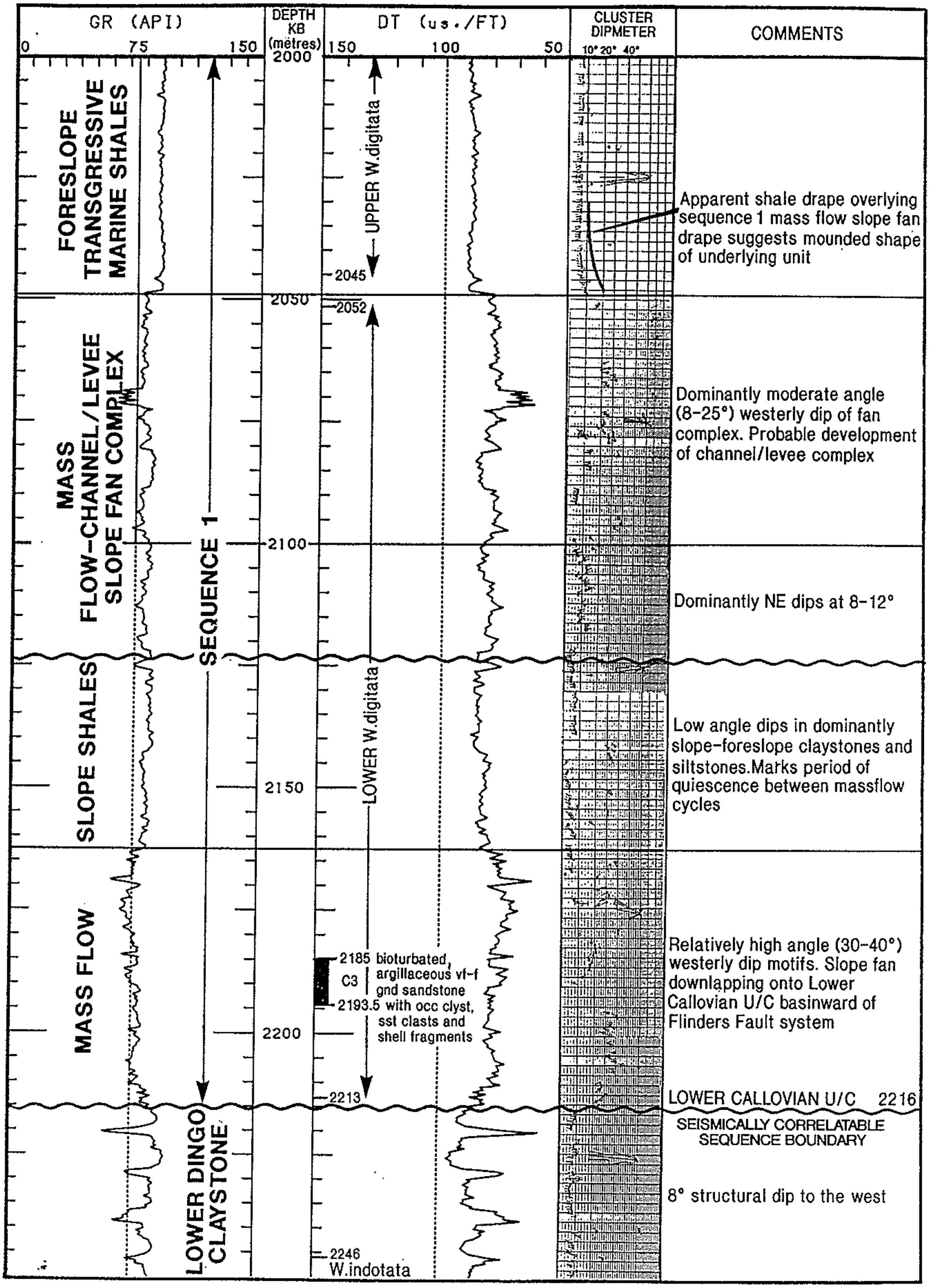


Figure 76

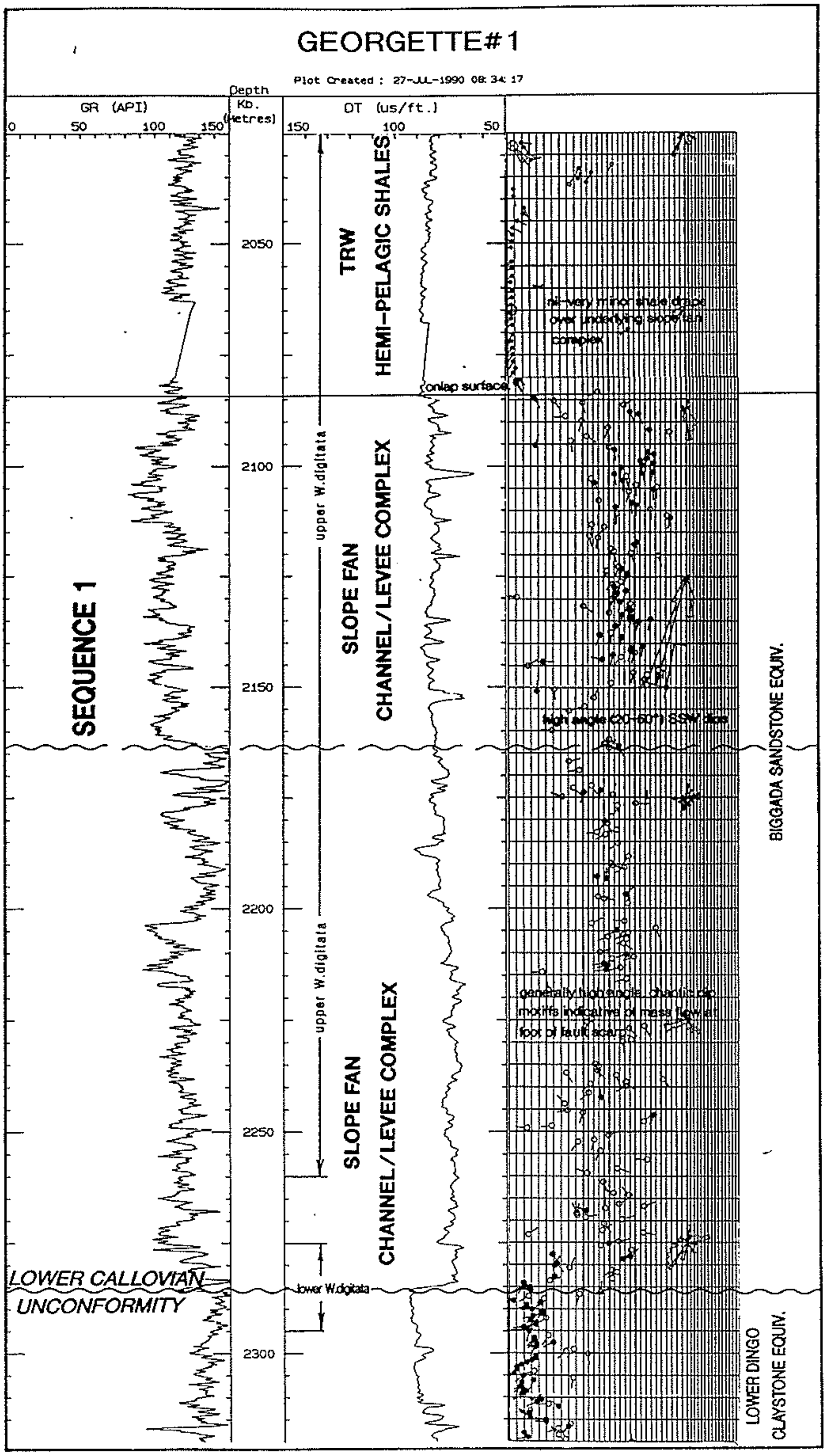
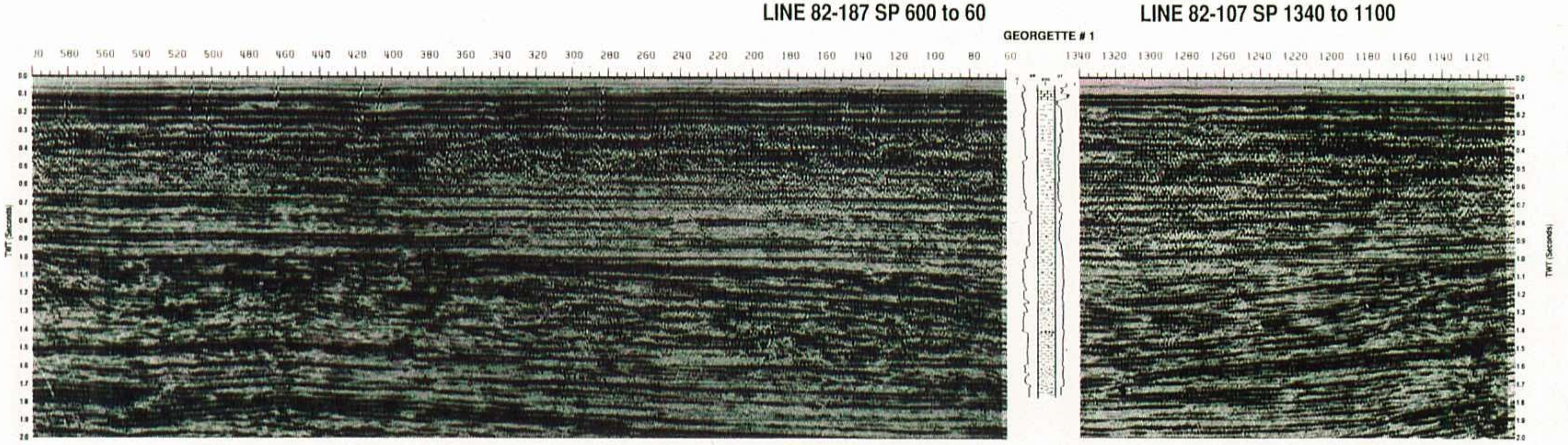


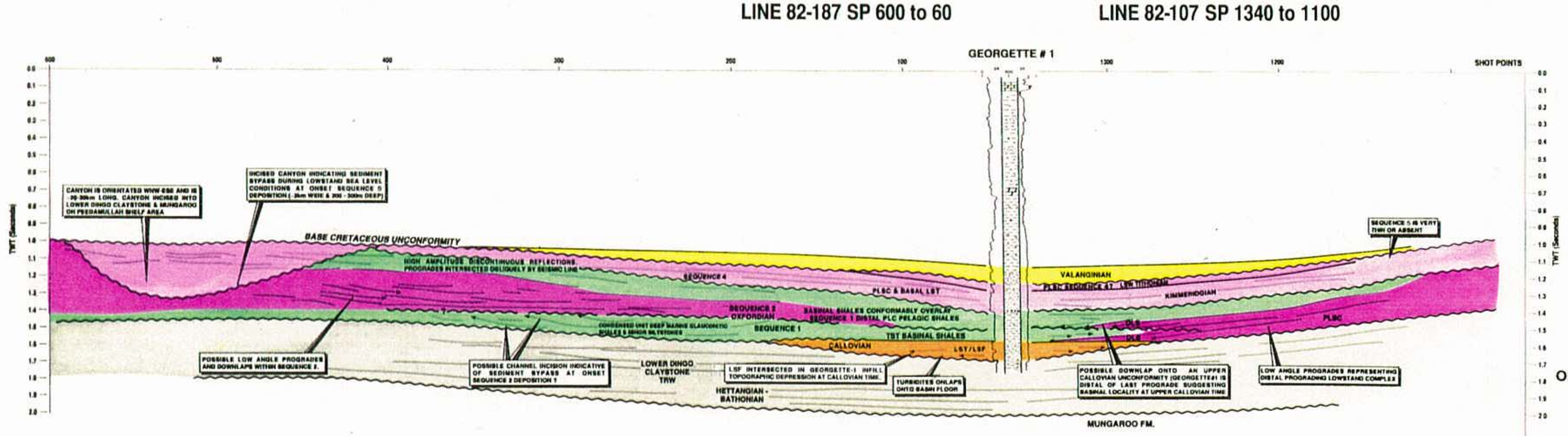
Figure 77. Georgette-1 Gamma/sonic/dipmetre plot displaying characteristics of Callovian Sequence 1



UNITERPRETED SEISMIC LINE
82-107 SP. 600 - 60
82-187 SP. 1340 - 1100
TYING @ GEORGETTE - 1

K WULFF JULY 1990

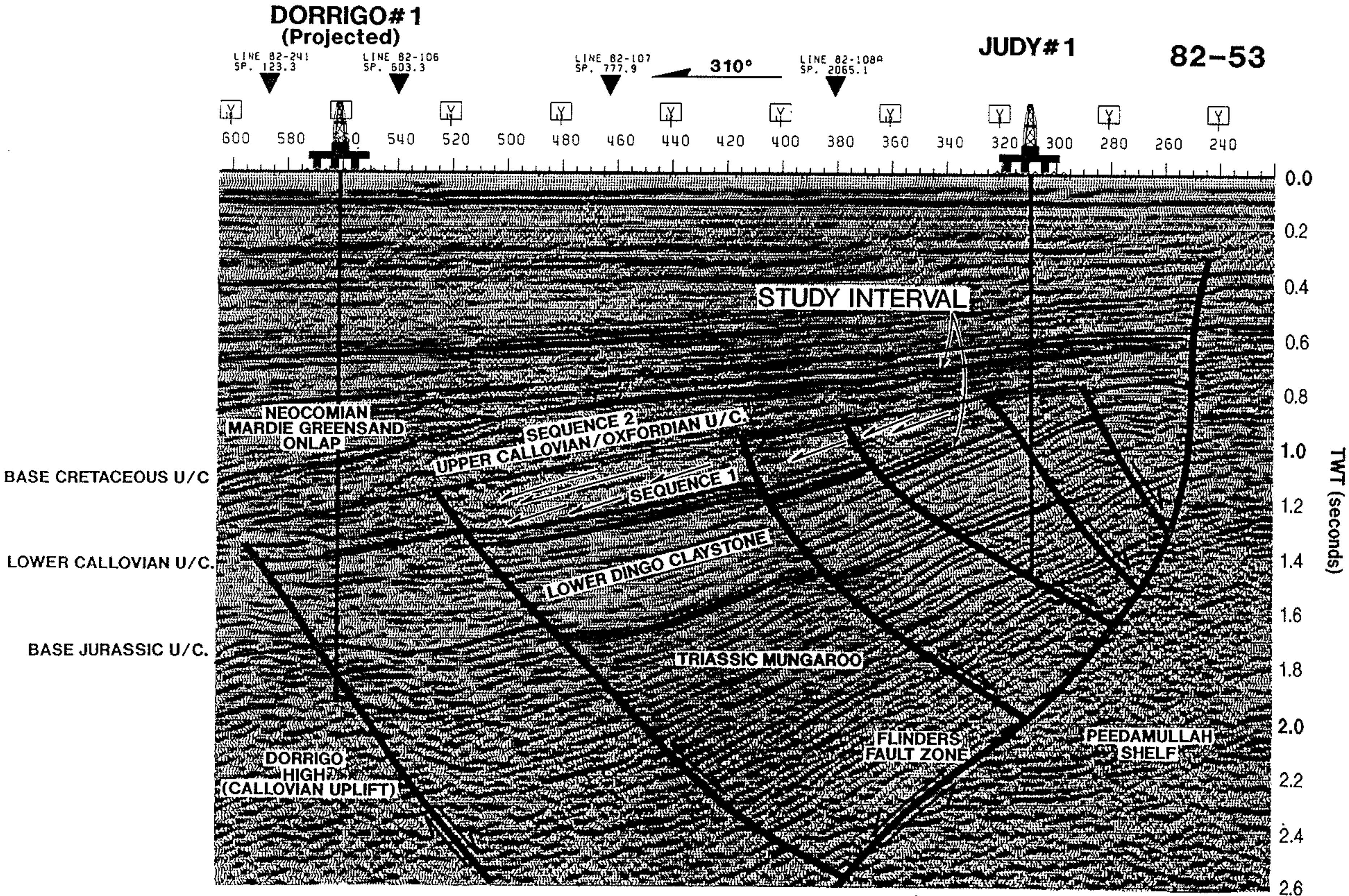
Figure 78



SEISMIC - STRATIGRAPHIC
INTERPRETATION
OF SEISMIC LINES 82-107 SP 600 to 60
&82-187 SP 1340 to 1100
TYING IN AT GEORGETTE #1

K WULFF JULY 1990

Figure 79



Seismic Line 82-53 SP. 600-220 displaying seismic characteristics of Sequences 1&2 on the Flinders Fault Terrace between Judy#1 & Dorrigo#1. The westerly hading Flinders Fault displays major movement during the Callovian/Oxfordian with the development of antithetic faults. The top of the antithetic faults are terminated by the Upper Callovian/Oxfordian Unconformity. The Flinders Fault displays approx 1000m+ displacement associated with the Callovian/Oxfordian Unconformity.

Figure 80

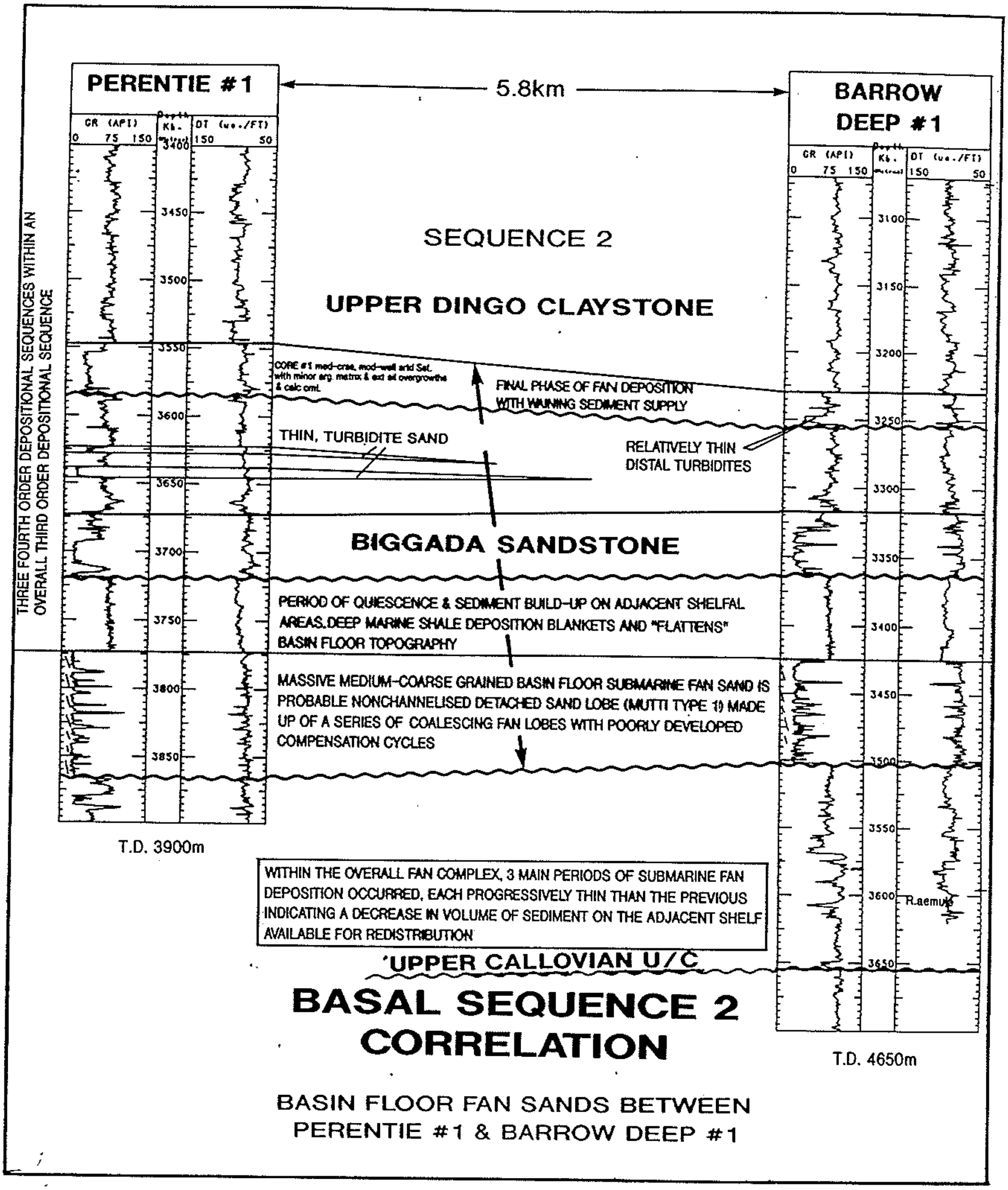
a distal lowstand wedge (Enclosure VIII).

Detached, basin floor fan sands (Mutti Type I) have not been intersected by wells or recognised on seismic in the study area. Massive quartzose sandstones of Bathonian/Lower Callovian age (W.indotata - lower W.digitata) have been intersected in the Dampier Sub-basin to the north of the study area (Legendre Formation). This suggests that a major lowstand period occurred at that time. The potential therefore exists for localised, detached Sequence 1 lowstand fan sands to also occur within the central Barrow Sub-basin at depths exceeding 4000 m downdip of the type III slope fans intersected at Emma-1 and Georgette-1.

In the Emma/Georgette localities the boundary between Sequence 1 and Sequence 2 is difficult to discern on the basis of lithology due to the transgressive/regressive pelagic shales of Sequence 1 are directly overlain by the distal shales and silts of the Sequence 2 slope fan and prograding lowland complex.

6.4.2.2 Sequence 2, Upper Callovian - Mid Oxfordian (R.aemula - W.spectabilis)

Sequence 2 is bounded by regionally correlatable unconformities and is marked by a period of active tectonism. Uplift of the Peedamullah Shelf relative to the Barrow Sub-basin, sediment bypass of the shelfal areas and massive basin floor



CORE #1 med-crse, mod-well srtd Sst. with minor arg. matrix & ext sil overgrowths & calc cmt.

FINAL PHASE OF FAN DEPOSITION WITH WANING SEDIMENT SUPPLY

PERIOD OF QUIESCENCE & SEDIMENT BUILD-UP ON ADJACENT SHELFAL AREAS. DEEP MARINE SHALE DEPOSITION BLANKETS AND "FLATTENS" BASIN FLOOR TOPOGRAPHY

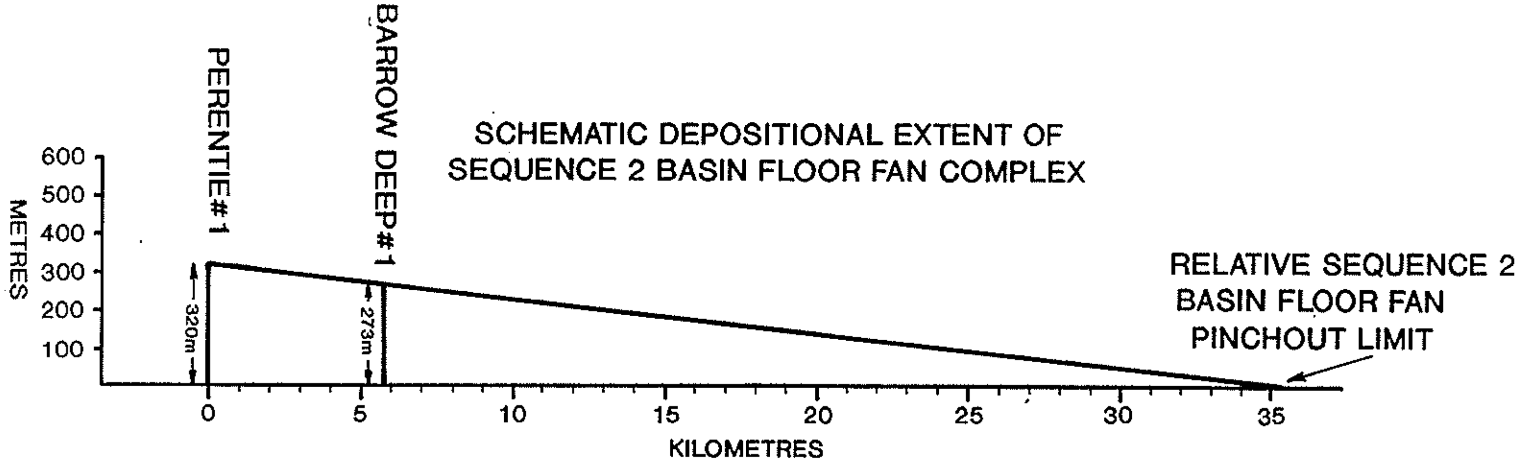
MASSIVE MEDIUM-COARSE GRAINED BASIN FLOOR SUBMARINE FAN SAND IS PROBABLE NONCHANNELISED DETACHED SAND LOBE (MUTTI TYPE 1) MADE UP OF A SERIES OF COALESCING FAN LOBES WITH POORLY DEVELOPED COMPENSATION CYCLES

WITHIN THE OVERALL FAN COMPLEX, 3 MAIN PERIODS OF SUBMARINE FAN DEPOSITION OCCURRED, EACH PROGRESSIVELY THIN THAN THE PREVIOUS INDICATING A DECREASE IN VOLUME OF SEDIMENT ON THE ADJACENT SHELF AVAILABLE FOR REDISTRIBUTION

Figure 81. Sequence 2, Submarine fan correlation between Perentie#1 & Barrow Deep #1, Barrow Island, Central Barrow Sub-basin, NW Shelf Australia

submarine fan deposition into the subsiding basinal areas are characteristics of this period.

Relative sea level fall related to uplift of the basin boundary rift shoulders resulted in rapid fluviatile progradation and consequent canyon incision into the exposed eastern shelf as the depositional system equilibrated with the downward shift in base level. Massive fluvial-deltaic sediments derived from the continent and reworked shelfal sediment built up on the shelf edge. Sediment instability resulted in massive failure and slumping resulting in the deposition of submarine fan sands downlapping the regional Upper Callovian unconformity within the central basin axis. These massive fan sands have been intersected in Barrow Deep-1 (3245-3500 m) and Perentie-1 (3550-3887 m) (Enclosure V and Figures 81-84). These sandstone packages reach a thickness of 350-400+ m with individual sand beds 5-25 m stacked to form sandstone intervals 10-80 m thick. The individual sandstone beds are separated by thin shales (0.3-1 m thick), while the stacked sand units are separated by shales 30-80 m thick (Figure 81). Lithologically these fan sands consist of Bouma A cycle, fine - medium, occasionally coarse grained, moderate - well sorted sandstones with moderate - good reservoir potential (Figure 32). Wireline log characteristics, of this Sequence 2 fan package are 'boxcar' like, typical of basin floor fan deposits. The correlatability and apparent thinning of the sand packages between Barrow Deep-1 and Perentie-1, suggest that the fan lobes intersected by these two wells may extend for greater than 20 km to the north and west of these two wells (Figure 82). Initial sand transportation via turbidity currents and channels from



SCHEMATIC DEPOSITIONAL EXTENT OF SEQUENCE 2 BASIN FLOOR FAN COMPLEX

(**N.B.** THIS IS CONSIDERED A HIGHLY UNRELIABLE TECHNIQUE FOR ESTIMATING THE LIMITS OF BASIN FLOOR FAN DEPOSITION. HOWEVER,GIVEN THE LACK OF WELL CONTROL AND POOR SEISMIC QUALITY IT IS THE ONLY MEANS BY WHICH AN ESTIMATE MAY BE MADE.)

Figure 82. Schematic depositional limit calculation method for Sequence 2 basin floor submarine fan complex.

the point sources may be in the order of 50-100 km. The seismic data in the Barrow Island area was unavailable to this study and seismic resolution of the deep Upper Jurassic reflectors west of the Flinders Fault Zone is poor, making seismic stratigraphy analyses impossible.

The biostratigraphy within this submarine fan package suggests deposition over a period of approximately three million years. The sharpness of the sandstone/shale contacts and relative thickness of the interbedded shale intervals (80-120 m) indicates extensive periods of quiescence between the rapid deposition of submarine fans. This submarine fan complex represents a second order depositional sequence as categorised by Mutti and Normark, 1987 (Section 5.2, page 27). Second order turbidite depositional systems are bodies of turbiditic sediments that occur within depositional sequences that are typically separated by highstand mud facies. Most commonly these systems encompass spans of geologic time measurable in the order of 10^5-10^6 years. Turbidite depositional systems (Mutti, 1985) have the same geologic significance as individual fan lobe deposits, i.e. a package of turbidites that forms during a period of fan activity and is bounded above and below by fine grained facies produced during phases of fan deactivation and/or by submarine unconformities.

Bambra-2, north of Barrow Island, penetrated distal, thinly bedded turbiditic sandstones overlying the Upper Callovian unconformity (Figure 83). These thinly bedded sandstones consist of very fine to fine grained argillaceous sandstones, moderately sorted and siliceously cemented with frequent loose, clear to light

BAMBRA–2

GAMMA/SONIC/DIPMETER PLOT SHOWING WIRELINE LOG CHARACTERISTICS OF BIGGADA SST TIME EQUIVALENT DISTAL TURBIDITES IMMEDIATELY POST UPPER CALLOVIAN UNCONFORMITY

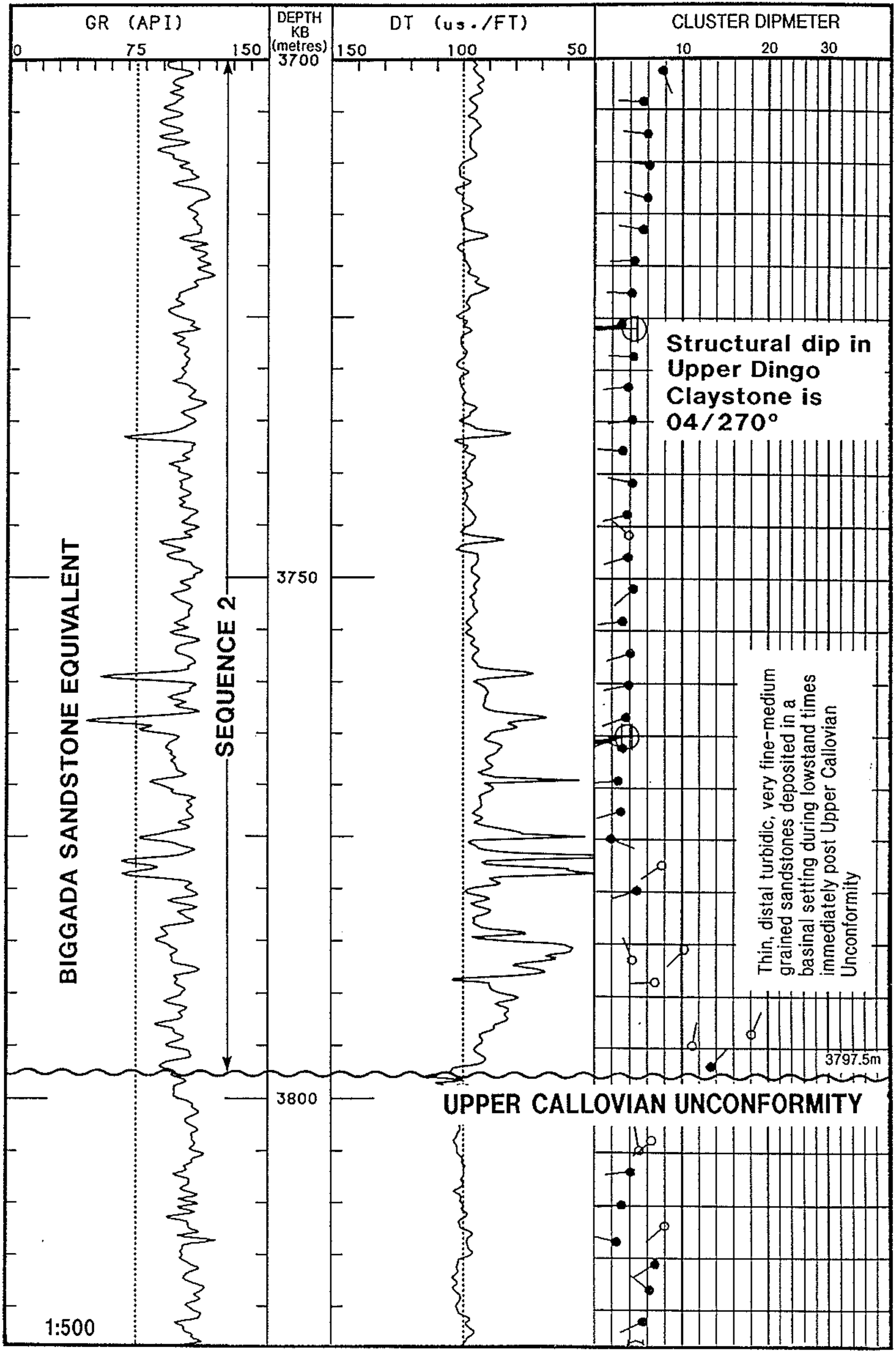
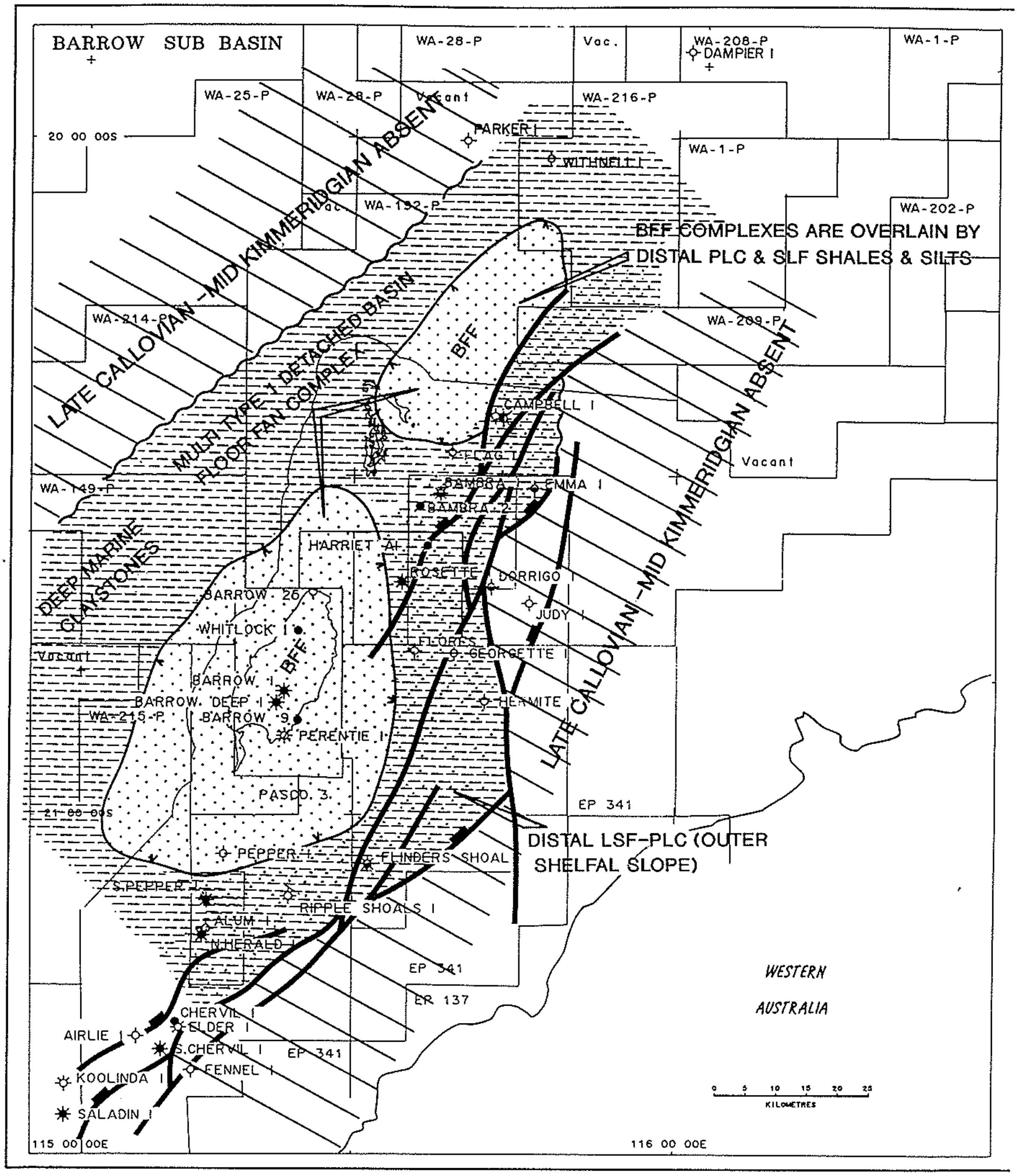


Figure 83

yellow, subrounded quartz grains. Based on cuttings descriptions (Bambra-2, Well Completion Report) the loose quartz sand frequently constitutes 30-90% of the samples and occurs in beds generally less than 1-2 m thick (Figure 83). The nature of these interbedded sands and dispersive clays supports deposition in a distal turbiditic environment within a basin floor setting. Bambra-1 and Flag-1, to the northeast and north-northeast respectively from Bambra-2, did not drill deep enough to intersect the Upper Callovian unconformity. However, a thin (2.4 m) sand at 3640 mRkb in Bambra-1 correlates with the increase in sand content in Bambra-2, immediately overlying the Upper Callovian unconformity. This suggests that Bambra-1 reached a total depth immediately above the Upper Callovian unconformity (~20-30 m) (Enclosure VI). This sand in Bambra-1 is medium - coarse grained, slightly argillaceous with an average log calculated porosity of 18% and RFT calculated permeability of 47-87 md (Bambra-1, Well Completion Report). The facies association between the thinly bedded medium - coarse grained sandstone and overlying deep marine claystone supports deposition in a turbiditic system.

The presence of coarse grained sandstone in Bambra-1, Perentie-1 and Barrow Deep-1 support a lowstand associated with a Type I unconformity allowing fluviatile and continental derived clastics to be redistributed into the basin depocentres via submarine fans and turbidity currents (Figure 84).

Flag-1 terminated above the Upper Callovian/Lower Oxfordian unconformity and displayed no significant development of basin floor turbidites.



N.B.(SEQUENCES 2&3 HAVE BEEN COMBINED DUE TO THE LACK OF REGIONAL RECOGNITION OF SEQUENCE 3)

BFF	BASIN FLOOR FAN COMPLEX
╱	UPPER JURASSIC FAULTS AFFECTING SEDIMENT DISTRIBUTION
⁘	BFF - DETACHED BASIN FLOOR FAN COMPLEX
▤	LSF-PLC LOWER SLOPE FAN OVERLAIN BY DISTAL PROGRADING LOWSTAND COMPLEX
☰	DEEP MARINE CLAYSTONES (MID-UPPER BATHYAL)
▨	SEDIMENTS ABSENT DUE TO EROSION

LATE CALLOVIAN - MID KIMMERIDGIAN

(SEQUENCES 2 & 3)

PALEOGEOGRAPHY

K.WULFF APRIL 1991

Figure 84

Figure 85 displays a composite seismic line tying Bambra-2, Bambra-1 and Flag-1. This line shows the near upper Callovian unconformity reflector generally deepening from Bambra-2 to Flag-1. North northeast of Flag-1 weakly developed onlaps are present suggesting the possible development of a basin floor fan sand complex (Enclosure VII). Depths to the Upper Callovian unconformity in that locality are in the order of 4100-4400 m. Figure 85 and Enclosure V indicate that at Upper Callovian time the Bambra area was a relative high within the basin depocentre. This high was set up by the rotation of a large intrabasinal Upper Callovian fault block. This resulted in the initial lowstand basin floor fan complex infilling the topographic lows and onlapping onto the intrabasinal high. The potential for submarine fan development north of the Bambra area, as well as south, is likely and supported by the apparent onlaps and possible mound forms recognised on seismic (Figure 84 and Enclosures V & VII).

Upper Callovian rifting and uplift of basin margin areas caused the shoreline to prograde to the shelf edge resulting in canyon incision? and deposition of continental and fluviatile sediments into the basin axis as Mutti Type I submarine fans and massflow deposits.

Overlying these lowstand turbidite systems in the central axial areas are generally massive, claystone and siltstone intervals displaying regionally continuous, moderate amplitude, subparallel seismic reflections which onlap on the basin margins. Uplift along the eastern Peedamullah shelfal areas has resulted in significant erosion of Sequence 2 (Figure 86). The palaeoshelf break has not

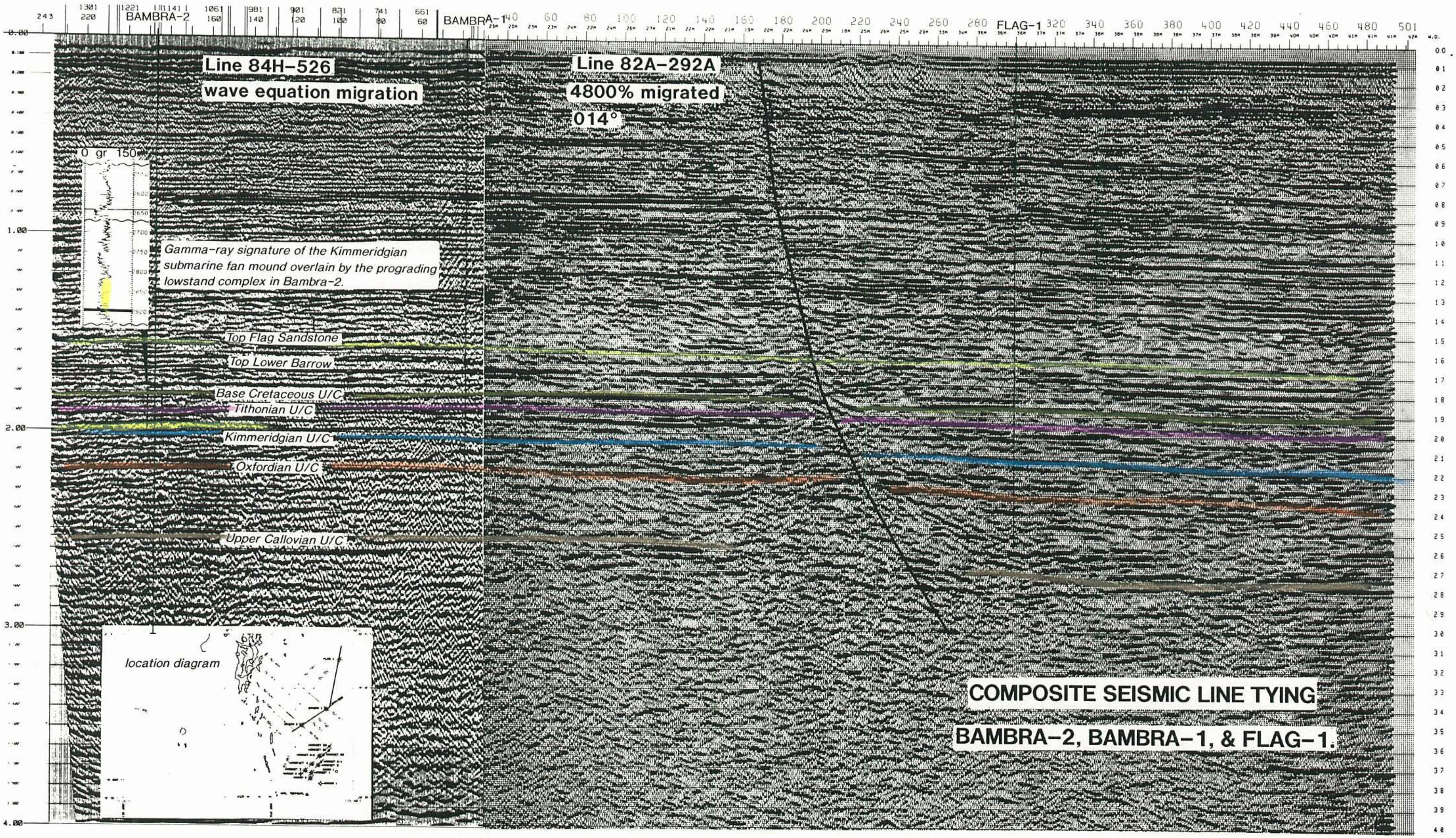
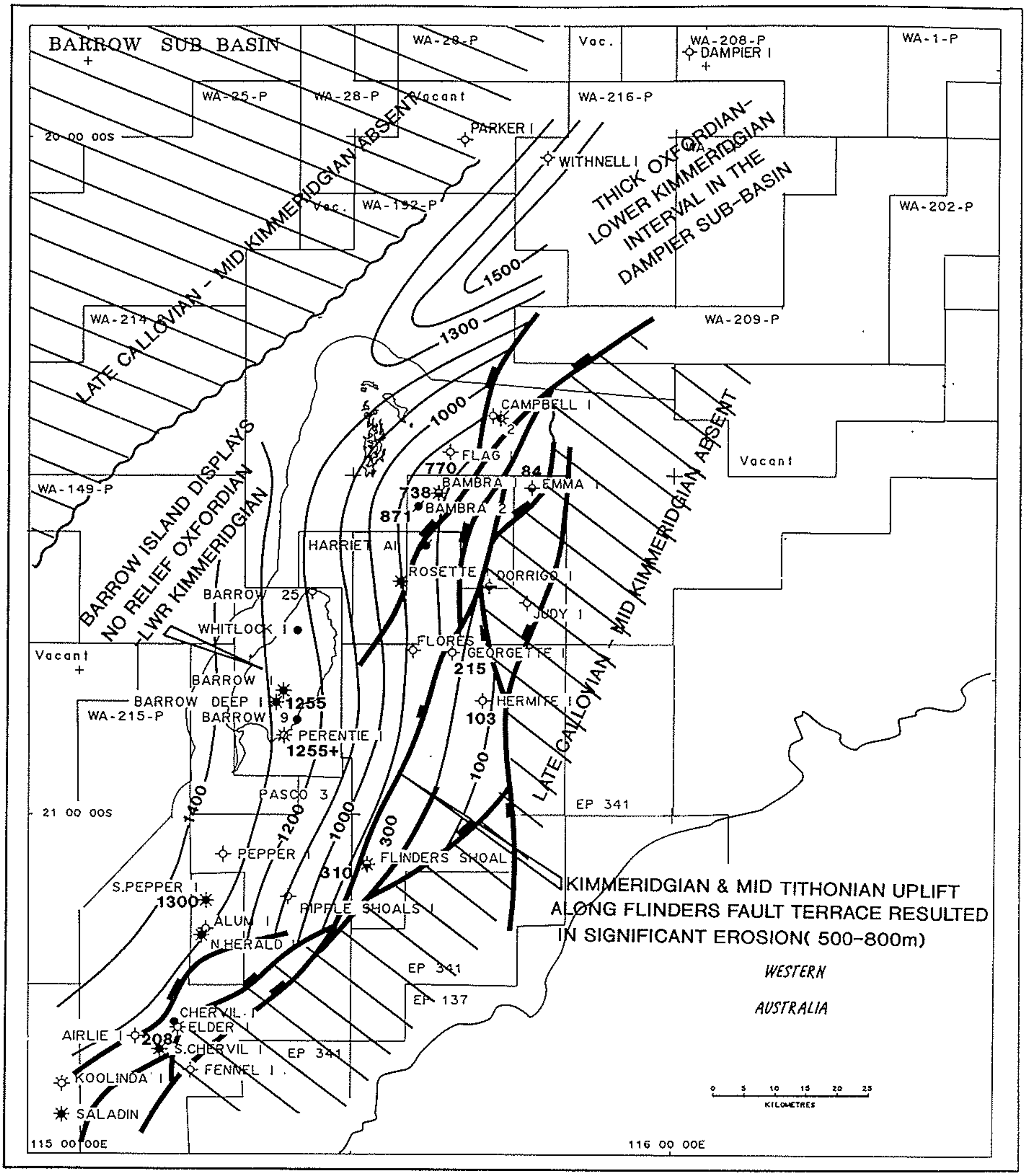


Figure 85. Seismic lines 84H-526 & 82A-292 displaying Bambra#2-Bambra#1-Flag#1 tie. Note the localised Kimmeridgian sand mound @ Bambra#2 not extending to Bambra#1.



(SEQUENCE 3 HAS BEEN INCORPORATED WITH SEQUENCE 2 DUE TO THE LACK OF RESOLUTION OF SEQUENCE 3 ALONG AND ADJACENT TO FLINDERS FAULT ZONE)

(**N.B.** ISOPACH WAS GENERATED FROM WELL CONTROL AND REGIONAL SEISMIC MAPPING.)

LATE CALLOVIAN - MID KIMMERIDGIAN

(SEQUENCES 2 & 3)

ISOPACH (C.I. 100m).

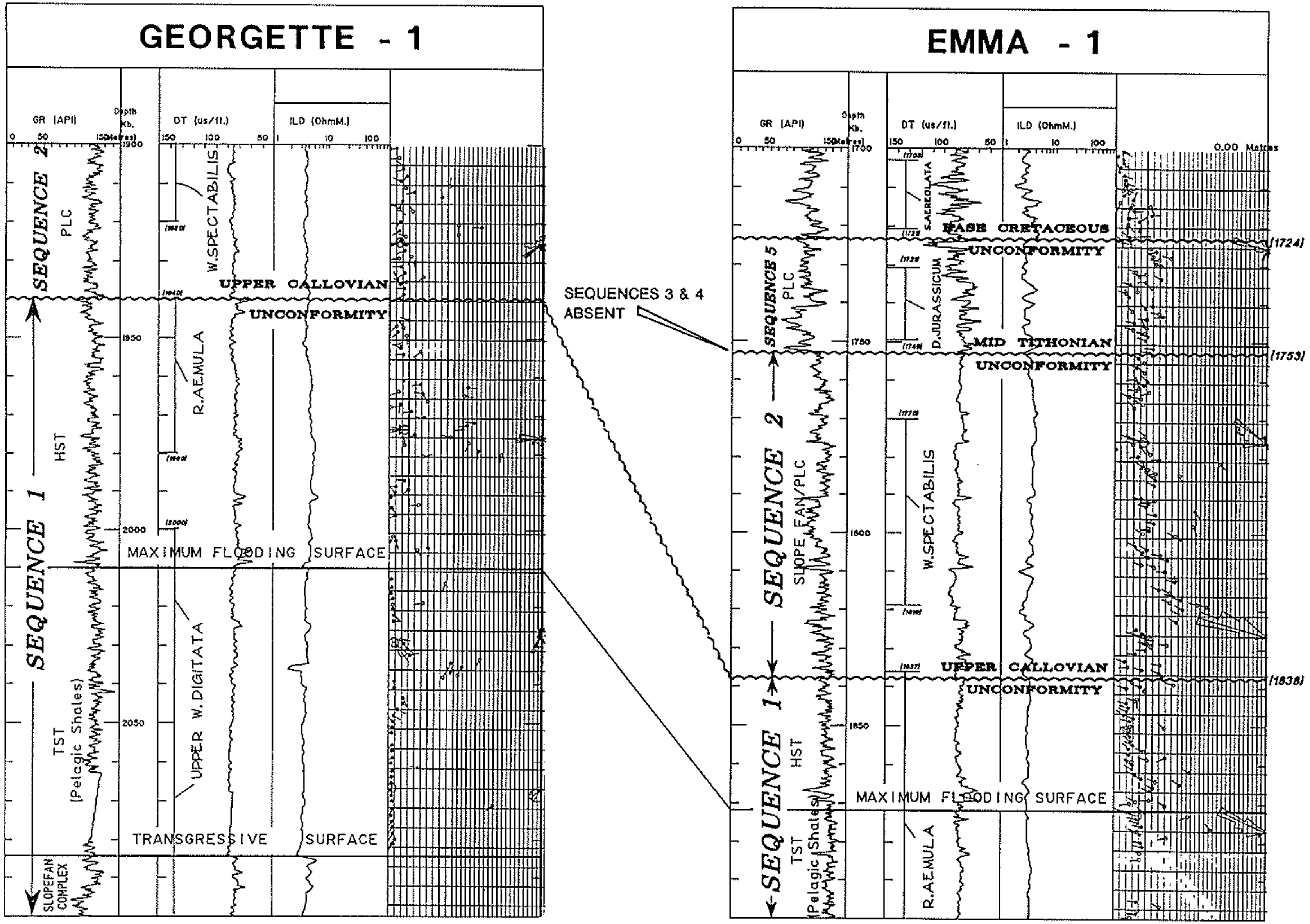
K.WULFF

Figure 86

been recognised in the study area and only the distal prograding lowstand complex and pelagic shales of the overlying highstand are likely present. The Sequence 2 and 3 isopach (Figure 86) clearly defines the Bambra High trend with rapid thickening into the western depocentre. Thicknesses in excess of 1500 m exist in the western study area.

Based on lithology, little obvious evidence exists for the presence of an unconformity separating Sequences 1 and 2 in the Georgette-1 and Emma-1 areas. However, as shown on Figure 75, downlap onto an unconformity surface immediately east of the Georgette-1 well locality is apparent. Consequently, at Georgette-1 the pelagic basinal marine shales of the Sequence 1 transgressive/regressive wedge are overlain by pelagic shales and silts of the distal prograding lowstand complex of Sequence 2 (Figures 75 & 87). At the Emma-1 locality the unconformity between Sequence 1 and 2 is clearly discernible on the dipmeter (Figure 87) which displays a change in structural dip across the unconformity. At Emma-1 the pelagic shales of the transgressive/regressive wedge are overlain by distal slope fan/prograding lowstand complex of Sequence 2.

Depositional Sequence 2 is incomplete in that no well developed highstand shoreface progradation is recognised. This is related to post depositional uplift of the Flinders Fault Zone and Peedamullah Shelf during Kimmeridgian, Tithonian and Lower Neocomian times which resulted in erosion of the shelfal - shoreface highstand and transgressive system tract sediments. Termination of Sequence 2



GAMMA / SONIC / RESISTIVITY / DIPMETER PLOTS

Displaying Sequence boundaries between Sequences 1&2, probable systems tract boundaries and biostratigraphic subdivision.

Figure 87

deposition by the development of a lowstand during Upper Oxfordian prior to significant progradation of the highstand systems tract resulted in a limited supply of coarse clastics available for redistribution into the basin by the ensuing lowstand. Long distance channel incision into the exposed shelf was also required to transport alluvial and fluviatile sediments to the shelf break. The result is that no massive basin floor fan sands are prognosed to have developed during the lowstand conditions of Sequence 3.

6.4.2.3 Sequence 3, Mid Oxfordian - Mid Kimmeridgian (W.spectabilis - Base D.swanense)

Sequence 3 is poorly developed and only recognised in wells drilled within the central Barrow Sub-basin. Thin, correlatable (10-25 m) distal turbiditic facies intersected immediately above the Oxfordian unconformity are present in Bambra-2, Bambra-1 and Flag-1 (Enclosures VI & VII). These units consist of silty, very fine to fine grained argillaceous sandstones with occasional loose, floating, fine to medium subrounded quartz grains. This facies has very poor porosity, negligible permeability. Overlying these thin, poorly developed sandstone facies are massive marine claystones and siltstones with occasional, thin argillaceous very fine grained sandstone stringers. The upper claystone interval has weakly developed coarsening upward cycles which display abrupt upper contacts (Enclosure V). These abrupt contacts represent flooding surfaces making the top of parasequences within an overlying transgressive/regressive wedge.

As shown on Figure 73, Sequence 3 has been interpreted to have established the shelf edge position basinward of that present during Sequence 2 deposition. Combined with the dominantly shale prone facies of the intervals intersected by the central Barrow Sub-basin wells suggest that Sequence 3 is either a shelf margin wedge system tract or a prograding lowstand complex associated with a relatively low rate of sediment supply.

In accepted Carnarvon Basin nomenclature, Sequence 3 equates to the Dingo Claystone (Figure 72).

6.4.2.4 Sequence 4, Mid-Kimmeridgian - Mid-Tithonian (D.swanense - O.montgomeryi/D.jurassicum)

The onset of Sequence 4 deposition is marked by a regionally correlatable Type I unconformity associated with rifting, indicating massive uplift (>1 km in parts) of the Peedamullah Shelf and Flinders Fault Terrace (Figure 73). This tectonic upheaval resulted in canyon incision and sediment bypass of the uplifted shelfal areas and establishment of the shoreface west of that immediately prior to the period of tectonic uplift. The fall of sea level below the shelf edge allowed the development of fluviatile and deltaic systems to rapidly prograde across and incise into the exposed shelf margin. This Kimmeridgian unconformity is correlatable throughout the study area on seismic and wireline logs and is defined as base D. Swanense dinoflagellate zone. In wells within the basin depocentre, Perentie-1, Bambra-1, Bambra-2, Barrow Deep-1 and Flag-1, this unconformity is marked by a regionally correlatable upward coarsening lowstand system tract with the development of isolated basin floor fan sands in the basal interval. These sands have been intersected by Bambra-2 (Figure 85) and are overlain by the prograding lowstand complex which is a rapid coarsening upward interval precluding the development of an adequate sealing shale.

Figures 72 & 73 display the facies association and sequence development of Sequence 4 in relation to Sequences 1, 2 and 3. The interpretation of seismic lines 82-141 (Figure 75) and 82-108/82-187 (Figure 79) display the seismic character of the sequence and facies associations.

Sequence 4 is the most fully developed depositional sequence in the study area; i.e. lowstand, transgressive and highstand systems tracts can all be identified. No well has penetrated massive detached quartzose submarine fan sands similar to those intersected in Sequence 2 by Barrow Deep-1 and Perentie-1. However, smaller basin floor mounds are identified on seismic and have been intersected in Bambra-2 and Bambra-1.

These mounds consist of homogenous very fine - fine grained sandstones which display extensive quartz overgrowths and abundant sideritic cementation. Rapid deposition and dewatering structures (dish structures, flame structures and rip up shale clasts) are present within these sands, e.g. Bambra-1, Core 2, 2713-2730 m. The concentration of these small clasts near the top of the depositional cycles suggests long distance turbidity flow allowing time for the buoyancy effect of the less dense shale clasts to rise to the surface of the fluidised flow regime. This is shown on Figure 36. Episodic deposition is supported by the presence of siderite cemented layers and thin bioturbated subfissile claystone layers suggesting quiescent periods between times of rapid turbiditic deposition.

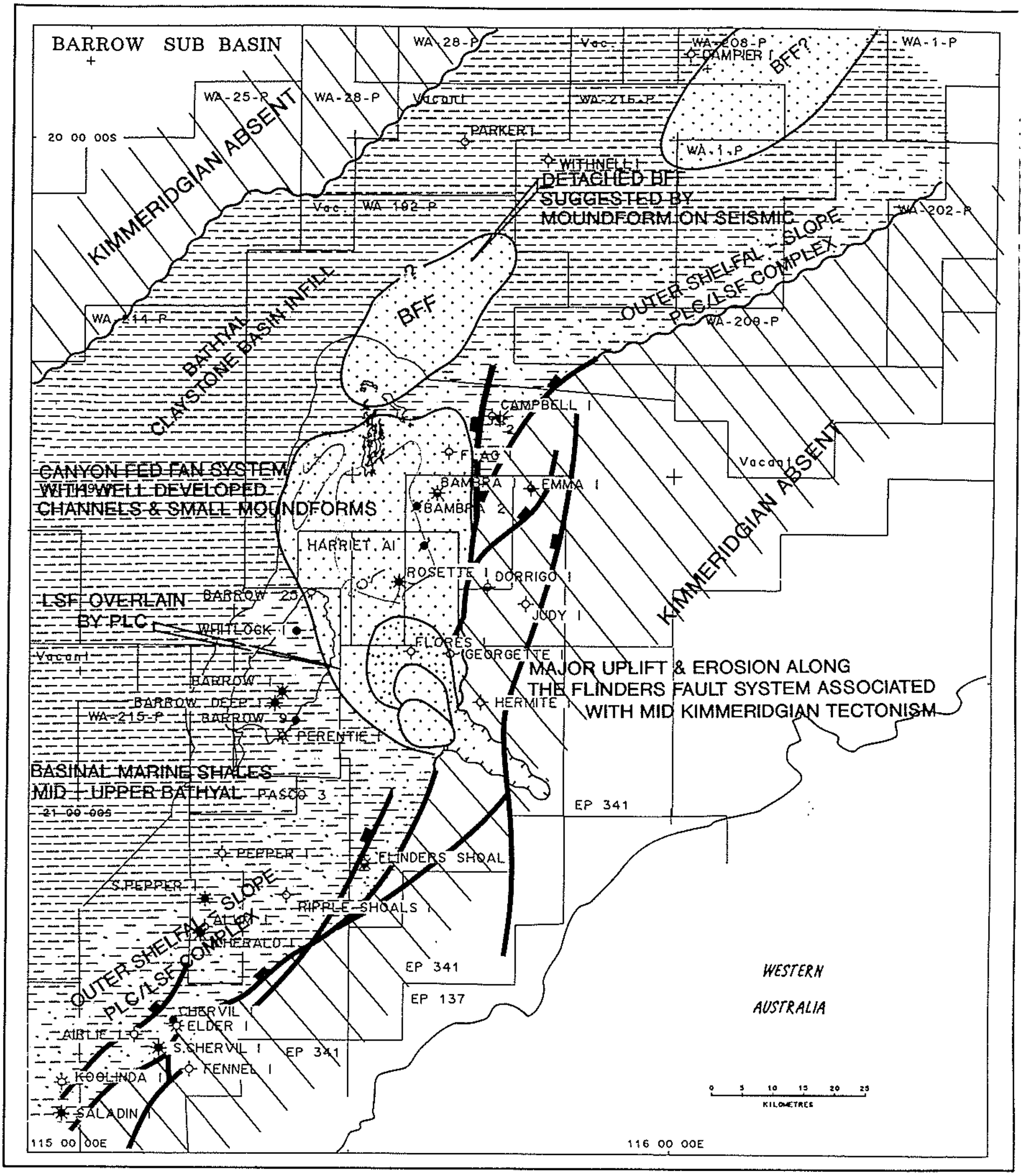
Overlying these fan sands are coarsening upward shaly siltstone and very fine grained sandstone intervals marking the development of a prograding lowstand or slope fan complex. The absence of thick pelagic shales overlying the mound forms precludes the development of top seal in the Bambra/Flag locality. The seismic expression of this interval is shown on Figure 85 which clearly displays the restricted lateral extent of the individual mound forms.

Based on the facies associations between the central basin wells (Flag-1, Bambra-1 and Bambra-2), it is apparent that the prograding lowstand complex was from northeast to southwest in the northern half of the study area. This is evident by the relative increase in coarser grained clastics within a correlatable parasequence within the lowstand systems tract from Bambra-2 through Bambra-1 and Flag-1 (Enclosure V). This depositional package in Flag-1 consists of basal, deep marine claystones grading upward into very fine to fine grained argillaceous sandstones with interbedded thin (<2.5 m) medium - occasionally coarse grained sandstones. This overall coarsening upward cycle represents progradational (northeast to southwest) submarine fan deposition. Depositional influence was also being experienced during this time from the southeast associated with the channelling effect of sediments related to the onset of growth of the Barrow

Anticline at this time (Figures 88 & 89).

Four coarsening upward cycles representing four separate periods of fan progradation are recognised in the northern study area. Massive coarser grained, excellent reservoir quality sandstones of the same age are present in the wells approximately 60 km northeast within the Dampier Sub-basin. Campbell-1 and 2 intersected massive blocky fine grained sandstone packages of Kimmeridgian age that display apparent pinchout between the Flag-1 and Campbell well locations. This depositional thinning is shown on Figure 90 which is seismic line 83-429 oriented NNE-SSW and tying the Campbell-1 well location. This thinning of the Tithonian section in the Campbell area was related to active late Kimmeridgian / early Tithonian tectonism which resulted in significant uplift and rotation of fault blocks. The Campbell area lies on the back of one of these rotated fault blocks as shown on Figure 90 and Enclosure XI. Based on sidewall core descriptions from this interval in Campbell-2 (Campbell-2, Basic Well Data, Volume 1), this sandstone is dominantly very fine to fine grained, moderately argillaceous with trace glauconite and calcareously cemented. One sample, at 2587 m, within the central massive sandstone package, contained a poorly sorted, fine to very coarse grained sandstone with minor argillaceous matrix and abundant calcareous cement.

Depositional systems in the southern half of the study area are less well defined due to the lack of well data drilling deep enough to intersect the sequence and lack of good quality seismic data to reliably evaluate the seismic stratigraphy.



▨ BFF PROXIMAL BASIN FLOOR FAN SANDS @ MOUTH OF INCISED CANYON

▨ DETACHED BASIN FLOOR FAN COMPLEXES

▤ BASINAL MARINE SHALES MID - UPPER BATHYAL

▤ OUTER SHELFAL - SLOPE PLC/LSF COMPLEX

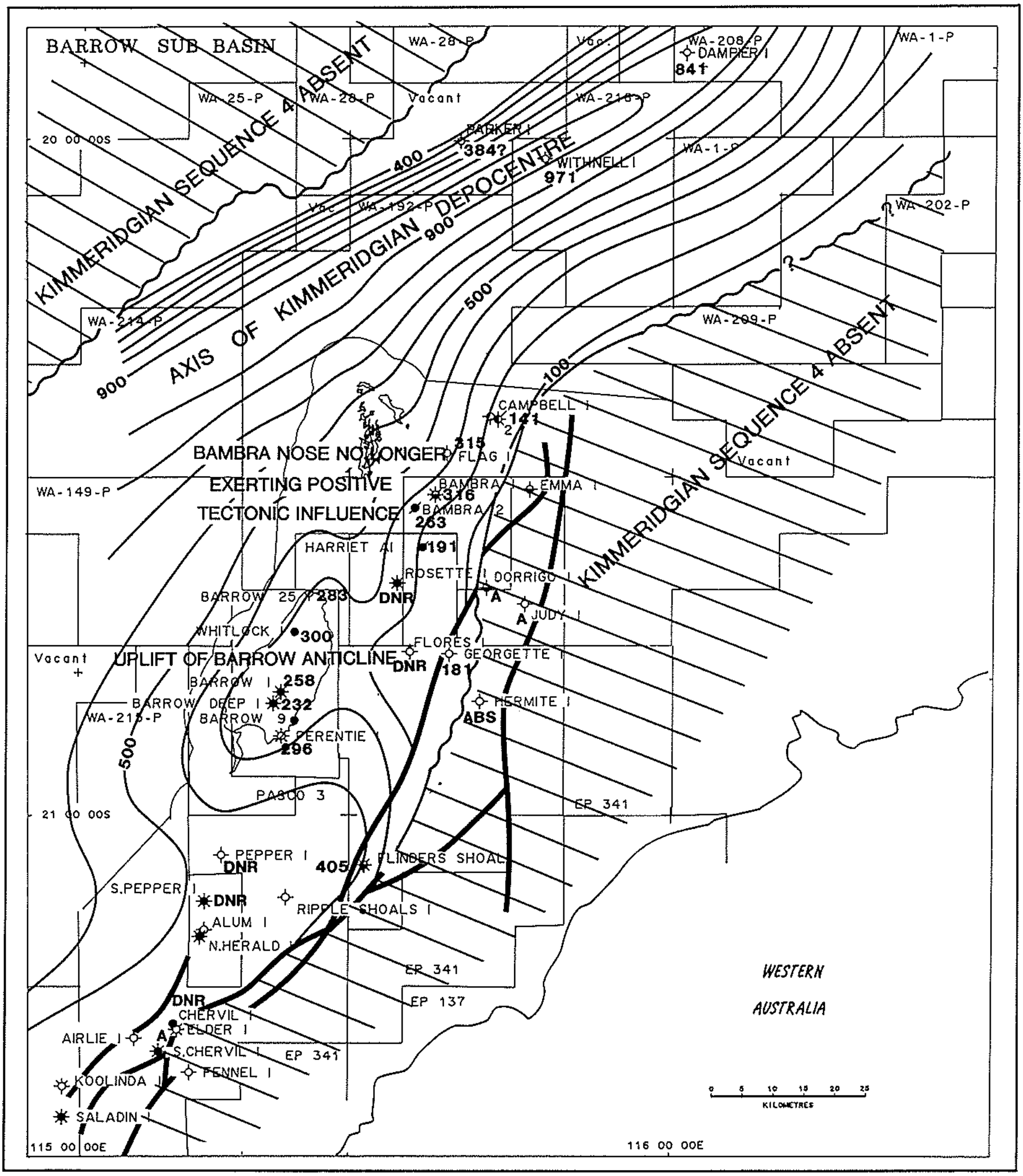
MID KIMMERIDGIAN - MID TITHONIAN

(SEQUENCE 4)

PALEOGEOGRAPHY

K.WULFF APRIL 1991

Figure 88



(**N.B.** ISOPACH WAS GENERATED FROM WELL CONTROL AND REGIONAL SEISMIC MAPPING.)

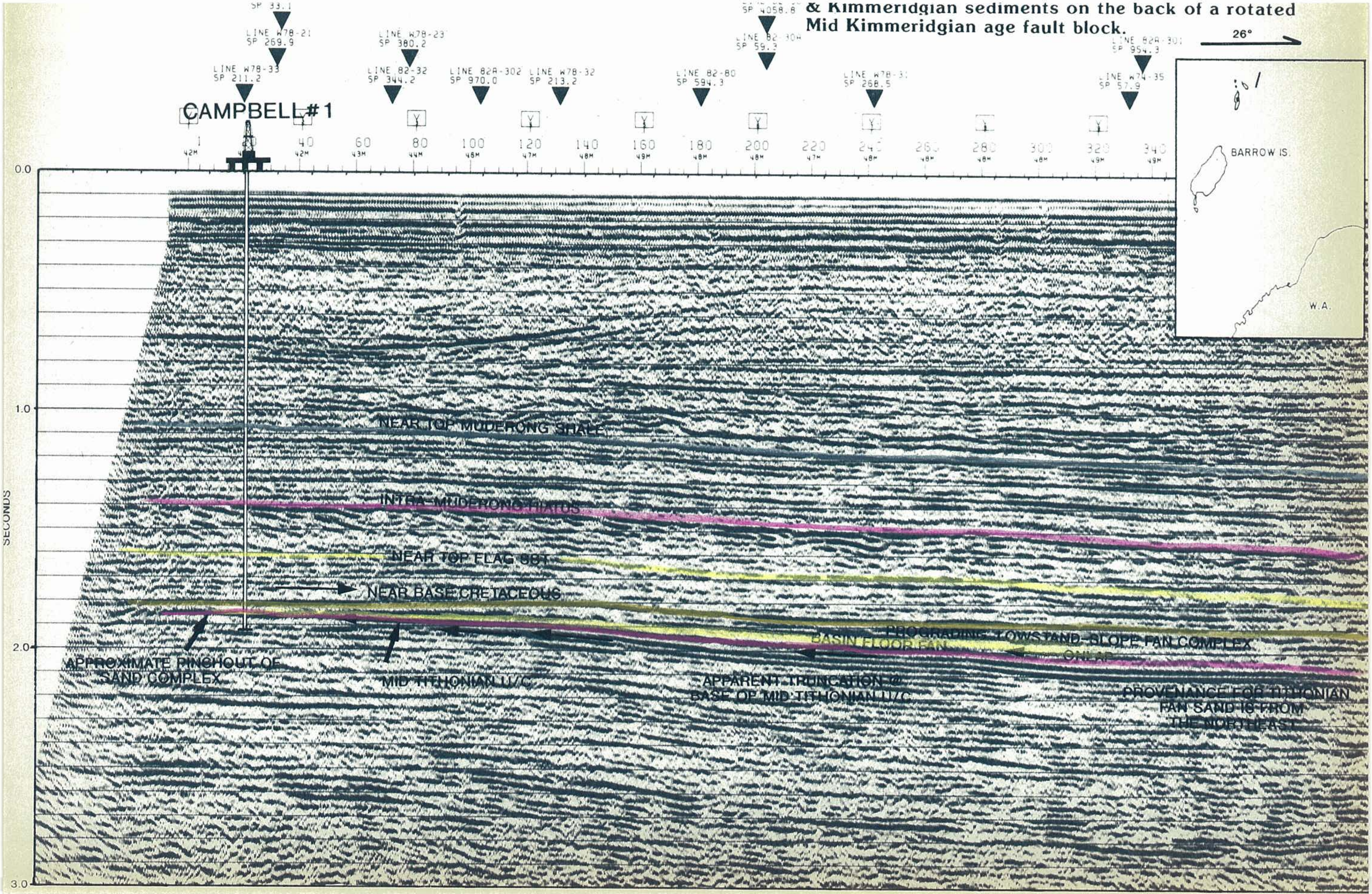
MID KIMMERIDGIAN – MID TITHONIAN

(SEQUENCE 4)

ISOPACH (C.I.–100m)

K.WULFF

Figure 89



& Kimmeridgian sediments on the back of a rotated Mid Kimmeridgian age fault block.

Well intersections in the south, Koolinda-1, Alum-1 and Flinders Shoal-1 (Enclosure III) contain no reservoir quality sandstones and consist typically of very argillaceous, bioturbated very fine to fine grained sandstone deposited in an outer shelfal - slope environment. Weakly developed coarsening upward cycles are apparent in some of these wells in the area (e.g. Koolinda-1) suggesting shelfal progradation. Isostatic adjustment of fault blocks in the southern area on the flanks of the depocentre have frequently resulted in erosion and/or non deposition of Sequence 4 causing difficulty in correlating depositional Sequence 4 between the sparse well control.

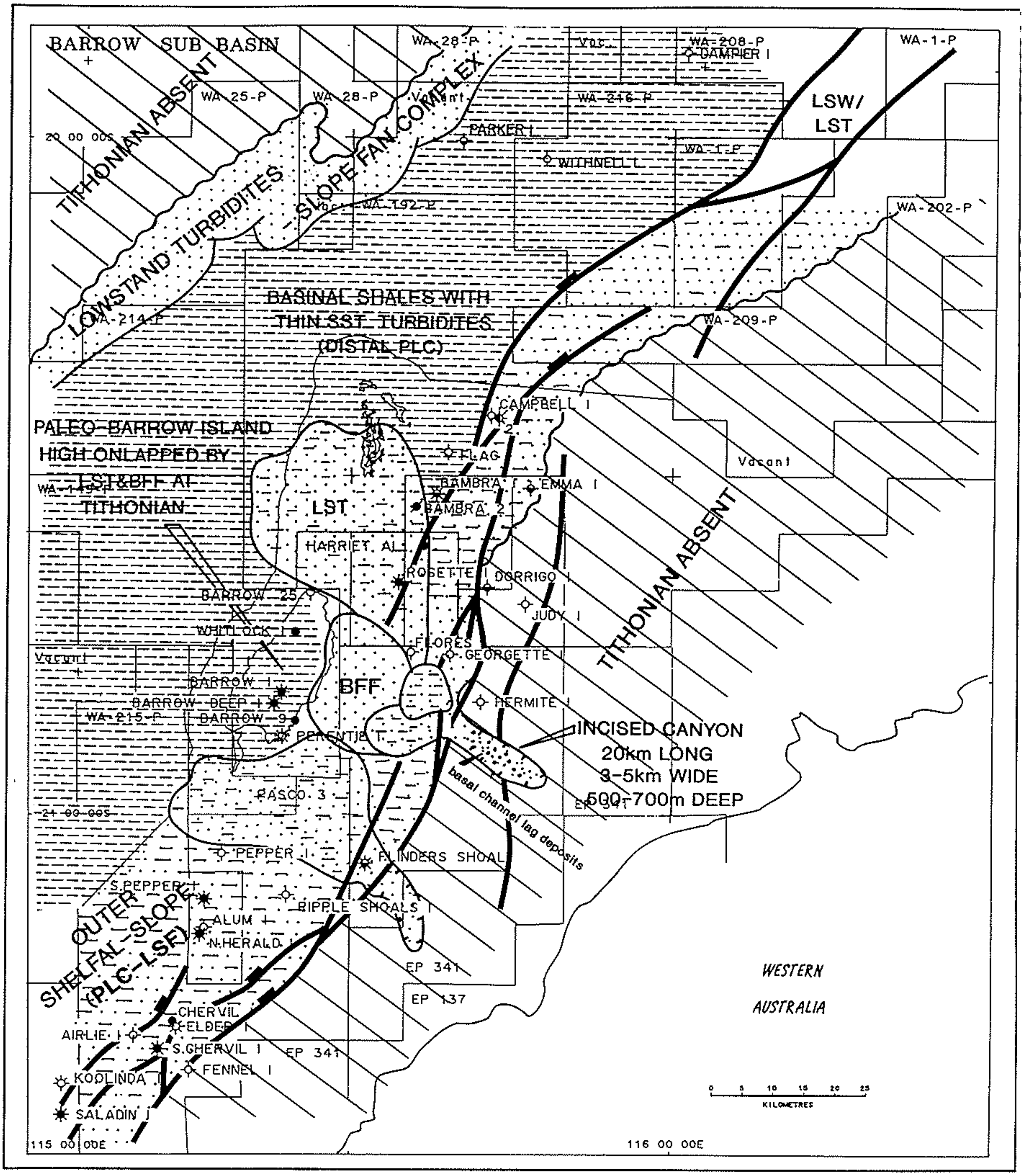
Only Georgette-1 penetrated depositional Sequence 4 in the central eastern study area. At the other well locations Sequence 4 was either absent due to non deposition and/or erosion. Uplift of the Peedamullah Shelf and Flinders Fault Terrace during the Lower Tithonian and possibly Valanginian times probably resulted in significant erosion of Sequence 4 from uplifted areas. At Georgette-1 however, the base of the sequence is characterised by a 10 m thick mass flow unit consisting of poorly sorted, matrix supported very coarse to fine grained sandstone. The 10 m thick unit can be subdivided into two mass flow pulses separated by a thin (<2 m) shaly siltstone interval. Overlying and downlapping onto the basal mass flow unit is a progradational complex which appears to infill a relative topographic low between the Hermite-1 and Judy-1 well locations. This progradational unit is characterised on seismic by high amplitude, subparallel, moderately continuous reflections which display toplap at the upper boundary, indicative of truncation and erosion (Figure 75). Lithologically this unit consists dominantly of very fine to fine grained argillaceous sandstones with thin interbeds of olive grey claystone grading to siltstone. On log character the system contains small scale coarsening up cycles (5-15 m) with frequent thin (<2 m) coarse to very coarse, well rounded, moderately sorted sandstone beds. This 160 m thick unit in Georgette-1 most likely represents a channel/levee slope fan - progradational lowstand complex associated with high sedimentation rates. The shoreface and shelfal sediments of Sequence 4 have been eroded.

Sequence 4 deposition was terminated during the Lower - Mid Tithonian by active tectonism and uplift resulting in a relative fall in sea level.

6.4.2.5 Sequence 5, Mid Tithonian - Base Cretaceous (D.jurassicum - P.iehiense)

Sequence 5 is poorly developed in the majority of the study area and is recognised as an incomplete depositional sequence consisting of basinal lowstand turbidites in the central study area and overlying progradational lowstand complexes on the flanks of the depocentre. The wells drilled along the Flinders Fault Zone and Peedamullah Shelf area have intersected thin or absent Sequence 5 due to post Tithonian uplift of the basin margin areas or existing topographic highs at the time of Sequence 5 deposition. Maximum recognised thickness of Sequence 5 is 135 m identified in Bambra-2 (2530-2665 m) (Enclosure VI). The development of highstand and lowstand systems tracts are not recognised in Sequence 5 within the study area (Figures 71 & 72). Haq et al recognised a rapid succession of global lowstand periods during the Portlandian (Upper Tithonian) (Figure 71) which did not allow the significant development of highstand and transgressive systems tracts. The Tithonian unconformity is marked by a period of active tectonism causing significant uplift of the Peedamullah Shelf area and rotation of fault blocks on the shelf margin. This is clearly shown on Figure 86 displaying the thinning of the Tithonian sequence on the back of a rotated fault block in the Campbell area. The result of the massive uplift of the Peedamullah Shelf was major erosion of Sequence 4 sediments and the generation of relative lowstand conditions.

The relationship of Sequence 5 to the prior depositional sequences within the Upper Jurassic mega sequence is summarised in Figure 72 & 73. These figures show the development of turbidite facies in the central basin areas. These distal turbidites were recognised in the cores from Barrow-1 and Barrow-25. The medium coarse grained nature of the thin sandstone facies and presence of small rounded pebbles of chert and banded iron formation attest to the long distance transportation of sediment from continental and fluviatile environments to the deep marine basin depocentre (Figure 91). This transportation of sediment occurred during the initial lowstand when fluviatile and deltaic sediments prograded to the shelf edge causing major canyon incision into the shelfal margins (Figure 91). Slumping associated with sediment instability and/or sea level perturbations caused massive redistribution of the coarse grained sediment into the basinal depocentre via turbidity currents. The periodic - episodic nature of deposition is exhibited on the wireline logs (Enclosure VI) and within the cores



LSF	LOWER SLOPE FAN
LSW	LOWSTAND WEDGE
PLC	PROGRADING LOWSTAND COMPLEX
BFF	BASIN FLOOR FAN
LST	LOWSTAND TURBIDITE
▬	FAULT AFFECTING DISTRIBUTION OF TITHONIAN SEDIMENTS
～	TITHONIAN ABSENT
⊃	INCISED CANYON

MID TITHONIAN – BASE CRETACEOUS

(SEQUENCE 5)

PALEOGEOGRAPHY

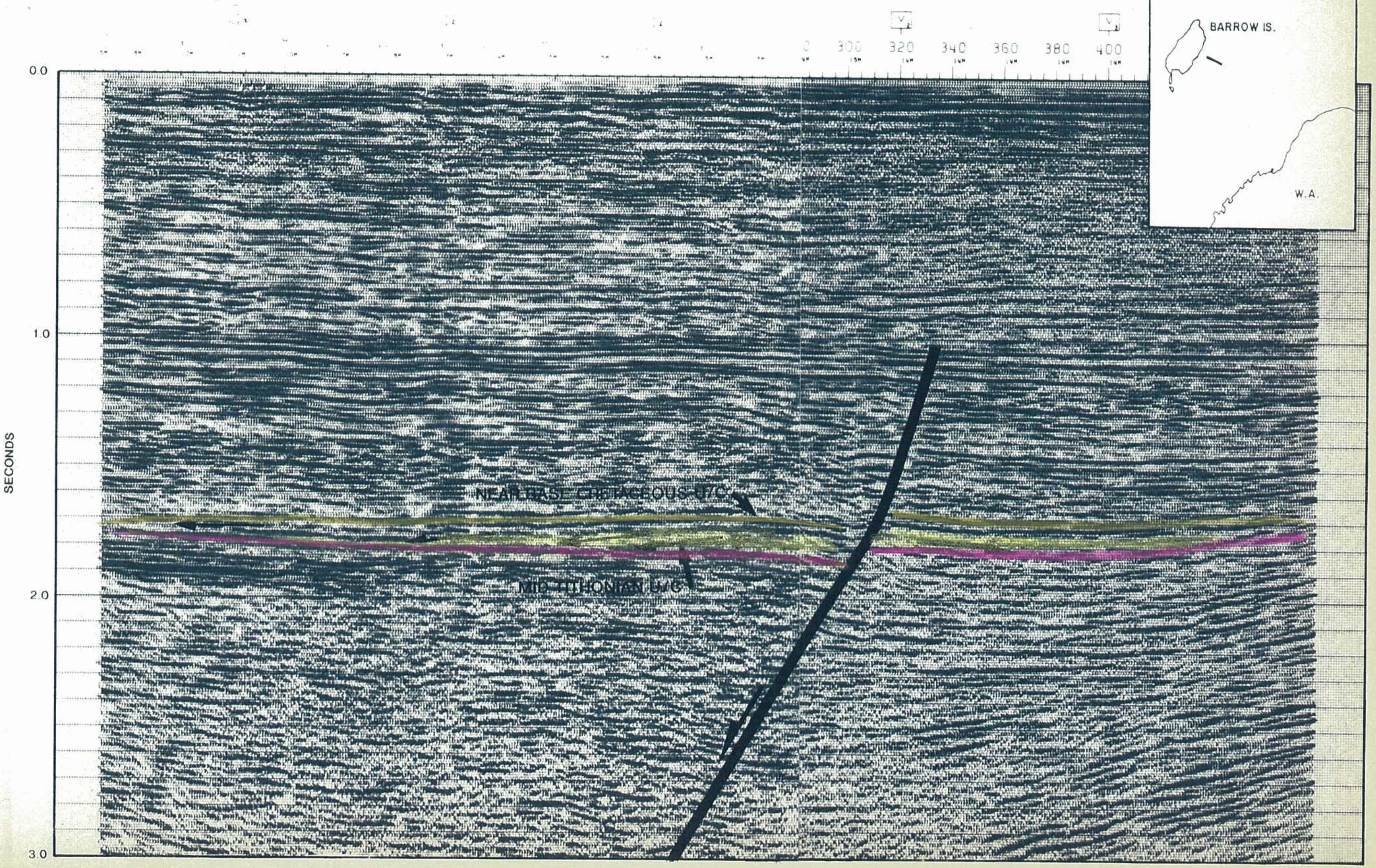
K.WULFF APRIL 1991 Figure 91

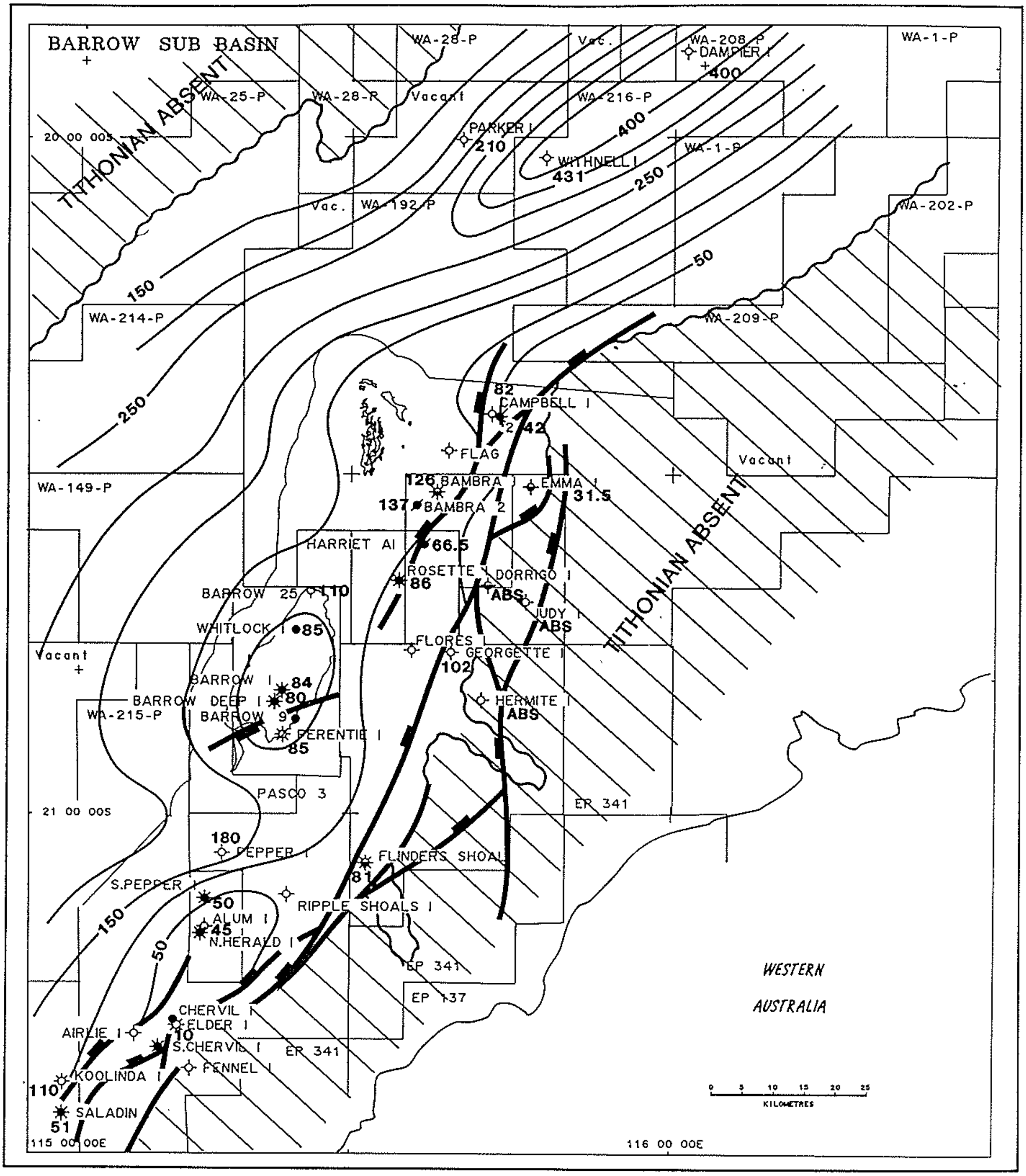
by the rapidly interbedded nature of the system. Seven periods of turbiditic sandstone deposition can be recognised in Barrow-25 (Enclosure VI).

The intensity of the bioturbation in the wackestones interbedded with the coarser grained sandstone supports periods of quiescence and episodic deposition. These thinly bedded turbidites represent the distal portions of larger submarine fan complexes located closer to the provenance in the east. It is therefore likely that a larger, more sand-prone system exists between the Flinders Fault Zone and Barrow Island (Figure 91). A fan complex of probable Portlandian age is recognised on seismic line 82-74 (Figure 92). This may represent one of many similar fans developed in this area. Barrow Island continued to grow through the Tithonian resulting in a channelling effect of turbiditic deposition between the Flinders Fault zone and Barrow Island (Figure 93).

Canyon incision into the shelfal areas is most clearly evident south of Hermite-1 (Figures 79 & 91 and Enclosure VIII). This canyon is approximately 300-500 m deep, 3-5 km wide and 20-25 km long and represents a significant conduit for fluviatile and continental sediments to bypass the shelf areas. The sediments are deposited at the shelf break and slumped as a result of sediment instability or tectonic perturbations and redeposited as mass flow turbiditic sands in the basin axis.

As shown on Figure 94 the ancestral Robe River was active as early as the Valanginian depositing Yarraloola Conglomerates on the Peedamullah Shelf


300
320
340
360
380
400
0.0
1.0
2.0
3.0
SECONDS
NEAR BASE CRETACEOUS U/C
MID TITHONIAN U/C
BARROW IS.
W.A.



(**N.B.** ISOPACH WAS GENERATED FROM WELL CONTROL AND REGIONAL SEISMIC MAPPING.)

MID TITHONIAN – BASE CRETACEOUS
(SEQUENCE 5)
ISOPACH (C.I.– 50m)

K.WULFF

Figure 93

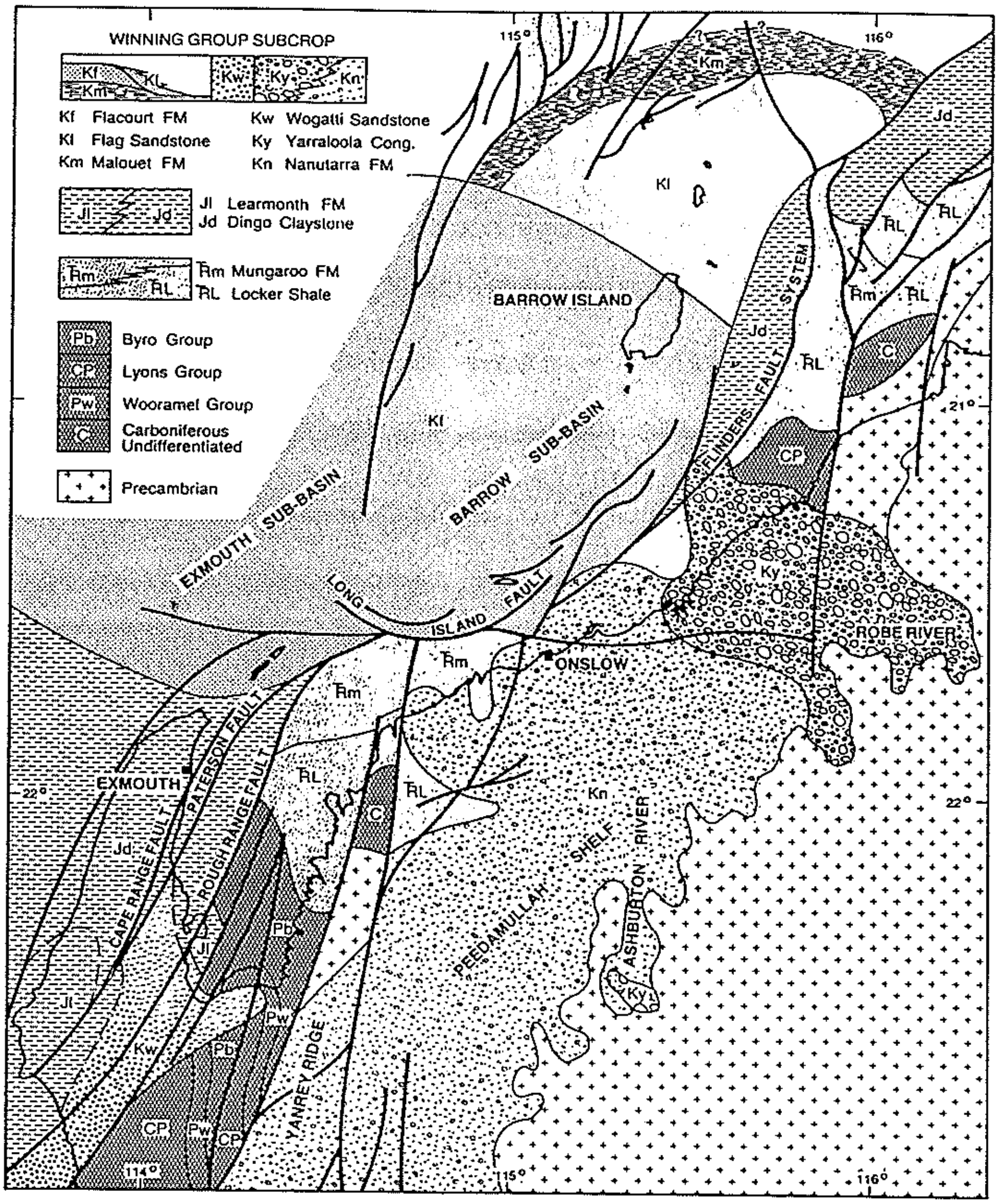


Figure 94 Interpreted geology prior to Winning Group transgression (approximately Mid Valanginian) (Hocking etal,1987)

southeast of Barrow Island and extending to the northwest beyond the Flinders Fault Terrace. This northwest - southeast orientation of the fluviatile facies is similar to the orientation of the incised canyon recognised on the Peedamullah Shelf and Flinders Fault Terrace. As shown on Figures 79 and 91 this incised canyon has been correlated to the initial lowstand conditions of Sequence 5. It is highly probable that the Robe River and other rivers feeding off the Pilbara Shield were active as early as the Kimmeridgian and may have been responsible for transportation of the coarse continental derived quartz and lithic fragments recognised in core samples. This supports the southeast provenance proposed for these massive basin floor sands of Tithonian age in the Lowendal Syncline.

Kirk (1985) recognised this canyon incision on the Peedamullah Shelf and Flinders Fault Terrace and two mounds at the mouth of the basinal extremity of the canyon (Figure 95). Kirk commented that the apparent high height to width ratio possibly suggested a muddy nature to the mounds. He also concluded that at least two periods of channel discharge took place. Kirk demonstrated that the channel fill had good seismic contrasts, suggesting sand/shale interbeds indicating the likelihood of turbiditic infill of the channel. The mounding at the base of the canyon was also recognised in this study (Figure 91), however it is highly unlikely that the fan deposits at the mouth of the canyon were responsible for the canyon incision. These mound forms are extremely small (<4 km across) and the volume of sediment within these mounds would not be sufficient to infill the incised canyon. The incised canyon would have been formed during the initial lowstand by the development of fluvial-deltaic systems prograding across and

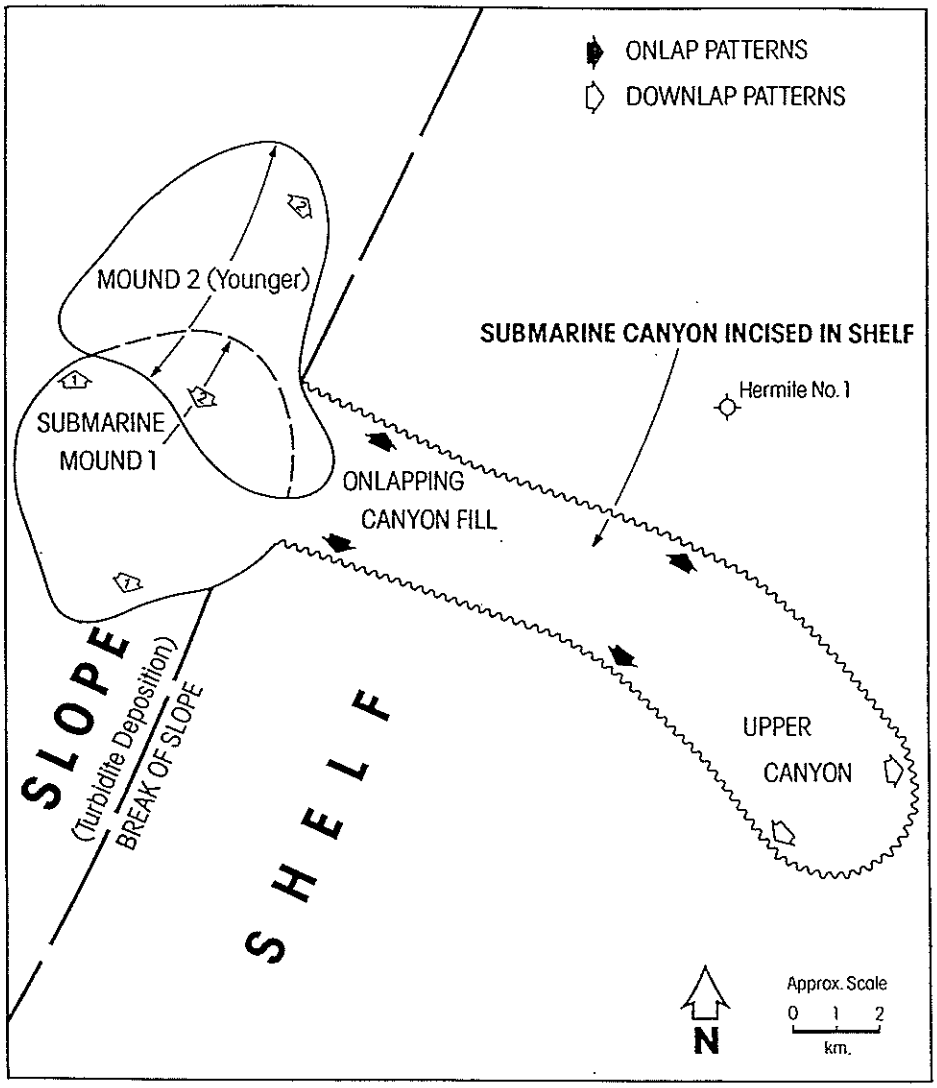


Figure 95

Seismic facies map of the channel and resultant fan system recognised by Kirk,1985 in the Upper Dupuy Member (Sequence 4 of this study) (after Kirk, 1985)

incising into the shelf. These systems would have been responsible for transporting fluviatile and continental derived sediment to the shelf edge. The relief of the shelf edge relative to the adjacent basinal areas at that time would have resulted in slumping and detachment of submarine fan lobes from their sediment point sources (Figure 17). The 'muddy' mounds proposed by Kirk at the base of this canyon (Figure 94) are likely due to the final stages of turbiditic deposition as sea level began to rise slowly retreating the shore face back eastward across the Peedamullah Shelf area. Minor sea level fluctuations, or sediment instability associated with earthquakes or storms probably funnelled small scale turbiditic facies down the existing incised channel. Infill of the canyon was associated with waning turbiditic or outer shelfal deposition. The westernmost recognisable limit of the canyon incision marks the shelf edge of the previous Sequence 4 deposition cycle. This allowed the shelfal and fluvial/deltaic sediments of Sequence 5 to develop well into the basin.

Turbiditic facies have also been recognised in Harriet-1, Bambra-2 and Flag-1. In Harriet-1 a thin (10 m) moderately sorted, fine to coarse grained sand immediately overlies the Upper Tithonian unconformity (Enclosure VI). This 10 m sand has been interpreted as being deposited in a slope to basin floor depositional setting as part of a lowstand turbidite complex. Fine to coarse grained turbiditic sandstones were also recognised in Bambra-2 which intersected a 25 m thick lowstand turbidite complex. The lithology based on sidewall core descriptions (Bambra-2, Basic Well Data, Volume 1) is moderately sorted, variably argillaceous and very calcareous sandstone. This sandstone in Bambra-2 displayed good visible porosity and 40-60% patchy, blue-white, natural fluorescence with slow streaming cut. A similar hydrocarbon show was noted in the Harriet-1 10 m sand, supporting the migration of hydrocarbons through these coarser grained sandstones. The recognition of this complex located in a structurally or stratigraphically favourable location may provide excellent reservoir objectives. Very thin (<2 m thick) sandstones are also recognised in Flag-1. These resemble the episodic turbiditic deposition identified in Barrow-25 and Barrow-1.

Campbell-1 and Campbell-2 intersected a basal Sequence 5 sandstone section not recognised elsewhere in the study area. This sandstone interval is approximately 20 m thick, coarsening upward and lies directly above the massive blocky Kimmeridgian sandstone interval.

The seismic displays depositional thickening to the north and west from the Campbell-1 and 2 well locations with a probable pinchout between the Campbell-1 and Flag-1 well locations (Figure 90 and Enclosure XI). The lack of these massive sandstone packages in Flag-1 supports the depositional pinchout between the Flag-1 and Campbell well locations related to the rotation of Tithonian age fault blocks. Figure 90 displays the thickening of Sequence 5 to the northeast suggesting that the provenance for the sand unit recognised in both the Campbell wells is from the northeast, toward the Dampier Sub-basin. Dipmeter analysis of the sandstone packages in Campbell-1 and 2 display moderate angle (5-18°) dips in opposing directions. The dominant dip direction in Campbell-1 is to the northeast while the dominant dip direction in Campbell-2 within the same unit is to the west-northwest. Neither dipmeter has been processed for detailed stratigraphic interpretation. The dip azimuths may be dipping toward the axes of a channel, however, it is more likely that little reliable stratigraphic information may be gleaned from this data. No channel is identifiable from seismic. Based on the seismic it can be expected that a massive Tithonian sand interval occurs north of the Campbell well locations.

In the southern part of the study area a Tithonian unconformity is discernible based on wireline log analyses of Flinders Shoal-1 (1162 m), Koolinda-1 (1966 m) and Saladin-1 (1656 m). Due to the extensive isostatic adjustment of fault blocks in the South Pepper/Elder area and lack of seismic resolution on available seismic the unconformity cannot be reliably correlated in this area. It is apparent however, that the Tithonian unconformity is a basin-wide event marking a period of lowstand and sediment progradation. Massive clastic progradation was occurring during this period in the Dampier Sub-basin to the north with the deposition of basin floor fan sands and overlying lowstand wedge complexes.

Overlying these lowstand turbiditic complexes in the study area are coarsening upward cycles with occasional thin (< 1-2 m) coarser grained sandstones which represent turbiditic deposition associated with storms, earthquakes or minor sea level falls during an overall prograding lowstand wedge complex. The discernible coarsening upward cycles immediately overlying the lowstand turbidites indicates that the shelf edge was significantly closer to the basin depocentre during the Tithonian than for previous depositional sequences where the lowstand turbidite complexes were overlain by pelagic deep marine shales. In more proximal locations this may provide a risk for sealing lowstand Tithonian turbidites due to the lack of thick overlying deep marine shales.

Sequence 5 deposition was terminated by a basin-wide event which saw reactivation of basin margin faults, uplift of the Peedamullah Shelf area and northward progradation of an overlying deltaic complex from south of the study area down the axis of the Barrow Sub-basin. This unconformity is clearly discernible on the flanks of the Sub-basin as shown in Figures 75 and 80 but is more difficult to discern in the basinal localities. The tectonism which terminated Sequence 5 deposition also caused a change in provenance from clastic derivation from the east to a dominantly southerly provenance initiating Neocomian Barrow Group delta progradation down the axes of the Barrow Sub-basin.

7 REGIONAL SYNTHESIS

The Upper Jurassic depositional system of the eastern Barrow Sub-basin developed on a tectonically active continental margin. The Northwest Shelf of Australia continental margin developed in response to rifting associated with the commencement of separation of Gondwanaland during the Earliest Triassic (Sinemurian - Pliensbachian). Onset of rifting during Lower Callovian followed by major rifting during Upper Callovian times with fault reactivation during the Mid Kimmeridgian and Mid Tithonian resulted in a steep, terraced slope (Flinders Fault Zone) separating an extensive shelf area (Peedamullah Shelf) from the subsiding axial depocentre (Barrow Sub-basin). Differential uplift along the fault zone controlled the distribution of sedimentary facies. The steep slope allowed sediment bypass resulting in canyon incision and non-channellised submarine fan deposition in the axis of the subsiding basin during times of relative lowstand.

The uplift of the Peedamullah Shelf area in response to the rifting episodes has resulted in erosion of the Upper Jurassic paralic-shoreface sediments in this area. As a consequence only outer shelfal to deep marine Upper Jurassic sediments occur in the Barrow Sub-basin study area. The absence of the shelfal-shoreface sediments of the transgressive and highstand system tracts precludes the detailed evaluation of the relationship between eustasy, tectonics and sediment supply on the basis of the Barrow Sub-basin study area alone. The results and models proposed here form a basis from which a more detailed and regional evaluation may be undertaken.

Due to the relative sparsity of well data containing a complete Upper Jurassic sequence (3 out of 31 wells), poor seismic quality and loss of section due to erosion and/or non deposition along the Flinders Fault zone, precise dating of the unconformities or sequence boundaries was impossible. A chronostratigraphic stage subdivision rather than a numerical value was considered more appropriate when estimating the age of each sequence boundary.

The five depositional sequences identified within the Upper Jurassic sedimentary section were:

Sequence 1	**Lower - Upper Callovian**
Sequence 2	**Upper Callovian - Mid Oxfordian**
Sequence 3	**Mid Oxfordian - Mid Kimmeridgian**
Sequence 4	**Mid Kimmeridgian - Mid Tithonian**
Sequence 5	**Mid Tithonian - Base Cretaceous**

Sequence 1 (Lower - Upper Callovian) developed in response to an active period of rifting preceding major rift onset during Upper Callovian time. Truncation of the underlying Dingo Claystone is apparent and normal fault displacement in excess of 500 m occurs along the Flinders Fault Zone. This Lower Callovian

rifting period caused localised basin inversion with the development of large intra basinal horst blocks, e.g. Dorrigo Feature (Figure 80), and antithetic faults to the westerly hading Flinders Fault Zone. Basal slope fan and debris flow deposits (facies 3 and 4, Section 6.1) have been intersected at the foot of fault scarps and infilled topographic lows. However, massive sand prone basin floor fan complexes (facies 7, Section 6.1) of Lower Callovian age have not been penetrated in the study area. This is most likely due to depths of burial in excess of 5000 m in the basin depocentre. Sedimentation following the initial rift phase was dominantly passive occurring within an outer shelfal - deep marine environment of deposition.

Sequence 1 deposition was terminated during the Upper Callovian by renewed rifting along the Flinders Fault Zone which caused further uplift of the Peedamullah Shelf. Sequence 2 commenced with progradation of the shelf margin. The distal downlap unit of the lowstand prograding complex is definable on seismic basinward of the Flinders Fault Zone. Deposition distal of the last prograde occurred at water depths of ~500 m or greater. These basinal claystones have good oil generative source potential and overlie the outer shelfal - slope shales and siltstones of Sequence 1. Further basinward within the central Barrow Sub-basin, massive detached basin floor fan sands (Facies 1, Section 6.1) have been intersected on Barrow Island, an intrabasinal inversion anticline which developed from Kimmeridgian through to Miocene time. These massive fan complexes have been derived from continental detritus shed off the Pre-Cambrian Hammersley Ranges and Pilbara Shield, east of the Peedamullah Shelf. Major fluvial systems such as the proto-Robe, Ashburton and Fortesque rivers, were probably well established by Upper Jurassic time. These fluvial systems fed extensive deltas which prograded out across the Peedamullah Shelf during periods of relative sea level lowstand, or due to high rates of sedimentation related to climate or tectonic conditions. Following the initial lowstand period, transgressive marine conditions followed, resulting in widespread deep marine (water depths >500 m) claystone deposition blanketing much of the study area. These claystones have good oil generative potential, especially within the central basin where condensed sections have been intersected. Occasional thin sandstone stringers (facies 1 and 5, Section 6.1) occur interbedded with the massive basinal claystones, probably representing storm periods causing reworking and distributing shelfal sediment into the subsiding basin. Following the Upper Callovian rifting episode, conditions were tectonically quiet through to the Lower Kimmeridgian.

<u>Sequence 3, Mid Oxfordian - Mid Kimmeridgian</u> is a poorly developed sequence and only recognised within the central basin wells. It is difficult to establish whether or not Sequence 3 is tectonically induced, due to the erosion of Sequence 3 along, and east of the Flinders Fault Zone due to post depositional uplift. Since no significant tectonism apparently occurred during this time elsewhere in the Barrow Sub-basin, it was likely that the sequence boundary separating Sequences 2 and 3 was induced by a eustatic sea level fall. Tentative correlation with the Haq et al (1987) relative sea level chart (Figure 72) indicates that a Type II, medium magnitude, sequence boundary occurs around Mid

Oxfordian time associated with a global eustatic sea level fall. This correlation is speculative due to the different chronostratigraphy applied by Haq et al (1987) compared to the Harland et al (1982) scheme which has been applied by Helby et al (1987) (Table V) and other workers on the Northwest Shelf.

Within the basin depocentre, Sequence 3 consists of a generally coarsening upward sequence of claystones and siltstones with occasional thin fine-medium grained sandstone beds with sharp basal contacts. Deposition is interpreted to occur within a shelf margin systems tract grading to a transgressive regressive wedge.

Deposition of Sequence 3 was terminated abruptly during the Mid-Lower Kimmeridgian by renewed tectonism which resulted in further uplift along the Flinders Fault Zone initiating large scale clastic input into the basin. Basin floor fan complexes (facies 1, 2 and 7), lower slope fan (facies 3, 4 and 5) and progradational lowstand complexes characterise Sequence 4 in the study area. The shelf edge prograded basinward of the Flinders Fault hinge zone during this period. Following the initial clastic influx, deepening marine conditions resulted in transgressive and highstand outer shelfal to deep marine claystone deposition, blanketing much of the study area as the shoreline retreated to the east.

Active tectonism during the Mid Tithonian occurred within the Barrow Sub-basin resulting in further uplift of the platform areas. Canyon incision on the exposed Peedamullah Shelf and Flinders Fault zone allowed large scale sediment bypass of the previous shelf and platform, initiating the development of basin floor fan deposition. These basin floor fan and turbiditic complexes of Sequence 5 (facies 1, 2, 4, 5 and 7) have been intersected within the central basin and consist of fine-coarse, dominantly medium grained quartzose sandstones with good reservoir characteristics (Figure 32) interbedded with bioturbated argillaceous sandstone grading to siltstones in the more distal basinal wells. The sequence boundary between Sequences 4 and 5 corresponds to a major period of fault activity. However tentative correlation with Haq et al's (1987) sea level chart also marks this time as a major period of eustatic global sea level fall. It is possible that the Mid Tithonian lowstand may be associated with both tectonism and a global eustatic sea level fall. Overlying these fan complexes are well developed shelfal slope prograding lowstand deposits with well developed sigmoidal - oblique clinoforms (Enclosure XI). Sequence 5 is not fully developed due to the northerly tilt and inception of Lower Cretaceous Barrow Delta progradation down the axis of the Barrow Sub-basin. This resulted in a change in provenance direction from dominantly the east during Upper Jurassic deposition to the south and southeast during Lower Cretaceous Barrow Group deposition.

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8 APPLICABILITY OF SEQUENCE ANALYSES MODELS, GLOBAL SEA LEVEL CURVES AND SUBMARINE FAN MODELS TO THE UPPER JURASSIC OF THE BARROW SUB-BASIN

8.1 INTRODUCTION

Sequence analyses and seismic stratigraphy were introduced to the general petroleum industry in 1977 in the AAPG Memoir 26, 'Seismic Stratigraphy - Applications to Hydrocarbon Exploration'. Memoir 26 contains a series of papers on seismic stratigraphy by P.R. Vail, R.M. Mitchum, R.G. Todd, J.M. Widmer, S.l Thompson III, J.B. Sangree, J.N. Bubb, and W.G. Hatlelid of the Exxon group of Companies. These papers constituted the first authoritative source of published concepts, techniques and examples on Sequence Stratigraphy that culminated almost two decades of work in seismic stratigraphy by Exxon (Brown, 1985). The seismic stratigraphic techniques as outlined by Vail et al (1977) have provided an invaluable service to the geoscience community and were applied during the course of this research.

Haq et al (1987) published a Mesozoic - Cenozoic Cycle chart which summarised magnetostratigraphy, standard chronostratigraphy, biochronostratigraphy, sequence chronostratigraphy and eustatic sea level curves based on Exxon's research. The global eustatic sea level curve was determined from seismic evaluation of the onlap of coastal deposits in maritime sequences. The global cycle chart is simply an average of correlative regional cycles from several areas around the world.

Other studies (Hubbard, 1988) discount the applicability of global synchronicity suggesting that tectonism, not glaciation, is the controlling factor on sequence boundary development in tectonically active settings. Problems with correlating the Barrow Sub-basin Upper Jurassic sedimentation with the Global Cycle Chart are also identified by this study. These are dealt with in greater detail in Section 8.2

Over the past two decades significant research on ancient and recent deep marine clastic sedimentation has resulted in the development of numerous models explaining the facies distribution and controls on sedimentation of turbiditic and submarine fan deposits (e.g. Walker, 1978; Mutti & Ricci Lucchi, 1975; Normark, 1978; Heller & Dickinson, 1985; Mutti, 1985; Mutti & Normark, 1987). The models integrated into this study were Mutti's (1985, 1987), subdivision of deep marine clastic sedimentation into three categories dependent on presence or absence of channels, size and sedimentary facies constituting the complex. The compatibility of Mutti's models with the deep marine clastic sedimentation present in the Upper Jurassic of the Barrow Sub-basin are discussed in greater detail in Section 8.3

8.2 SEQUENCE ANALYSES MODELS AND GLOBAL SEA LEVEL CURVES

To fully evaluate the sequence analyses of a sedimentary succession for comparative purposes, a fully integrated study incorporating a multidisciplinary approach utilising geological, geophysical and biostratigraphic information is required. The worldwide data base used by Exxon has not been released, due to proprietary constraints. The B.P. research summarised by Hubbard (1988) on the age and significance of sequence boundaries on Jurassic - Early Cretaceous rifted continental margins in three oceanic basins (Santos Basin, Grand Banks and Beaufort Sea) incorporated some 460 wells and 195,000 km of seismic data. In contrast with the large volumes of data used by Exxon (Vail et al) and B.P. (Hubbard) this study incorporated 31 wells and 3,500 km of seismic. The sparsity of wells (1 well/3666 km^2), combined with the generally poor seismic quality made categorical conclusions from the results of this study impossible. The following therefore only discusses observations related to the applicability of sequence analysis concepts and the Haq et al (1987) cycle chart with respect to the Barrow Sub-basin where tectonism, sediment supply and eustasy all play a role in the facies distribution and sequence subdivision within the Upper Jurassic sedimentary succession. As discussed previously the loss of shelfal-shoreface Upper Jurassic section through erosion on the uplifted eastern platform areas precludes detailed evaluation of the interplay between tectonics, eustasy and sediment supply in the eastern Barrow Sub-basin study area.

8.2.1 Applicability of Global Synchronicity to the Upper Jurassic of the Barrow Sub-basin

Global synchronicity of sequence boundaries related to short term glacio-eustatic sea level fluctuations as proposed by Vail et al (1977), Vail et al (1990) and Haq et al (1987) is a hotly debated and much discussed issue. With respect to the Upper Jurassic of the Barrow Sub-basin there were major limitations in the ability to correlate the global sea level chart in detail with the results derived from this study. The following discusses in more detail those limitations.

i <u>Variation in the geochronological chart and dinoflagellate zonation between the Haq et al curve (1987) and that used by Helby, Morgan and Partridge (1987).</u>

Table V displays the discrepancies in the geochronological age distribution of the Upper Jurassic stages as published by Haq et al (1987) and Helby et al (1987). The Helby subdivision is based on Harland et al radiometric scale (1982) which also correlates closely to the geologic time scale used by the Geological Society of America (1983). Haq et al's geochronological subdivision has been derived from Exxon radiometric age dating of numerous samples which were then screened by a Horner plot to obtain the line of best fit (Partridge, 1990 personal communication). The sample locations, number of samples and absolute age values are not published.

The inconsistent difference in magnitude of ages and validity of stage subdivision make gross correlation with the Haq et al curve tenuous. Until the geochronological and stage classification differences can be resolved, detailed correlation with the Haq et al curves is highly tenuous.

ii Sediment Accommodation - rate of subsidence versus sea level fluctuations.

The global sea level cycle chart published by Haq et al (1987) dictates that worldwide synchronous sequence boundaries are developed as a result of periodic short term falls in the global eustatic sea level. The degree of development of each sequence is controlled by the extent of the eustatic sea level fluctuation. It is probable that global sea level fluctuations played a role in the facies distribution within the Upper Jurassic depositional sequences identified in the Barrow Sub-basin, however, it is most likely that the major control on the development of sequence boundaries, accommodation space and facies distribution was tectonism.

The Upper Jurassic sedimentary succession is a synrift depositional sequence that developed in response to the sequential separation of Greater India from Northwest Australia during the initial Callovian break-up phase through to final separation during the Valanginian. In the eastern Barrow Sub-basin, four of the five sequence boundaries identified in the Upper Jurassic appear synchronous to active faulting and uplift along the Flinders Fault Zone (Section 6.4). Hubbard (1988) also found that 80% of the

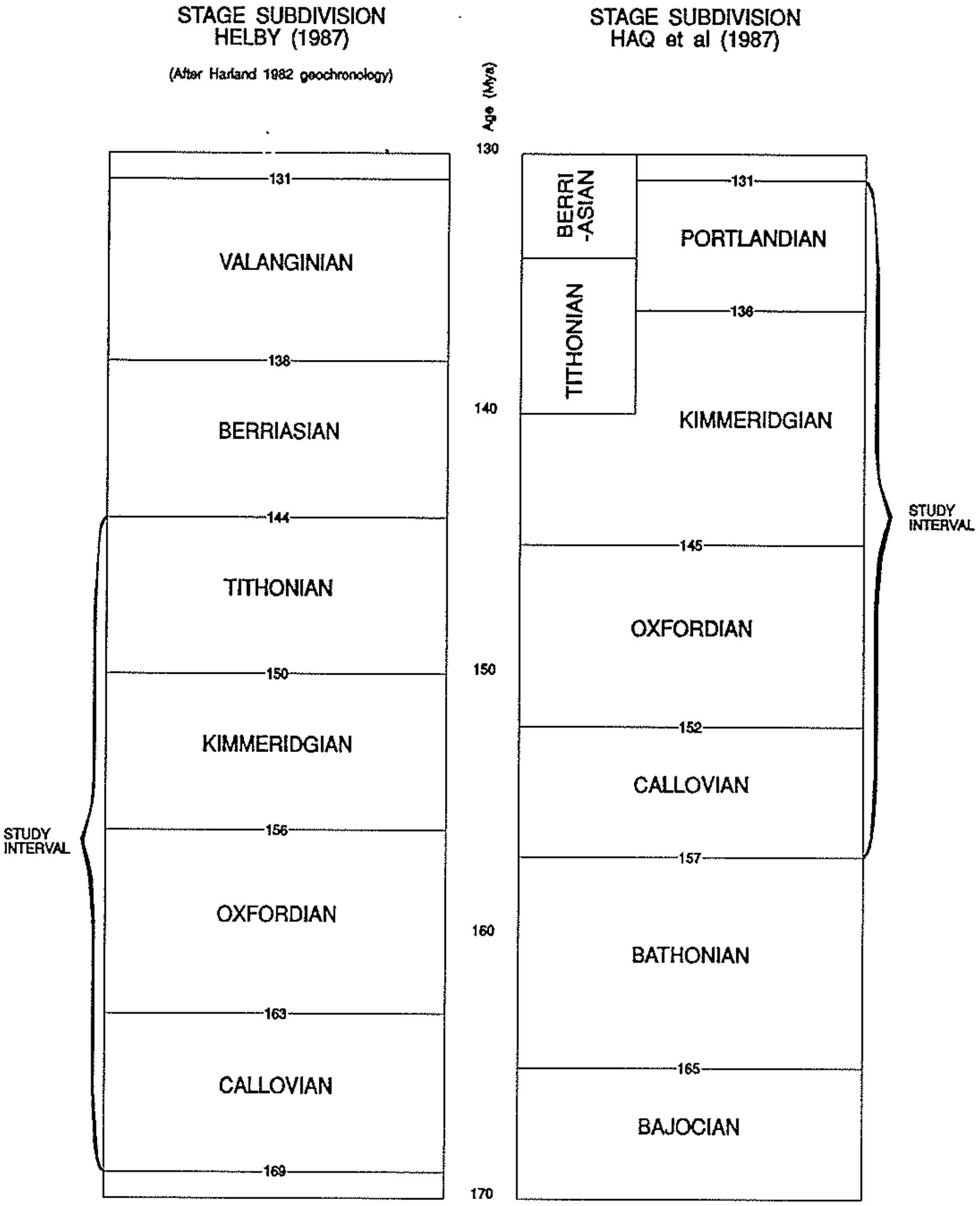


Table V displaying discrepancy between the geochronological subdivision of Upper Jurassic stages between that used by Helby et al (1987) and Haq et al (1987). The difference in absolute stage ages and range make correlation of the Haq et al Global Cycle chart with sequences whose ages are based on Helby (1987) dinoflagellate zonation highly unreliable in the Barrow Sub-basin.

sequence boundaries within the three Jurassic and Early Cretaceous rifted continental margins that were studied by British Petroleum showed a direct causal connection with coaxial faulting and/or folding. Hubbard concluded that only in basins of the same age, with identical subsidence and sediment input rates are boundaries likely to develop synchronously and that a global approach to basin analysis should be discarded.

The results of this study however cannot be so categorical as to completely discard the affect of global sea level fluctuations. It is more likely that both tectonic and eustatic processes combine to cause relative sea level changes which control the accommodation space available for sedimentation in the eastern Barrow Sub-basin.

Vail et al (1990) contend that the relationship between tectonism and eustasy is that stratigraphic signatures may be subdivided into two categories, major continental flooding cycles and depositional cycles. Major continental flooding cycles are caused by tectono-eustasy (changes in ocean basin volume) while depositional sequence cycles are caused by glacio-eustasy (changes in water volume). Vail et al (1990) further contended that even though major transgressive - regressive cycles are related to second order, non periodic tectonic episodes (Table VI), sequence boundaries when dated to at the minimum hiatus match the age of global eustatic falls and not the plate tectonic event causing the tectonism. Therefore tectonism may enhance or subdue sequence and systems tract boundaries but does not create them.

In the case of the Upper Jurassic of the Barrow Sub-basin Vail's comments are impossible to substantiate due to the lack of well data, erosion of shelfal - shoreface sediments, imprecise age dating and generally poor quality seismic data. However, the magnitude of faulting episodes (vertical displacement in excess of 1 km) and frequency within the Upper Jurassic (four active periods within a 25 my period) cast doubt on the validity of Vail's comments with respect to the Barrow Sub-basin. In such a highly tectonically active setting it is doubtful that sequence boundary development is related solely to glacio-eustasy causing changes in water volume.

The Upper Jurassic of the Barrow Sub-basin was a time of active rifting and fault re-activation. Four (4) separate Upper Jurassic periods of tectonism are evident in the Barrow Sub-basin with the major rift and post rift phases being the Lower Callovian and Upper Callovian respectively. This active tectonism has resulted in variation in the rate of accommodation space for sedimentation as shown in Figure 96. This figure is a palaeoburial diagram of the sedimentary succession intersected at Bambra-2.

As can be seen from the comparison of Jurassic - Early Cretaceous sedimentation rates (a period of active tectonism) versus Mid Cretaceous - Present (generally tectonically quiescent period), variations in accommodation space are most greatly affected by periods of active

TABLE VI: SIGNATURES IN THE STRATIGRAPHIC RECORD

	TECTONICS			EUSTASY		SEDIMENTATION
SIGNATURE	Sedimentary basin	Major Transgressive Regressive Facies Cycle	Folding, Faulting, Magmatism, and Diapirism	Major Continental Flooding Cycle	Sequence Cycle Systems Tracts Parasequences Stacking Pattern Sets Parasequences	Depositional Systems Lithofacies Tracts Marker Beds Bed Sets Beds Laminae Sets Laminae
DISTRIBUTION IN SPACE	Regional	Regional	Local	Global	Global	Local
DISTRIBUTION IN TIME	1st Order Episodic Event 50+ my	2nd Order Non-periodic 5-50 my	3rd Order Episodic Event 0.5-5 my	1st Order Cycle	2nd-5th Order Cycles	Episodic Event
CAUSE	Crustal Extension, Flexure Loading, Thermal Cooling	Plate Boundary Readjustment, Thermal Perturbation Sediment Supply	Local and Regional stress release	Change in Ocean Basin Volume	Changes in Climate, Water Volume	Local Sedimentary Processes

(After Vail et al, 1990)

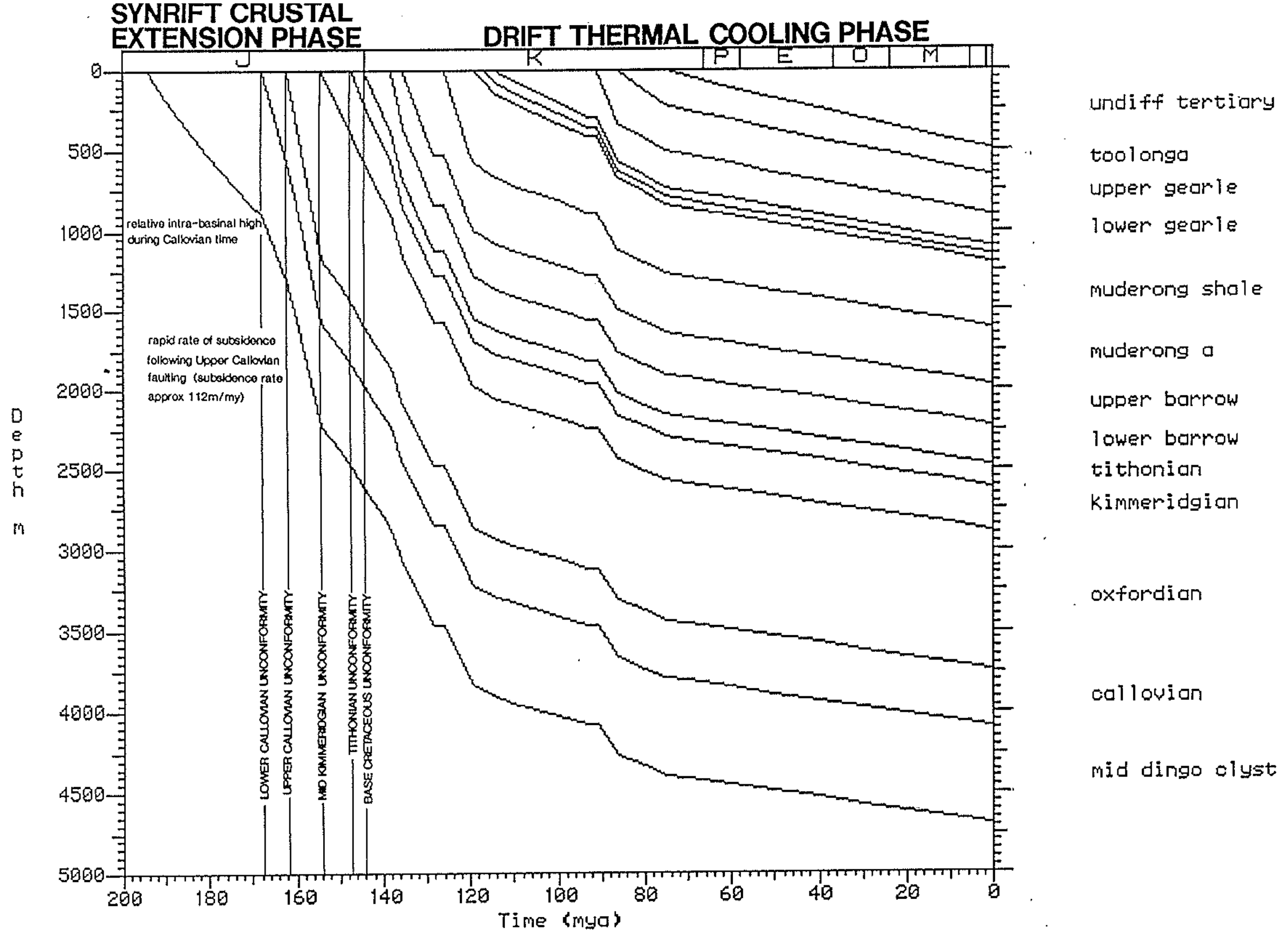


Figure 96 Tectonic subsidence curve for Bambra-2 well location. Plot displays variation in the rate of accomodation space related to tectonism' and thermal cooling. (Plot generated using 'Basinmod' program developed hv Platte River & Associates. Denver. Colorado)

tectonism. This is supported by Vail et al (1990) where he comments that "in general, extensional basins show at least two concave upward subsidence patterns, one during the synrift crustal extensional phase and another during the drift thermal cooling phase", in the Barrow Sub-basin the Upper Jurassic - Early Cretaceous and the Mid Cretaceous - Present respectively.

Tectonic episodes between the Upper Callovian and Base Cretaceous have resulted in substantial modification of the basin configuration as evident by major shifts in the basinal axis, as indicated by comparisons of figures 86, 89 and 93. These figures are isopachs of Sequences 2 & 3, Sequence 4 and Sequence 5 respectively as identified by well data and seismic control where possible. The combined isopach of Sequences 2 and 3 (Figure 86) indicates a broad structural nose trending northwest to southeast and plunging to the northwest centred on the Bambra locality. The isopach shows no evidence for the growth of the Barrow Anticline during this time.

Figure 89, Mid Kimmeridgian - Mid Tithonian Sequence 4 isopach, displays the onset of growth of the Barrow Anticline and a change in the deposition axis from the Oxfordian time (Figure 86). The Sequence 4 isopach displays an elongate northeast to southwest trending depositional axis immediately adjacent to the east flank of the Rankin Platform. The structural nose in the Bambra area evident on Figure 86 is no longer prominent being a result of onlap and ultimate blanketing of the plunging nose by Upper Callovian - Oxfordian sediments.

Sequence 5, Mid Tithonian - base Cretaceous isopach (Figure 93) displays a further change in basin configurations with the development of the depocentre axis to the northeast toward the Dampier Sub-basin. The Barrow Anticline displays growth throughout this period.

Tectonic uplift during Kimmeridgian and Tithonian time along the Flinders Fault Zone and Peedamullah Shelf area is evident by the abrupt changes in sequence thickness across the Upper Jurassic age faults marking the Flinders Fault Zone. Uplift in excess of 800-1000 m is evident from seismic (e.g. figures 75, 80 and 86) and biostratigraphy during Kimmeridgian time resulting in significant erosion of Oxfordian - Callovian sediments from uplift areas. This period of uplift and erosion caused massive clastic influx into the basin at this time initiating a sequence boundary definable along the entire Northwest Shelf of Australia.

Based on the Mesozoic - Cenozoic Cycle Chart (Haq et al, 1987), short term sea level fluctuations during the Upper Jurassic related to glacio-eustasy were in the order of 50-100 m. The long term eustatic sea level trend between the Callovian to Base Cretaceous time was largely one of transgressive marine conditions to Mid Kimmeridgian time followed by regressive conditions through to Mid Valanginian time. This trend generally fits the gross pattern of Upper Jurassic Barrow Sub-basin sedimentation. However, it is unlikely that short term sea level fluctuations of generally less than 60 m related to glaciation can account for the massive erosion (in excess of 1 km in certain areas) that occurs on the faulted terrace of the Flinders Fault Zone and Peedamullah Shelf area. In the Barrow Sub-basin it is most likely that tectonics controlled the relative sea level and rate of change in accommodation space, with modification or enhancement by eustatic sea level fluctuations.

iii Correlatability of the relative sea level (or coastal onlap) curves between the Barrow Sub-basin and Haq et al (1987) global cycle chart. On the Haq curve three medium magnitude and two major magnitude sequence boundaries are present between the Callovian and Base Cretaceous. Fan development is suggested during the Callovian / Bathonian and Mid Tithonian lowstand events. The Haq curve was bulk-shifted 10 million years down to approximate the geochronological subdivision of the Upper Jurassic stages (Harland, 1982) applied by this research. This is undoubtedly a very crude method and is used only to identify any potential relationship that may exist. No conclusions have been made other than to compare the overall shape of the curves. From the sequence analyses of the Upper Jurassic sediments in the Barrow Sub-basin the relative sea level chart and chronostratigraphy (Figure 72) suggest that the rate of sedimentation (controlled by tectonics and climate) and the rate of accommodation space variation (controlled by tectonism and eustasy) are closely related to tectonic episodes identified during that periods.

With respect to the apparent similarity between the Haq et al curve and

Barrow Sub-basin curve (this study), the Jurassic period was the time of Gondwanaland separation and it is possible that tectonic effects initiated as a result of the rifting episode, related to massive plate movement, may be widespread. As a consequence, basins that underwent rifting during the Upper Jurassic period have been caused by the separation and plate movement of Gondwanaland. It is therefore likely that these tectonic episodes may either control, or at least enhance, sequence boundary development in widespread sedimentary basins depending on the magnitude of the tectonic event and the effect on accommodation space. Consequently, the similarity in gross shape of the curves may be a function of the global effect on relative sea level of the separation of Gondwanaland during the Jurassic - Early Cretaceous period.

8.3 APPLICABILITY OF SUBMARINE FAN MODELS TO THE BARROW SUB-BASIN

Submarine fan models used by this research have been discussed in detail in Section 5.2. The aim of this discussion is to compare the depositional models applicable to the Upper Jurassic sedimentary section of the Barrow Sub-basin with deep water sedimentary models proposed by authors for classic turbidite and submarine fan deposition localities elsewhere in the world. Fan complexes that have developed in response to varying factors (namely tectonism, sediment supply and type of crust) have been chosen for comparison with the Barrow Sub-basin. Depositional settings chosen include the:

i Pleistocene Mississippi Fan Complex.

ii Late Oligocene Monterey Fan, Pacific Ocean, California.

iii Eocene Hecho Group Turbidites, South Central Pyrenees, Spain.

iv Kimmeridgian Brae Fan Complex, South Viking Graben, North Sea, UK.

These submarine fan systems are considered a fair representation of the general range of depositional settings applicable to submarine fan sedimentation. They do not however, represent the plethora of depositional settings in which submarine fan development can take place.

The first, and most critical point to consider when making these comparisons is to highlight the lack of well control and generally poor quality seismic in the Barrow Sub-basin from which to draw conclusions. Only 3 of the 31 wells studied penetrated hydrocarbon productive sand bodies (Perentie-1, Barrow Deep-1 and Barrow-1) and only two of which penetrated the same sand complex (Perentie-1 and Barrow Deep-1). Seismic quality was very poor on available data in the Perentie / Barrow Deep area and stratigraphic character could not be resolved. This compares with years of scientific research on the Mississippi Fan including deep sea drilling, piston coring and high resolution seismic (Sangree, 1990). The morphology and controlling processes of the Monterey Fan (Wilde et al, 1978) have been studied using high resolution seismic profiles and extensive coring. With respect to the Eocene Hecho Group turbidites in the South Central Pyrenees, Mutti and his fellow workers have been studying the well preserved and extensive outcrop for the last 15 years, consequently the depositional models proposed for that sequence are well established.

The Brae Field was discovered in 1975 and up until 1985 fourteen additional English-sector wells had been drilled into the field with over 2500 m of core was recovered. The detailed sedimentological study undertaken, combined with dipmeter and seismic profiles over the field, provided an excellent data base for the development of depositional models and controls for the Brae oil field turbidite system (Stow, 1985).

Correct recognition and interpretation of turbidite sediments is of great importance for evaluating reservoir geometry and distribution. In choosing the most appropriate depositional models it is therefore important to understand all the processes controlling deposition in that particular area. With respect to the Upper Jurassic of the Barrow Sub-basin, the lack of data precludes the study of individual fans; however by understanding the controlling processes (i.e. tectonics, sea level and sediment supply), depositional models for expected fan complexes can be proposed.

An important criteria that categorises the style of submarine fan deposition in the study area, is the syntectonic control on the Upper Jurassic sedimentation in the Barrow Sub-basin. Turbidite depositional systems deposited in tectonically active settings tend to be short lived, with the intensity of the tectonic episode being the principle control on facies associations and the size of the turbiditic complex (Mutti & Normark, 1987). In contrast, the larger submarine fan systems (e.g.

Mississippi Fan) form over a period of millions of years, in a stable basin, with long term supply of sediment. Conversely, the episodic tectonic characteristics of the Barrow Sub-basin limits the type of submarine fan and turbiditic complex that can be expected to have developed during this period.

As discussed in Section 5.2.2, the Barrow Sub-basin formed on continental crust where tectonic activity resulted in the continual modification of the basin configuration through time (Figures 86, 89 and 93) and can be classified as a Type D basin under Mutti and Normarks' (1987) basin classification. According to Mutti and Normark (1987) the turbiditic deposits in the D category tend to develop in a relatively short time span (10^4 - 10^5 years) and consist of dominantly coarse grained channel and lobe sequences which are volumetrically much smaller than the turbiditic fill of the other three basin types (Section 5.2.2). The presence of well developed incised canyons on the eastern shelf margin of the Barrow Sub-basin (Figures 78, 91 and 95) attest to abundant sediment supply bypassing and incising into the uplifted shelf margins during periods of relative lowstand related to uplift of the Peedamullah Shelf and Flinders Fault Zone. These incised canyons allowed fluviatile and continental derived clastic sediments to be deposited in the basin depocentre, bypassing the shelfal area.

The differences in style of turbidite complex related to type of crust, tectonic activity and sediment supply are clearly expressed in the comparison of the selected submarine fan examples to the potential Upper Jurassic fan development in the Barrow Sub-basin:

i Pleistocene Mississippi Fan Complex - a large fan complex which developed in response to long lived sediment supply in a tectonically stable basin on oceanic crust (Mutti & Normark Type A basin).

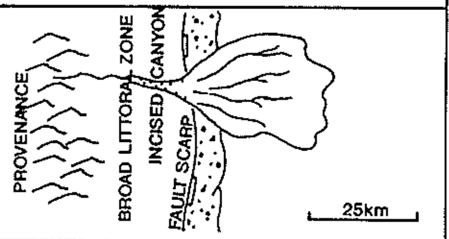
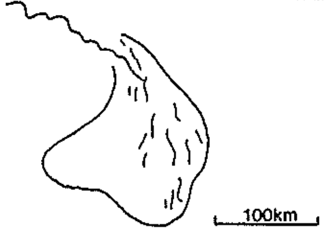
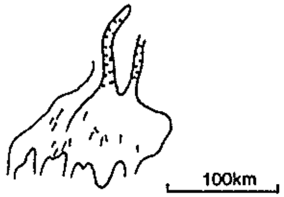
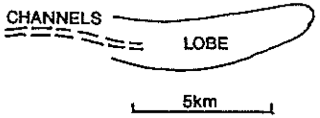
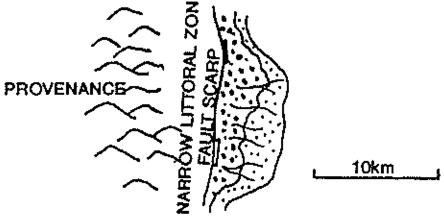
ii Late Oligocene Monterey Fan - deep water modern fan deposited on oceanic crust of Oligocene age with long lived sediment source with modifying tectonic activity (Mutti & Normark Type B basin).

iii Eocene Hecho Group turbidites, South Central Pyrenees, Spain - a turbiditic complex developed in a migrating foreland basin formed on continental crust (Mutti & Normark Type C basin).

iv Kimmeridgian Brae Fan Complex, South Viking Graben, North Sea Basin - a slope apron fan developed in a tectonically active continental rift basin (Mutti & Normark Type D basin).

A comparison of each submarine fan setting and applicable depositional models is set out in Table VII. This table summarises the controlling processes for fan development and resultant facies distribution. The following discusses in more detail the processes and sedimentological characteristics that differentiates the depositional settings.

TABLE VII: COMPARISON OF DIFFERENT SUBMARINE SETTINGS

FAN	BASIN TYPE	FAN SETTING & MORPHOLOGY	FACIES ASSOCIATIONS	DIAGRAMMATIC SIZE AND SHAPE
PROBABLE UPPER CALLOVIAN, KIMMERIDGIAN & TITHONIAN FAN COMPLEXES IN THE BARROW SUB-BASIN	Tectonically active rift basin developed on continental crust with relatively short lived sediment supply (Mutti & Normark Type D basin).	Point sourced fan complex developed basinward of rift margin in water depths >500 m. Incised valleys 3-5 km wide, up to 700 m deep & 15 km long attest to sediment bypass. Active faulting also resulted in separate poorly sorted slope apron fan development related to mass flow.	Sand is generally medium - coarse grained, occasionally granular. Probable well developed upper channellised fan complex. Sandy lobes 3-10 m thick with thin interbedded mudstones stack to form extensive fan lobes basinward of active fault zone. Incised valley infilled by final waning turbiditic deposits.	
MISSISSIPPI FAN	Tectonically stable basin formed on oceanic crust with long lived sediment supply (Mutti & Normark Type A basin).	Seven elongate fan lobes indicating lateral depositional shifting sourced via migrating incised canyons. Well developed channel / levee complex on upper & mid lobe. Water depth ranges from 1000-3500 m.	Sand generally fine grained with bed thickness to 2 m interbedded with silty mud. Sands & rare gravels generally confined meandering channels. Occasional overbank deposits and interchannel turbidites.	* 
MONTEREY FAN	Tectonically active basin developed on oceanic crust related to a transform margin with long lived sediment supply (Mutti & Normark Type B basin).	Two main submarine canyons feed a complex pattern of fan valleys & channels. Uninterrupted high sedimentation rates despite neogene transform movement. Water depths range from 3000-4700 m.	Dominantly sand prone up to pebble grade with abundant slump and olistostromes development on the upper fan surface. Lower fan is flat, channel free setting with thinly bedded & sand prone turbidites.	* 
HECHO GROUP FAN	Tectonically active migrating foreland basin developed on continental crust with long lived sediment supply (Mutti & Normark Type C basin).	Delta fed fan complex in an elongate foreland basin. Intra-basin uplift resulted in compartmentalised turbiditic deposition. Well developed upslope channel / levee complex & detached downslope lobes.	Well developed depositional lobes that bypassed upslope channels consisting of sand rich lobes 3-15 m thick interbedded with shale & siltstone. Channel / levee deposits occur upslope and consist of channel fill facies & overbank turbidites.	* 
BRAE FAN	Tectonically active rift basin developed on continental crust with short lived sediment supply (Mutti & Normark Type D basin).	Dominantly slope apron fan & mass flow complex related to active movement along a submarine fault scarp. Coarse clastics deposited along narrow (<5 km) zone adjacent to fault margin.	Breccia-conglomerate facies association at foot of fault scarp grading basinwards to pebbly sandstones to a progressively more mudstone dominated association.	

* Diagrams from Mutti et al (1987).

Mississippi Fan Complex

The geophysical setting, tectonic conditions and depositional models relevant to the Mississippi Fan complex bear no resemblance to those controlling the facies distribution of Upper Jurassic sediments in the Barrow Sub-basin. The Mississippi Fan Complex is of Pleistocene - Recent age and was deposited on oceanic crust under tectonically stable conditions and with continuous sediment supply.

The Mississippi Fan Complex shows a series of cycles of sedimentation typically consisting of a basal onlapping unit overlain by chaotic slump facies which in turn is overlain by well developed channel/levee complex. Pelagic shale drape has generally blanketed each depositional cycle. The cycles have been tied into eustatic sea level fluctuations (Sangree, 1990).

Sediments of the fan complex consist mainly of finely laminated mud and silt. Sandy and occasional gravels are generally confined to meandering channels within the channel / levee fan locality. Thin lobes of sand and silt occur on the outer fringes of the fan complex. The slump deposits typically consist of a melange of sands, silts and muds. Interchannel finely bedded turbidites and overbank deposits occur associated with the channel / levee (Mutti Type III) deposits.

Sangree (1990), proposes that the fan complexes are composed of repeated cycles of lowstand wedge sediments, with each cycle being blanketed by pelagic shale representing the condensed intervals relating to rapid sea level rises during highstand periods.

Monterey Fan Complex

The depositional setting and controls on deposition of the Monterey Fan Complex also bear little resemblance to the Upper Jurassic of the Barrow Sub-basin. The Monterey Fan is a Late Oligocene - Recent deep water fan (3000-4700 m) which has developed on Oligocene age oceanic crust. Tectonic activity in the source/basin transition area related to transform movement has affected sediment supply to the fan area. The fan is sourced via two well developed canyon systems, the northern Ascension Canyon and the southern Monterey Canyon. The Ascension Canyon is inactive during highstand sea levels whereas the Monterey Canyon remains active throughout sea level fluctuations as a consequence of high sediment supply.

Deposition on the upper fan is controlled by the relative activity within these two canyon systems. Deposition over the rest of the fan is controlled by oceanic crust topography, resulting in an irregular fan shape with periodic major shifts in the locus of deposition (Normark et al, 1985).

The sediments of the fan are dominantly turbidites and hemipelagic muds. Coarse grained sand and gravels are generally confined to the well developed channel / levee complexes that extend basinwards from the incised canyons. Occasional massive slumps (olistostromes) are developed on the upper fan surface consisting of contorted units of mud clasts and turbidites from sediment originally deposited on the upper slope and upper fan interchannel areas respectively.

Hecho Group Turbidite Complex

The Eocene Hecho Group Turbidite Complex was deposited in an elongate tectonically active migrating foreland basin developed on continental crust. The tectonically active nature of the migrating foreland combined with a long lived deltaic sediment supply resulted in the development of a succession of turbidite systems.

During the early stages of foreland basin development, relative and global sea level were the main controls on the development of the turbidite system. However, further orogenic shortening resulted in narrowing and fragmentation of the foreland basin. This later tectonic modification of the foreland basin resulted in uplift of the Boltana anticline, an intrabasinal feature which induced sediment instability. This lead to the failure of unconsolidated or poorly consolidated sediment of both shallow and deep marine origin. In the later stages of Hecho Group development, tectonic processes were the principle control for turbidite deposition, regardless of global sea level variations (Mutti et al, (1987).

The Hecho Group Turbidite Complex consists of both well developed channel /

levee sediments and massive sandstone lobe deposits, however the transition between the upper channel / levee complex and lower sandstone lobe deposits is poorly developed. The original transition zone, if any, between the channels and lobes must have occurred in a narrow zone across the Boltana Anticline which was subsequently removed by erosion (Mutti, 1985b).

The channel / levee complex consists of intricately stacked channels filled with late stage turbiditic sandstone representing the waning stages of turbidite deposition. Well developed interchannel turbidites (Figure 30) and crevasse splay deposits (Figure 29) attest to the high sedimentation rates traversing the channel complex before being deposited on the basin floor as detached sandstone lobes. The sandstone lobes consist of thick (1500-2000 m) accumulations of laterally continuous and graded sandstone beds that comprise the lobe and fan-fringe facies associations. The lobe facies associations are non channelised sand bodies 3-15 m thick that are made up of massive Bouma A cycle sandstone with similar thickness of thinly bedded turbidites.

Brae Oil Field Submarine Fan

The depositional setting for the Brae Fan on the western flank of the South Viking Graben bears resemblance to the eastern margin of the Barrow Sub-basin during the Upper Jurassic. Both basins developed on continental crust and display active rifting during the Upper Jurassic period with each major faulting episode resulting in the initiation of a new depositional sequence.

The major difference between the eastern Barrow Sub-basin and the South Viking Graben during the periods of fan deposition is the proximity to provenance. In the Brae Field submarine fan model a very narrow littoral zone exists between provenance and the active submarine fault scarp. As a result, coarse clastic sedimentation began with major fault movement and antithetic basin subsidence. Rapid erosion of the newly uplifted terrain resulted in rapid deposition of coarse clastic fringe in a narrow zone (~5 km wide) extending for 15-20 km along the fault margin (Stow, 1985).

Depositional processes included base of fault scarp breccia and conglomerate facies associations deposited as rock avalanches or mass flow. The development of a basinward inter-fan channel and lobe conglomerate / sandstone association resulted from grain flow - liquefied flow - turbidity flow processes which grade basinward to a mudstone dominant facies (Stow et al, 1982; Stow, 1985). Distinct slump units of variable thickness displaying contorted bedding and chaotic mudstone, conglomerate, sandstone mixes also occur associated with the rapid rates of sedimentation and periodic tectonic activity.

The distance between the provenance and active rift zone (>20 km) in the Barrow Sub-basin during Upper Jurassic time was significantly greater than the Southern Viking Graben. This meant that coarse clastics were not available in the outer shelfal regions for immediate redeposition into the subsiding depocentre at the foot of the active fault scarps. Massive slumping and mass flow deposits have been intersected in the Barrow Sub-basin, however they consist of reworked outer shelfal fine grained argillaceous and dominantly shaly sediments (Facies 6, Section 6.1.3). The deposition of coarse fluviatile and continental clastics resulted from the progradation of fluvial / deltaic systems across the shelfal areas during relative lowstands dominantly created by tectonic uplift. This caused canyon incision into the outer shelf margins and deposition into the subsiding basin via point source, canyon fed systems, rather than elongate mass flow processes that dominate depositional mode for the Brae Fan Complex.

A variety of depositional controls, depositional settings and fan models are applicable to submarine fan and turbiditic deposition. It is important to understand the controlling depositional processes; sediment supply, tectonics, sea level changes and reworking bottom currents when evaluating the type of fan deposition that is likely to occur in any given area. With respect to the Upper Jurassic of the eastern Barrow Sub-basin we are able to evaluate the relative timing and degree of fault movement from seismic profiles and well data, as well as the likely provenance and mode of deposition of the intersected sands from core analysis and petrographical studies. Unfortunately, due to the general lack of good quality seismic data required for detailed stratigraphic resolution and the significant overprinting effect of tectonism on eustatic sea level fluctuations in the study area, it is difficult to ascertain the degree to which sea level fluctuations controlled and modified fan distribution. The lack of data also precluded the evaluation of the effect of reworking bottom currents on the ultimate sand distribution. However, we know from recent studies that modification from bottom currents is a common phenomenon (Mutti & Normark, 1987). Consequently it can be concluded that the eastern Barrow Sub-basin during the Upper Jurassic was an area of relatively small, focussed fan deposition and is therefore analogous to Mutti & Normark (1987) Type D turbiditic basin. The submarine fans in the Barrow Sub-basin developed in response to active rifting on continental crust with periods of high sediment supply and progradation, plus continual tectonic modification of the basin shape affecting the distribution of basinal fan complexes.

With improved seismic quality required for detailed seismic stratigraphy plus an increased number of wells drilling through the Upper Jurassic interval for stratigraphic control, a more detailed analysis of the distribution of individual submarine fan complexes could be undertaken.

9 ECONOMIC APPLICATION OF RESULTS

The lack of good reservoir quality Jurassic sandstones intersected by wells in the study area has previously downgraded the prospectivity of this section. However, the results of this study suggest that potential for reservoir development exists in three of the five recognised depositional sequences (Sequences 2, 4 and 5) with secondary potential in Sequence 3. Sequences 2, 4 and 5 sandstones were deposited during periods of relative lowstand resulting in submarine fan and turbidite deposition in basinal areas. Massive Sequence 2 submarine fan facies have been intersected on Barrow Island by Barrow Deep-1 and Perentie-1, Sequence 4 submarine fan sandstones in Bambra-1 and 2, and Flag-1, while distal turbidite facies of Sequences 4 and 5 have been intersected in Barrow-1, Barrow-25, Harriet-1, Bambra-2 and Flag-1. No well has penetrated the proximal fan facies of Sequence 5 lowstand deposits, however mounds are recognised in the Lowendal Syncline area between the Flinders Fault zone and Barrow Island. One such Sequence 5 mound is shown on Figure 92 and may represent one of many similar features that potentially exist.

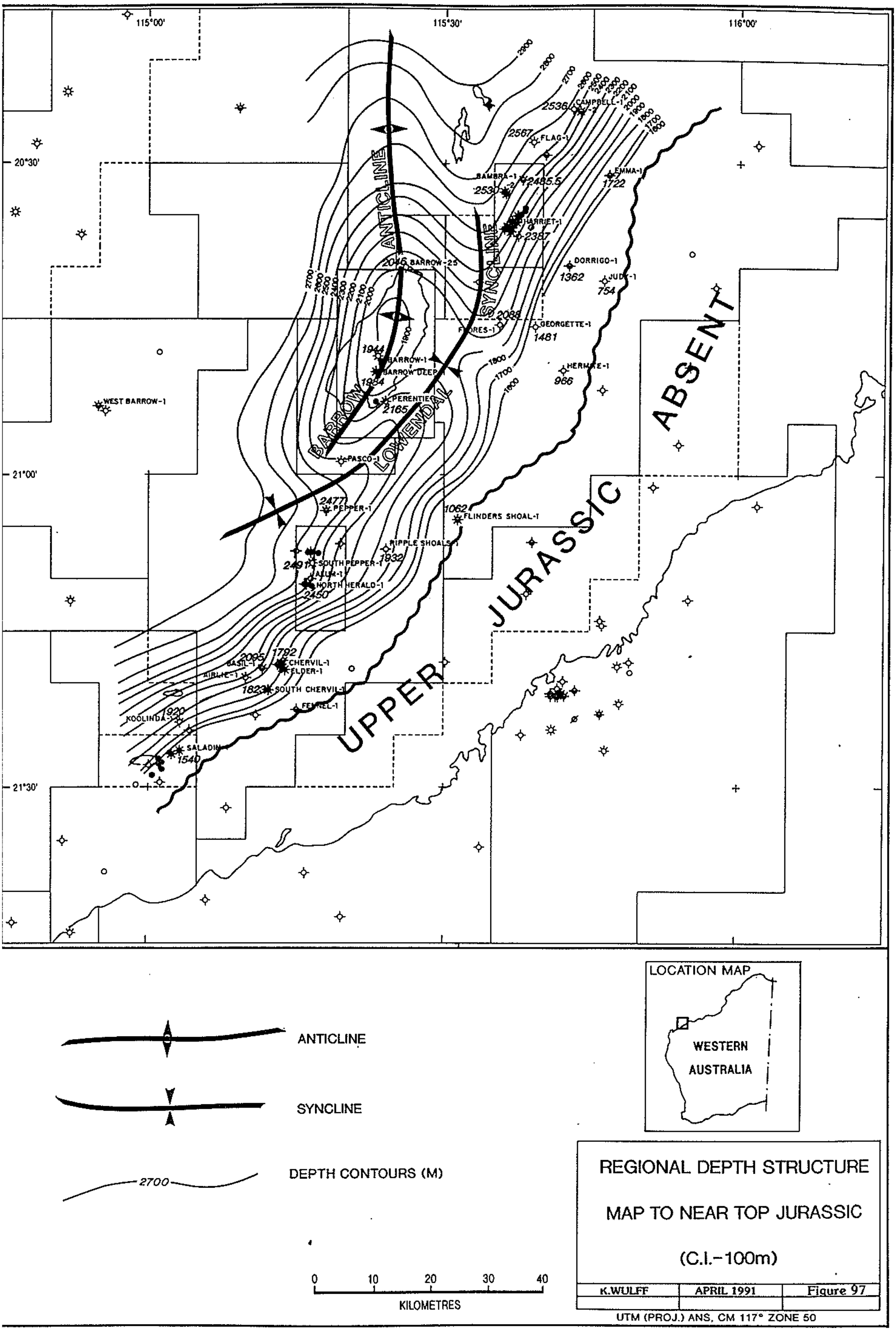
Producible hydrocarbons have been intersected within Sequence 2 and 5 sand packages on Barrow Island and oil shows have been noted in Sequence 4 and 5 sands in Harriet-1 and Bambra-2.

9.1 PLAY TYPES

9.1.1 Updip Pinchout Limit of Detached Sequence 2 Basin Floor Fan Sands

As shown on Figure 81 the massive submarine fan complex intersected in Barrow Deep-1 and Perentie-1 may extend for greater than 20 km to the north and west of Barrow Deep-1, and probably >20 km to the south and east of Perentie-1. These sands were deposited during the Callovian/Oxfordian prior to the onset of uplift of the Barrow Island anticline in the Late Tithonian. The deposition of the fan complex was concentrated within the axis of the developing rift systems. The growth of the Barrow anticline from Late Jurassic - Tertiary times resulted in the development of the Lowendal Syncline between the Barrow Anticline from the Flinders Fault zone. This is shown on Figure 97 which is a regional depth structure map to the Near Base Cretaceous displaying the structural trend of the Lowendal Syncline and Barrow Anticline. The depositional package represents detached basin floor fan sands deposited as a result of a Type I unconformity. The potential exists for hydrocarbon entrapment in the proximal updip pinchout of the basin floor fan complex south and east of the axis of the Lowendal Syncline. This is shown on Figure 97 which is a schematic of the play type. Recognition of this play type requires detailed seismic - stratigraphic interpretation and delineation of a structural nose.

As shown on Enclosures V & VII, the potential also exists for massive Upper



REGIONAL DEPTH STRUCTURE

MAP TO NEAR TOP JURASSIC

(C.I.-100m)

K.WULFF	APRIL 1991	Figure 97

UTM (PROJ.) ANS, CM 117° ZONE 50

Callovian age basin floor fan sands north of the Bambra area onlapping onto an old pre Upper Callovian high. Depth to these sands in the central basinal areas would be in excess of 4,000 m. The Sequence 2 basin floor fan sands will be encapsulated by shale, namely the underlying Lower Dingo Claystone and overlying Upper Dingo Claystone (in Carnarvon Formation nomenclature) or the pelagic deep marine shale of the distal prograding lowstand complex or transgressive/regressive wedge of Sequences 1 and 2. The juxtaposition of mature source rock with the sand package increases the likelihood of early oil emplacement preserving porosity and inhibiting compaction effects. Gas flushing is considered the major risk of this play type.

9.1.2 Development of basal Sequence 4 & 5 Canyon Fed Fan Sands

Tithonian, and possible Kimmeridgian age, incised canyons have been recognised in the study area on the Flinders Fault Terrace and Peedamullah Shelf (Figure 78). Distal turbidite facies have been intersected in Bambra-1, Bambra-2 and Flag-1 immediately overlying the Kimmeridgian unconformity. Thin proximal mass flow deposits have also been intersected in Georgette-1. These sands were deposited in an outer shelfal - slope - basinal environment as a series of progradational submarine fan - foreslope deposits. The potential exists for the development of submarine fan sands downdip from the mouth of the incised canyons within the Lowendal Syncline area. This is displayed on Figure 98. The coarse grained nature of the basal Sequence 4 sediments intersected in Georgette-1 attests to the reworking and distribution of coarser grained sediment

KIMMERIDGIAN & TITHONIAN TURBIDITE MOUNDS

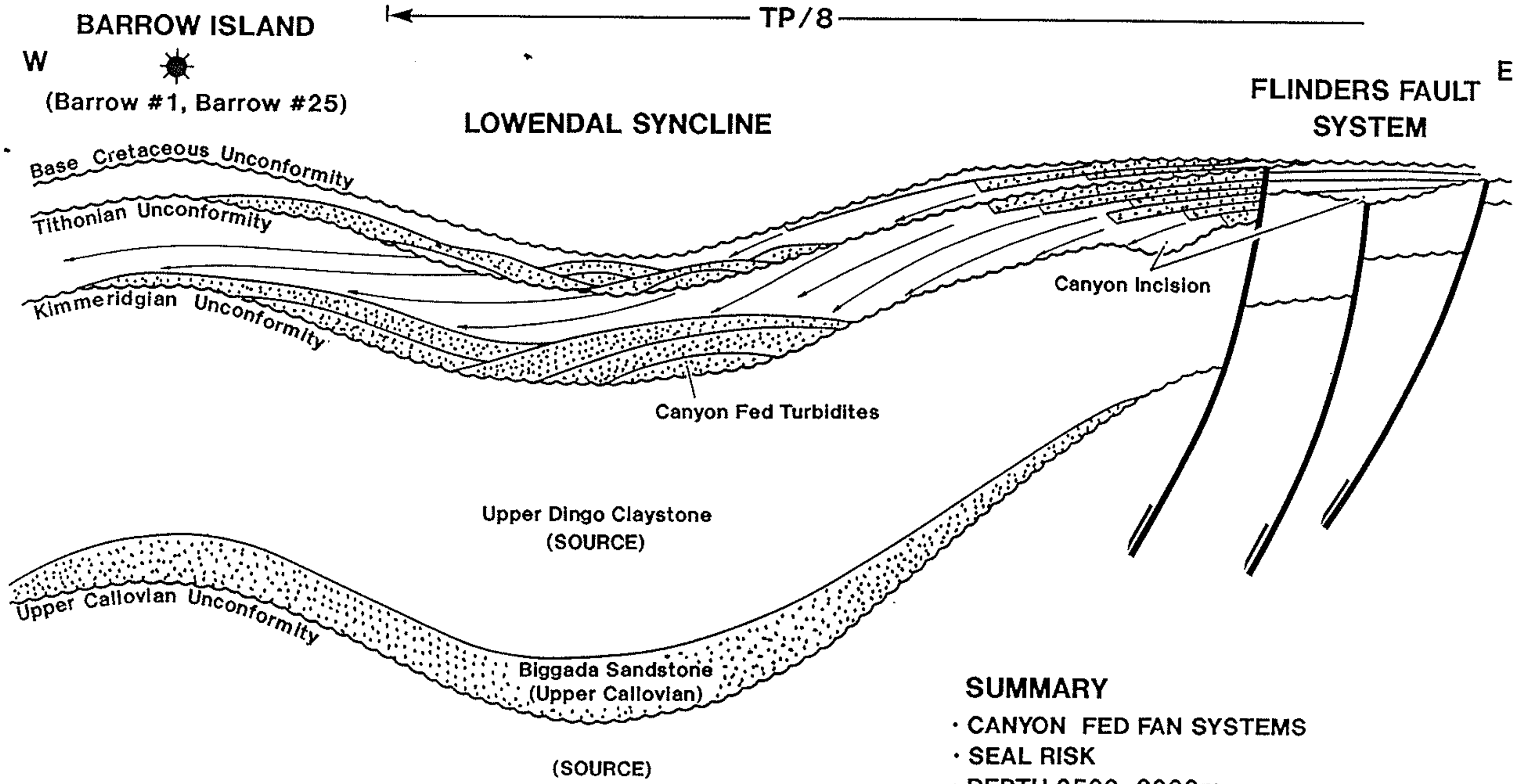


Figure 98 Schematic play type. Summary displaying pinchout of Sequence 2 basin floor fan plus Kimmeridgian & Tithonian mound complex in Lowendal Syncline area.

SUMMARY

- CANYON FED FAN SYSTEMS
- SEAL RISK
- DEPTH 2500–3000m
- EXCELLENT OIL CHARGE

which may provide adequate reservoir quality sandstones in optimal locations. A low relief mound at the mouth of a canyon south of Georgette-1 and Hermite-1 is one such feature. However, the low amplitude nature of this mound suggests a muddy nature (Kirk, 1985) and probably represents a final waning phase of turbiditic deposition down the canyon axis as the sea level began to rise. The size of the canyon (300-500 m deep, 3-5 km wide and 20-25 km long) attests to a moderately significant volume of sediment bypassing the shelfal areas and being deposited in basinal localities. Due to the relief of the developing rift shoulder (Flinders Fault zone) the potential exists for these sands to be detached from the point source and overlain by pelagic marine shales. Detailed seismic - stratigraphic studies of good quality regional data is required to substantiate this play type.

In the Bambra area small (<3 km) mounds can be recognised on seismic and have been intersected in Bambra-2. The superposition of overlying coarsening upward progradational lowstand facies precluded the development of top and lateral seal in that area. However, the potential exists for the development of fan complexes in more basinal localities where they may be overlain by pelagic shales. The potential also exists for better sand development to the north of the Bambra/Flag/Campbell area where seismic evidence suggests the thickening of sandstone packages towards the Dampier Sub-basin (Enclosure VII).

9.1.3 Anticlinal or Fault-Controlled 4-way dip Closures at Upper Sequence 4 level

Moderate to good oil shows have been recorded within this interval in Bambra-1 including patchy to even yellow - white fluorescence in Core 2 (2713-2730 m). No significant sealing shales were intersected whilst drilling this interval and hydrocarbons noted have been interpreted as representing post diagenesis migrating hydrocarbons trapped within the tight pore space and low permeability sand intervals. The presence of these hydrocarbon shows over a significant interval suggests that this sand unit acted as a carrier bed for migrating hydrocarbons from source kitchen areas. Sealing these fine grained, progradational fan facies is reliant upon shales associated with maximum flooding surfaces which occur at the top of the coarsening upward cycles representing period of rapid eustatic sea level rise. The thickness of the transgressive shales at the top of the parasequences is generally less than 10 m before the coarsening upward cycle is re-established. The thickness of these potential sealing shale units are expected to increase basinward, however it is likely that reservoir quality will deteriorate further, moving into more distal locations. This reservoir objective is considered high risk due to the lack of sealing shale intervals and the likelihood of overlying prograding lowstand deposits downlapping this interval precluding the possibility of stratigraphic traps.

9.1.4 Anticlinal or Fault-Controlled 4-way dip Closures in Sequence 5

The lowstand fan mounds interpreted within the Lowendal Syncline and adjacent to the Flinders Fault zone display possible 4-way dip closures (Figure 89) and offer exploration objectives within the study area. The presence of medium - coarse grained sands (Facies 7) with moderately preserved porosity and permeability (Figure 32) in the distal turbidite facies supports coarse clastic deposition into the basin depocentre. The reservoir quality within these proximal fan complexes may therefore be good. Lowstand turbidite sands have also been interpreted in Harriet-1 (2450 m) and Bambra-2 (2650 m). Both of these sand intervals contain good hydrocarbon shows with white - pale yellow patchy fluorescence with associated increases in background gas being recorded in these zones. The fan complexes occur within an active source kitchen area consequently hydrocarbon charge is not a concern. The primary risk with this play is top seal due to the generally silty, coarsening upward section of the Sequence 5 overlying lowstand wedge facies (Enclosure V).

The distal thinly bedded turbiditic Sequence 5 lowstand sandstones intersected on Barrow Island have produced hydrocarbons at rates up to 985 BOPD (Barrow-1). Production comes from thin (<3 m) dominantly medium grained sandstones interbedded with highly bioturbated laminated shales and siltstones.

10 CONCLUSIONS

The depositional models proposed for the Upper Jurassic sediments in this thesis by no means provide a unique solution to the sedimentological history of the section. They do however, provide a basis for future, more detailed sequence analysis to be carried out in evaluating the facies distribution, tectonic controls and sea level effects on sedimentation. Jurassic sands in the Barrow Sub-basin have in general been disappointing with respect to reservoir quality, downgrading this interval as a prospective sequence. This thesis has attempted to develop depositional models to enhance the understanding of facies and age relationships of Upper Jurassic sediments intersected by available well control. The following summarises the conclusions developed by this research project.

1 Seven sandstone facies were recognised whilst logging Upper Jurassic core in the study area. Each facies had unique reservoir properties related to depositional environment, diagenetic history and provenance. All seven sandstone facies were deposited in marine environments ranging from outer shelfal to basinal settings (neritic - bathyal). Upper Jurassic shelfal, beach and fluvial - deltaic sediments are absent in the study area due to episodic uplift and erosion of Jurassic and Triassic sediments from the Peedamullah Shelf and Flinders Fault Terrace.

2 Three sandstone facies related to submarine fan deposition displayed potential for reservoir development, two of which were restricted by intense

porosity-occluding diagenetic processes. The best reservoir development occurred in Facies 7, a medium-coarse grained, well sorted sandstone deposited in a proximal basin floor fan setting or interbedded turbidite.

3 Medium - coarse grains of banded iron formation, jasper, plagioclase and microcline in combination with abundant quartz are common in the Upper Callovian and Tithonian turbiditic sands. The provenance for these sands are most likely the being weathering products of the Banded Iron Formations and alkali granites that constitute the bulk of the Hammersley Ranges and Pilbara Shield. These pre-Cambrian complexes mark the eastern boundary of the Carnarvon Basin adjacent to the study area.

4 The diagenetic history of each sandstone facies is dependent upon the depositional setting and geographical position in the basin. Early calcite cementation restricting the development of syntaxial quartz overgrowths and compaction, which has later been leached by migrating acidic fluids, is responsible for the best porosity and permeability development. This was recorded in the dominantly medium grained turbiditic sandstones of Facies 7. Quartz overgrowths, siderite cementation and kaolinisation has generally occluded porosity and permeability in the remaining sandstone facies.

5 Tectonism throughout the Upper Jurassic has been the major control on the distribution and style of sedimentation within the Barrow Sub-basin. Rifting

within the study interval began during the Early Callovian, with reactivation during Upper Callovian, Kimmeridgian and Tithonian times. These periods of tectonism appear synchronous with the development of depositional sequences within Upper Jurassic of the Barrow Sub-basin. Vertical displacement in excess of 1000 m occurred during Kimmeridgian times resulting in significant erosion of Oxfordian and older section from uplifted areas. Similar displacement occurred during the Upper Callovian rifting episode while fault displacement during the Tithonian was in the order of 200-300 m.

6 The basin shape changed during the Upper Jurassic due to continued rifting and uplift of the Barrow Anticline as early as Mid Kimmeridgian time. The change in basin configuration affected the distribution and style of sedimentation in basinal areas.

7 Five depositional sequences were recognised within the Upper Jurassic, four of which appear to have been terminated by renewed tectonism which induced relative lowstands and unconformity surfaces. The five depositional sequences recognised were Lower - Upper Callovian, Upper Callovian - Mid Oxfordian, Mid Oxfordian - Lower Kimmeridgian, Kimmeridgian - Mid Tithonian and Mid Tithonian - Base Cretaceous.

8 Poor seismic data quality in the study area combined with the lack of well data throughout the entire Upper Jurassic sequence made it impossible to

evaluate in detail the degree to which sea level fluctuation has controlled or modified submarine fan development. The correlatability of sequence boundary development with active periods of tectonism however support tectonism being the principal control on submarine fan development in the eastern Barrow Sub-basin during the Upper Jurassic period.

9 Incised canyons up to 20 km long, 3-5 km wide and 700 m deep have been mapped on the eastern shelf margin. Major canyon incision occurred in relative lowstand periods during Tithonian and Kimmeridgian time. Upper Callovian canyon incision allowing the shelfal bypass of dominantly medium grained massive submarine fan lobes intersected on Barrow Island has not been recognised in the study area, probably due to post-deposition erosion.

10 Four play concepts are recognised which have not been tested in optimal locations within the Barrow Sub-basin: i) updip pinchout of detached Sequence 2 basin floor fan sands, ii) development of basal Sequence 4 canyon fed fan sands, iii) anticlinal or fault controlled dip closures at upper Sequence 4 level, iv) fault controlled or four-way dip (mounds) closures at upper Sequence 5 level.

11 The Upper Jurassic of the eastern Barrow Sub-basin cannot be correlated in detail to the global eustatic sea level charts developed by Haq et al (1987). This is due to the significant effect of active rifting on basin configuration, accommodation space and relative sea level associated with the break-up of

Gondwanaland during this period. The geochronological age of stages and stage ranges applied by Haq et al (1987) are also significantly different than those applied by Harland (1982) on which the geochronological subdivision for accepted Australian biostratigraphy is based. Consequently the applicability of global synchronicity on the basis of available charts is tenuous. The geochronological age differences need to be resolved and the effect of the separation of Gondwanaland on accommodation space needs to be researched in detail before the degree to which glacio-eustatic fluctuations control the development of sequence boundaries in the Upper Jurassic of the Barrow Sub-basin can be resolved.

12 To reliably predict the development and distribution of submarine fans in the Barrow Sub-basin or elsewhere, the major controlling depositional processes, namely tectonics, sediment supply and sea level must be well understood. With respect to the Barrow Sub-basin further effort is needed in acquiring and processing seismic data of sufficient quality to undertake detailed seismic stratigraphy studies. Depositional models explaining the lithofacies distribution can only be reliably postulated when the interplay between the controlling processes is understood. Analogies between basins should also only be drawn when controlling processes are similar. Drawing analogies from dissimilar basins can lead to interpretational error when models are used to drive the interpretation. This is clearly demonstrated with respect to submarine fan models whereby tectonics, sediment supply, type of crust and eustasy can all affect the type of submarine fan facies

deposited.

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APPENDIX I

CORES DESCRIPTIONS

BAMBRA-1, CORE 2, 2713-2728.75 m.
CHERVIL-1, CORE 7, 1785-1790.6 m.
DORRIGO-1, CORE 3, 1593-1607.65 m.
ELDER-1, CORE 2, 1536.2-1545.5 m.
EMMA-1, CORE 3, 2185-2194.3 m.
GEORGETTE-1, CORE 1, 2156-2160 m.
GEORGETTE-1, CORE 2, 2273-2281.45 m.
SOUTH PEPPER-1, CORE 8, 2367-2285.34 m.
BARROW-1, CORE 22, 6682-6700 ft.
BARROW-1, CORE 23, 6741-6759 ft.
BARROW-1, CORE 24, 6760-6778 ft.
BARROW-1, CORE 25, 6778-6793 ft.
BARROW-1, CORE 26, 6793-6805 ft.
BARROW-1, CORE 27, 6805-6823 ft.
BARROW-1, CORE 28, 6823-6841 ft.
BARROW-1, CORE 29, 6841-6859 ft.
BARROW-1, CORE 30, 6859-6877 ft.
BARROW-1, CORE 31, 6877-6895 ft.
BARROW-1, CORE 32, 7732-7745 ft.
BARROW-1, CORE 34, 7872-7889 ft.
BARROW-1, CORE 36, 8520-8526 ft.
BARROW-1, CORE 37, 9297-9304 ft.
FLAG-1, CORE 3, 2742-2750.2 m.
FLAG-1, CORE 4, 2993.1-3000.5 m.
FLINDERS SHOAL-1, CORE 5, 4903-4926 ft.

L NAME: BAMBRA #1 · | COMPANY: AUST OCCIDENTAL | DATE LOGGED: 3/6/1988 | SCALE 1:20

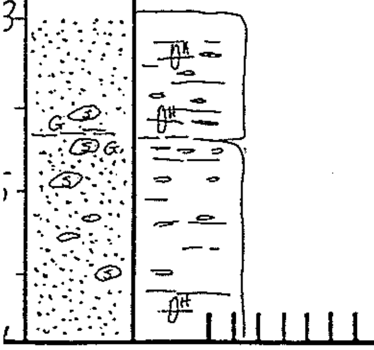
E No.: 2 | INTERVAL FROM 2713 TO 2728·75 m | RECOVERY % | LOGGED BY: K. WULFF

H	LITH.	GRAINSIZE / STRUCTURES clay silt v.fine fine medium coarse v.coarse pebbles	CORE DESCRIPTION	FACIES	ENVIRON.

TOP OF CORE @ 2713m.

3

5



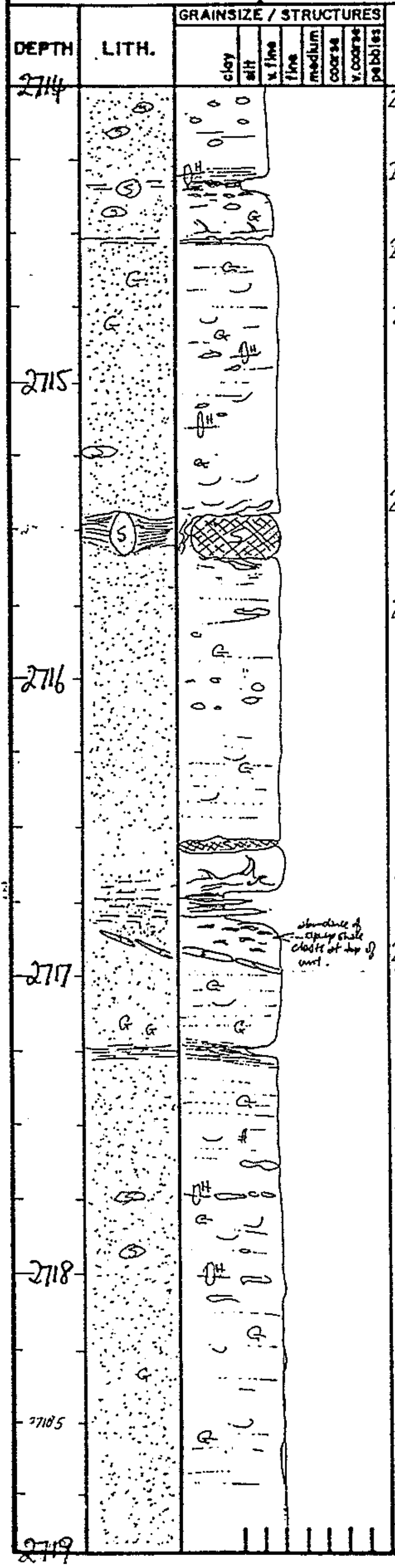
2713-2713·35m SSt lt bnshgy-lt ol gy; vf-f gnd, subang-rnd, sbsph, spherical, well srtd, qtz gns are transl, conch fract and occ frosted, sil cement^d, abdt qtz overgrowths, faint planar lam indicated by alignment of grains. mod glauc, vr pyrite, poor intergran porosity mnr arg in void space. mod abundt sideritised horizontal burrows.

2713·33m Arg Sltst - gag to - clyst

2713·33-2714m (As for 2713-2713·33m).

WELL NAME: BAMBRA#1 | COMPANY: OCCIDENTAL | DATE LOGGED: 3/6/1988 | SCALE 1:20

CORE No.: 2 | INTERVAL FROM 2713 TO 2728.76m | RECOVERY % | LOGGED BY: K. WULFF



CORE DESCRIPTION | FACIES | ENVIRON.

2714-2714.29 SSt (as for 2714.51-2715.45m)

2714.29-2714.31m Sideritised Arg Siltstone, (as for 2715.45-2715.6m)

2714.5m clay break indicating change in depositional cycle.

2714.51-2715.45m SSt. ltgy-lt olgy, vf grnd (occ fine), subang-rndd mod-well sorted, sil cementd minor calc, generally massive, very faint subhorizontal lam, mod glauc + vr pyrite, poor intergranular porosity.

2715.45-2715.6m Siderite nodule encapsulated by clyst bnsh gy - dk bnsh gy. 14x8cm siderite nodule, vertically orientated surrounded by silty clyst which has been extensively slickenslided and has a lustrous texture

2715.6-2716.75m SSt ltgy-lt olgy, vf grnd, mod-well sortd, well silica cementd, non calc, v sl planar laminated indicated by alignment of qtz grains. mod glauc, mod abdt sideritised worm burrows?? (2-4mm diam) SSt has poor observ porosity due to authigenic qtz overgrowths and minor white argillaceous matrix.

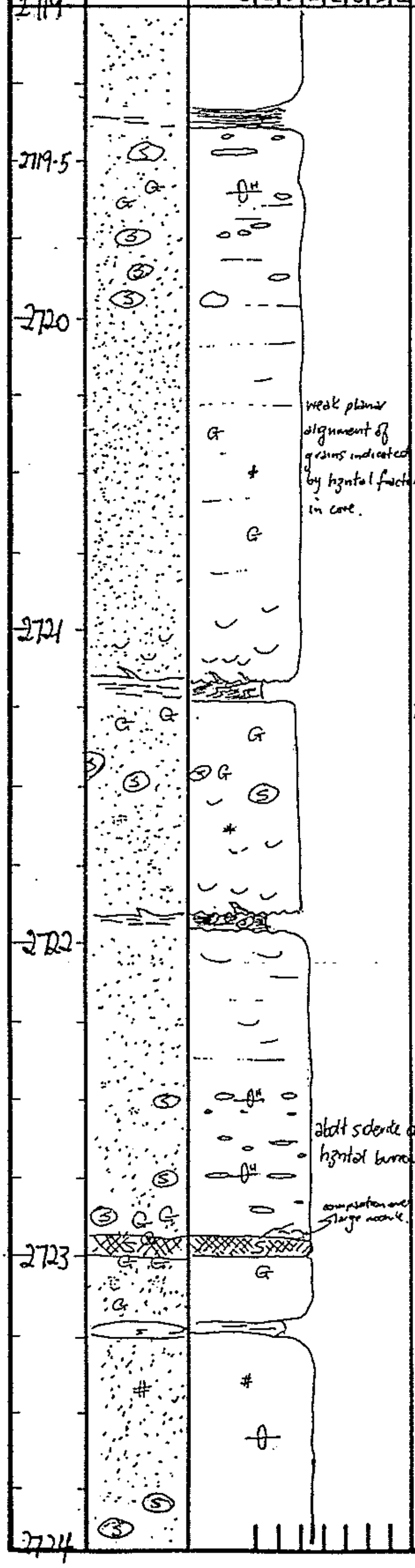
2716.75-2716.82m Sndy Siltstone and claystone interbeds. (1-2cm scale).

2716.82-2717.21m SSt-olgy-ltgy, vf finegrnd, poor-mod sortd, abdt small (<2 rip up clasts at top of unit. Sideritised basal contact with underlying massive fine grained sst.

2717.21-2719.0 SSt ltgy-lt olgy, vf-fgnd, mod well sortd, subang, gen massive, very weakly planar laminated, Dip angle ~2°. Well silica cementd, non calc, localised patches of siderite cement, nodules infill burrows 2-5mm in diam. Mod glauc + pyr t/o. Very poor vis porosity.

WELL NAME: BAMBRA #1
COMPANY: OCCIDENTAL
DATE LOGGED: 2 / 6 /1988
SCALE 1:20
CORE No.: 2
INTERVAL FROM 2713 TO 2728·75m
RECOVERY %
LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES (clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles)	CORE DESCRIPTION	FACIES	ENVIRON.



2719-2719·38m SSt ltgy-lt olgy, vfgnd, subrnd, well srtd, gen mass, weak planar orientation of grains, silc cemntd, poor intergran porosity, minor arg mtx.

2719·38-2719·4m - Core missing.

2719·4-2721·15m SSt ltgy-lt olgy, vf-f gnd, subrnd, well sorted generally massive, occasional glauc, silc cement, non calc, sucrosic texture, ext quartz overgrowths. occ siderite nodules, 1cm-5cm in diam. abdt horizontal burrows (2-4mm in diam), infilled by siderite cement weak planar laminations. occasional dish structures indicative of rapid dewatering and flame structures occur at the base of the unit. Base of the unit is sharp and erosional. Nil - poor visible intergranular porosity.

2721·15-2721·21m. Argillaceous Siltstone dkgy-gysh blk, v. argillaceous, mod micaceous, subfissile, contains slickensides and thin lenses (mm scale) of fine grained arg sst.

2721·21-2721·94m SSt. ltolgy-lt gy, vf-f gnd, mod-well sorted, subang-subrnd, sil^c cement^d, non calc, glauc, pyritic, occ sid nodules 1-2cm diam. hzntal burrows. minor intergran porosity.

2721·94-2721·97m (Siltstone gdg to clyst-(as for 2721·15-2721·21m)

2721·97-2722·75m SSt (as for 2721·21-2721·94m)

2722·75-2723·25m SSt lt olgy-ltgy, very f-fine grained, subang-subrnd, mod srtd, sil cmt^d, sl. calc, gen mass, weakly planar laminated, mod glauc and dissem pyrite. large siderite nodule (5×10cm) orient^d vertically. Compaction drape is obvious in overly sediments.

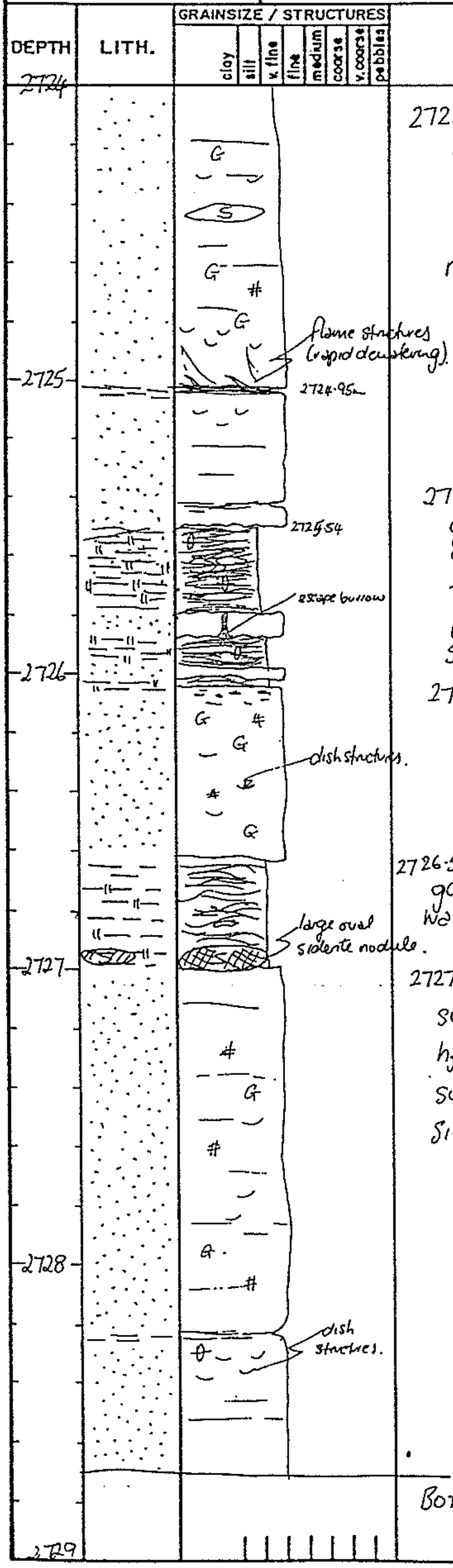
2723·25-2724m SSt lt olgy-ltgy, vf-f gnd, subrnd, mod-well srtd, gen massive, brittle, sil cemt^d, non calc, mod glauc, pyr, poss authigenic white clay infilling intergranular pore space. little observable porosity.

Wk4

WELL NAME: BAMBRA #1 | **COMPANY:** AUST OCCIDENTAL | **DATE LOGGED:** 3 / 6 /1988 | **SCALE** 1:20

CORE No.: 2 | **INTERVAL** FROM 2713 TO 2728·75m | **RECOVERY** % | **LOGGED BY:** K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES	CORE DESCRIPTION	FACIES	ENVIRON.



2724-2725·54m SSt- lt ol gy - lt brnsh gy - lt gy, dom qtzitic, vf-f grd, subang-subrnded, occ rnd, mod-well srtd, gen mass, v wkly planar lam (indicated by hzntal fractures + planar alignment of grains). dom silc cmt, non calc, mnr arg mtx, abdt dissem gluc + pyrite, ext qtz overgrowths, occ siderite nodules @ 2724·42m. flame structures + dish structures common between 2724·8-2724·95. Depn break @ 2724·95m. indicated by Shale break.

2725·54-2726m Sltst gdg to Slty Clyst grnsh blk - dk gy, gen mass, subfissile, occ qtz grns (f-med grd). ext bioturbated, gen wavy lam, trace carbonaceous matter, slickenslides. Thin sandstone beds occur @ 2725·8m + 2725·96m. Vertical Escape burrows within thin sst beds support rapid deposition. SSt- (as for 2724-2725·54m)

2726-2726·58m (as for 2724-2725·54m). but with concentration of small (<0·5cm long) rip-up shale clast concentrated near top of unit.

2726·58m- 2726·87m Sltst grnsh blk-dk gy, gen mass, subfiss gds i/p to silty clyst, occ floating med grn qtz. ext bioturb. wavy planar lam.

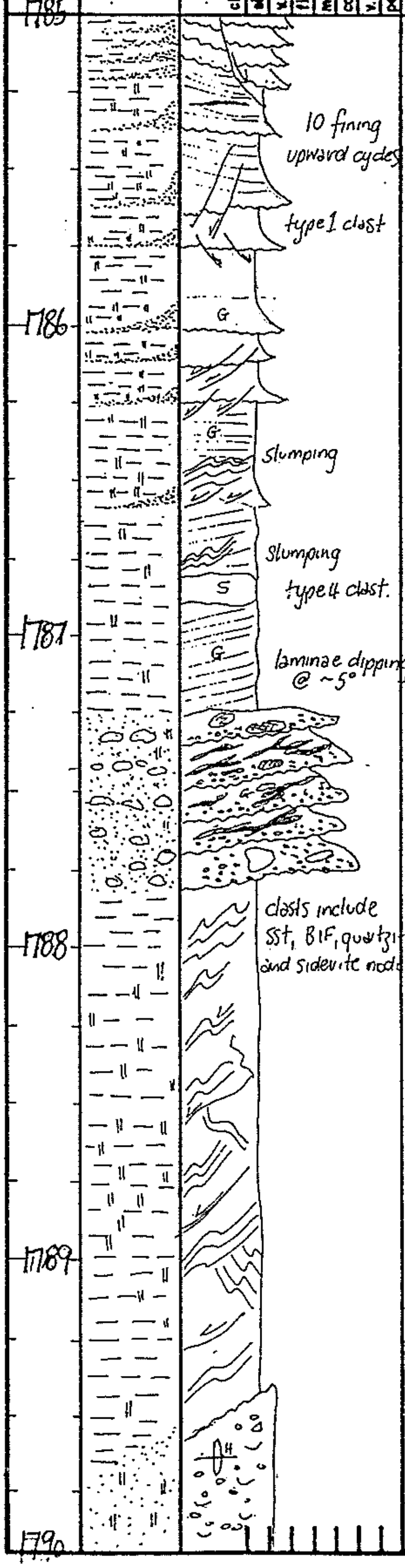
2727-2728·76m SSt dom qtzitic, v lt gy - lt ol gy, vf-f grnd, subang-subrnd (occ rnd); mod srtd, gen massive, v faint hzntal lam, com gluc and pyr, sil cemtd, non calc,-v sl calc sucrosic texture, occ hzntal burrows (0·2-0·5mm) infilled b siderite cement. depositional break @ 2728·25m

BOTTOM OF CORE @ 2728·75m

WELL NAME: CHERVIL -1 · | **COMPANY:** WMC | **DATE LOGGED:** 30/9 /1988 | **SCALE** 1:20

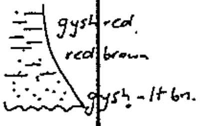
CORE No.: 7 | **INTERVAL FROM** 1785 **TO** 1790·6 **m** | **RECOVERY** % | **LOGGED BY:** K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES	CORE DESCRIPTION	FACIES	ENVIRON.



1785·0 – 1786·25m. Interbedded fine grained sandstone and claystone. red bn – gysh red clyst and pink'gy – lt bn gy sst. SSt is vf grnd, subang – subrnd, well srtd, gen mass, pore throats choked by white clay. rapidly grades upward into laminated silty claystone with thin sandstone lenses (mm scale). Grades in turn upward into gysh red silty claystone. planar laminated. abdt faulting. base of fining upward sequence is sharp and weakly erosive.

(faulting post dates compaction).



1786·25 – 1787·2m Sandy Siltstone gdg to silty claystone. lt gysh-red, mod-well srtd, occ thin sst lenses (mm scale) mod lam disrupted by faulting and compaction effects. Very weakly bioturbated, mod abundant argillaceous matrix

1787·2m – 1787·83m Agglomerate gysh green – pale yellowish brown silt – boulder sized, ang – rnded, v prly sortd. abdt type 1, 2 + 4 clasts within sandy siltstone matrix. abundant fract infilled by Kaolin(?). depositional dip ~15–20°. (5 apparent erosional mass flow cycles).

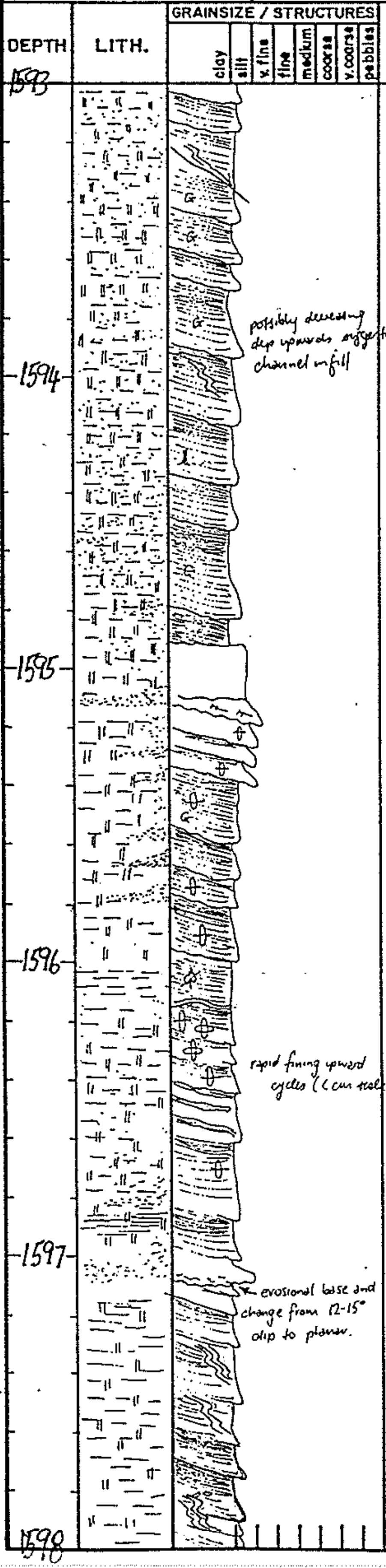
1787·83 – 1789·48m <u>Silty Claystone</u>

dk bn – bn gy, massive, abdt slickenslides. Core is fract and generally rubble. The claystone is ~~massi~~ faintly planar laminated however extensive post deposition deformation has obliterated primary sedimentary structures.

1789·48 – 1790m Glauconite and lithic fragments in Silty claystone matrix. gysh gn – dk gnsh gy, poorly sorted, weakly planar laminated, contains pisolitic nodules. mod hztal bioturbation. common dish-like structures. abdt glauc. occ pyrite. gen sil, minor calc.

WELL NAME: DORRIGO #1	COMPANY: OCCIDENTAL	DATE LOGGED: 23/6 /1988	SCALE 1:20
CORE No.: 3	INTERVAL FROM 1593 TO 1607.55m	RECOVERY %	LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES	CORE DESCRIPTION	FACIES	ENVIRON.



1593 = 1595·15m Interbedded, claystone, siltstone and fine gnd sandstone. med-dk gy – med ol gy – lt ol – lt bn grey. fining upward cycles in centimetre scale.

SSt – vf-f gnd, gds i/p to silty sst, subang – subrnd, mod arg, silc cemented, non calc, nil observ porosity.

Argill SSt – ol gy, vf gnd, subang – subrnd, mod sorted, silc cementd. abdt argill mtx, abdt glauc, trace pyrite.

Silty Clyst med gy – dark gy, faintly planar lam, occasional floating quartz grains (f-med gnd), mod carbonaceous, lam dip @ 10-15°. minor bioturbated.

FEATURES

1) Sand lenses are often boudinaged. mod abundant sand volcanoes indicative of rapid dewatering.

2) cyclic nature of deposition

3) probable detrital glauconite

4) occ ripple surfaces(?) with sand lenses in lee of claystone rippled.

1595·15 – 1596·1m As for 1593 – 1595·15 but with major erosional scour contact @ 1595·15m separating sequences.

1596·1 – 1596·34m Sandy Claystone grading to siltstone. dark greenish gy – bnsh gy, mottled, gen massive, mod calcareous, mod silc cement. ext bioturbated. 2 apparent depositional cycles. depn dip @ 10°

1596·34 – 1596·82m (As for 1597·1 – 1598m)

1596·82 – 1597·1m interbedded arg sst and claystone. (as for 1597·1 – 1598m except with erosional (scour) base with poorly developed lag deposit)

1597·1 – 1598m Interbedded argillaceous sandstone and silty claystone dk gn gy – med dk gy – lt bn gy. silt – very fine grained, mod srtd, sil cmt non calc, very faintly bioturbated, faint ripple surfaces, occ slumps. depositional dip @ 10°. gds rapidly into argill siltstone and clyst.

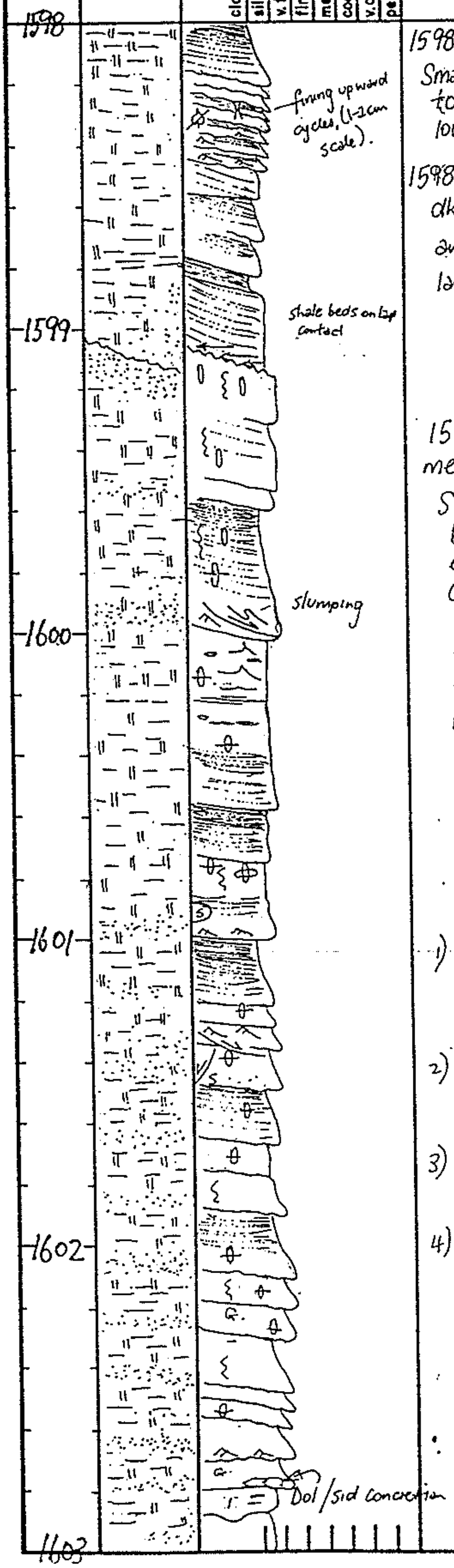
Clyst bn gy – ol gy, planar lam, rr biot, mod carbonaceous. rr glauc & pyrite.

2 of 3.

WELL NAME: DORRIGO #1 | COMPANY: OCCIDENTAL | DATE LOGGED: 23/6/1988 | SCALE 1:20

CORE No.: 3 | INTERVAL FROM 1593 TO 1607.55m | RECOVERY % | LOGGED BY: K. WULFF

DEPTH | LITH. | GRAINSIZE / STRUCTURES (clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles) | CORE DESCRIPTION | FACIES | ENVIRON.



1598 – 1598.4m <u>Interbedded SSt and Arg Clyst</u>.
Small scale fining upward cycles, base of vf gnd arg sst grading upward to silty clyst (2-4 cm cycles). depositional dip (?) @ 12°. minor low amplitude mm scale X-bedding in sst lenses.

1598.4 – 1599.15m <u>Intercalated SSt + Clyst</u>. lt gy - ol brnsh gy - med dk gy. <u>SSt</u> - is vf gnd, argillaceous, mod-well sortd, siliceous and grades up into <u>silty clyst</u> - generally massive, planar laminated, weakly x rippled. non calcareous.

1599.15 – 1603m <u>interbedded Sndy Sltst and slty clyst</u>
med - dk gy - lt med gy - lt ol gy.
<u>Slty SSt</u> - vf gnd, well sorted, abund arg mtx, hzntal lam. bioturbated. dom sil cmt, mnr calc, sharp basal contacts occ sym ripples (mm-cm scale) ctcs @ 1601.0, 1602.6m.
Grades upward into <u>Sndy Sltst</u>: - med - dk gy, argill ext bioturbated, contains dk gy claystone lenses (< 0.5cm) gds upward into <u>Slty Clyst</u>: - dk gy, mod carbonaceous, ext biot, rr vf gnd sst interbeds, (< 1cm thick). gen massive, weakly planar lam, subfiss, mod calcareous.

<u>FEATURES</u>

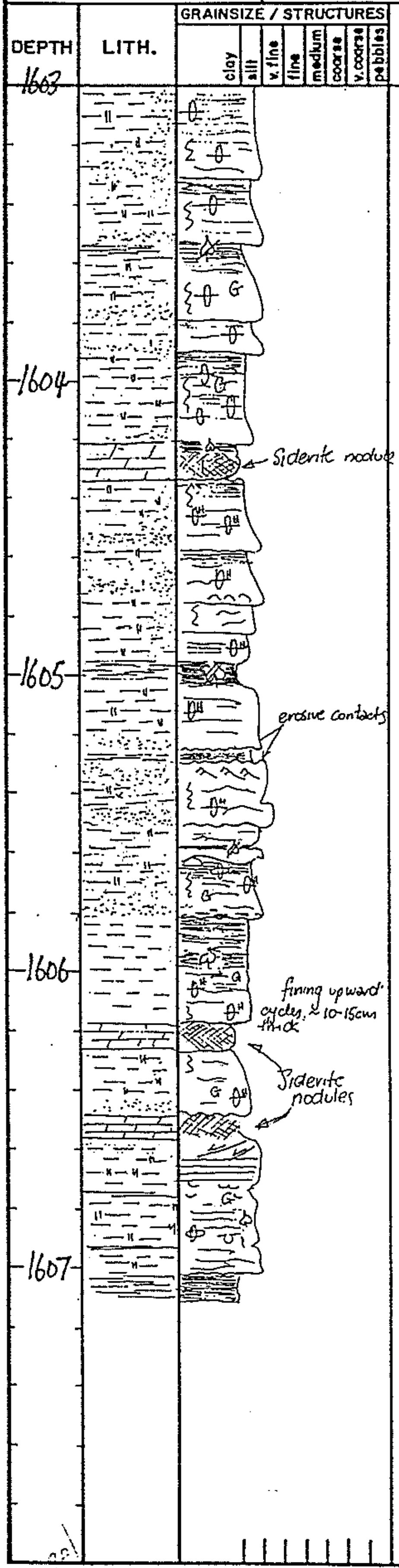
1) Siderite nodules occur in the argill sst and clyst. early diagenetic feature indicated by compaction drape over nodules.

2) Soft sediment deformation (slumping) @ 1599.98m may indicate deposition on slope.

3) major facies change at 1599.15m with obvious change in lithology and depositional dip.

4) lack of bioturbation in sandy layers probably indicates rapid deposition.

WELL NAME: DORRIGO #1	COMPANY: AOPL	DATE LOGGED: 23 / 6 /1988	SCALE 1:20
CORE No.: 3	INTERVAL FROM 1593 TO 1607·55 m	RECOVERY %	LOGGED BY: K. WULFF



CORE DESCRIPTION | **FACIES** | **ENVIRON.**

1603-1605·3m <u>Sndy Sltst grading to slty claystone</u>

lt bn gy - lt med gy - med dk gy, mottled,
<u>Slty SSt</u>: lt gy - lt ol gy, silt - vf gnd, subang - subrnd, generally poorly sorted, abdt arg mtx, silica cement^a, non calc, gen massive, very faintly planar laminated, gen non biot. occasional large (3cm diam) siderite nodules display compaction.

<u>Sandy Siltst</u>: md gy - ol gy, massive, occ floating qtz grains generally poorly srtd, silc cement^a, non calc, ext bioturbated, micromicaceous, abdt pyr,

<u>Slty Clyst</u>: dk-med gy, gen massive, ext bioturbated, mod carbonaceous, occ siderite nodules, pyrite dissem throughout.

1605·3 - 1607·12m <u>Sndy Sltst, dom qtzitic</u>

lt gy - md dk gy - lt bn gy, mottled, qtz is vf-f gnd, dom vf, subang - rnd^a, argill mtx, non calc, silc cement^a, ctns interlaminations of silty sandstone and silty claystone. generally fining upward cycles, extensively bioturbated, dom^n horizontal 2-3mm in diametre.

Mod Carbonaceous, faintly planar laminations (generally obliterated by bioturbation), mod abdt glauc and pyrite disseminated throughout. large siderite nodules @ 1606·5m, 1606·2m & 1607·05m upto 10cm in diam.

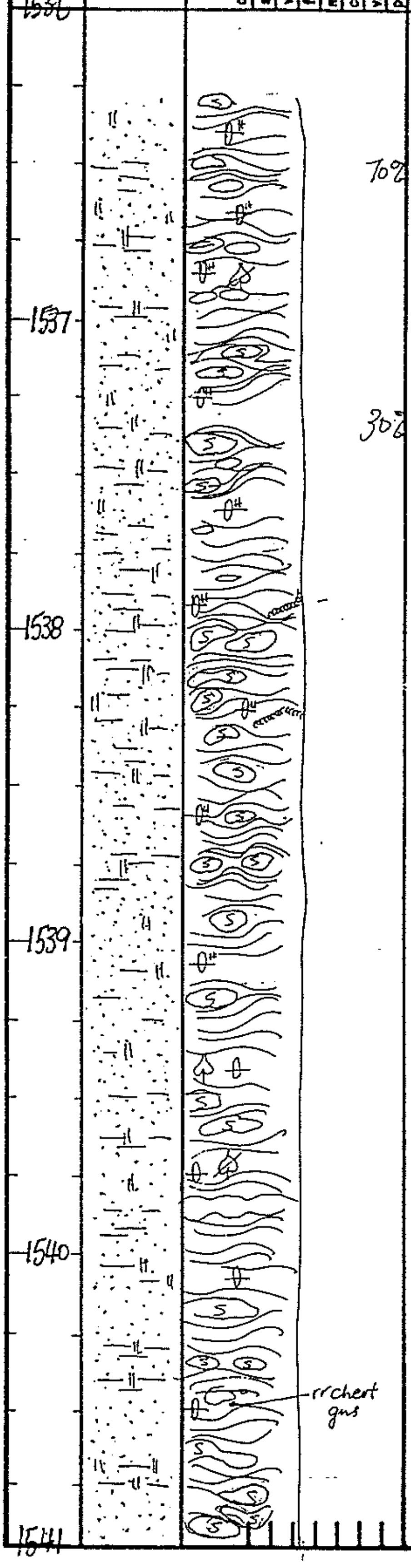
FEATURES

1 Some sandy layers 1-2cm thick have little or no bioturbation. These layers contain thin claystone laminae with apparent ripple bedding.

BOTTOM OF CORE @ 1607·55m

WELL NAME: ELDER # 1	**COMPANY:** WMC	**DATE LOGGED:** / /1988	**SCALE** 1:20
CORE No.: 2	**INTERVAL** FROM 1536·2 TO 1545·5 m	**RECOVERY** 74 %	**LOGGED BY:** K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES (clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles)	CORE DESCRIPTION	FACIES	ENVIRON.



1536·2 – 1545·5m Argillaceous Sandstone grading to silty claystone.

70% SSt v pl rdsh bn – orge bn, vf-f grained, sbang-subrounded, mod-poorly srtd, arg mtx, silc cemtd, mnr dol? cmt, mod-abdt detrital lithics – tourmaline, jasper + BIF, mod feldspathic, mod-abdt mica, v. poor-nil visible porosity. dom sil cmtd. Wavy planar laminae associated with intense, dominantly planar oriented bioturbation.

30% Silty Clyst – gysh bn – olgy, occas interlam w sandstone + lam on mm scale distorted by extensive bioturbation. gen subfissile, micromicaceous [illegible] rr + common carbonaceous matter

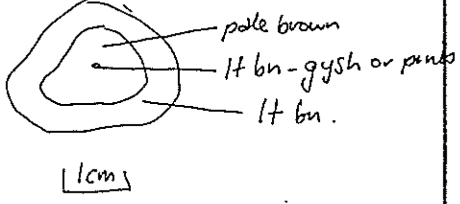
FEATURES

The core has been generally deposited in a single depositional cycle with minor fluctuations in depositional energy. The core is pervasively bioturbated by horizontal – oblique burrows (Zoophycos, Nereites + Rhizocorallium) burrows upto 1cm in diam. Nil observable sed structures due to burrowing.

Below 1537·4m there is an increase in abundance of med-crse qtz gns. within an arg mtx.

Siderite nodules are an early diagenetic feature indicated by the compaction and drape of clays over the nodules.

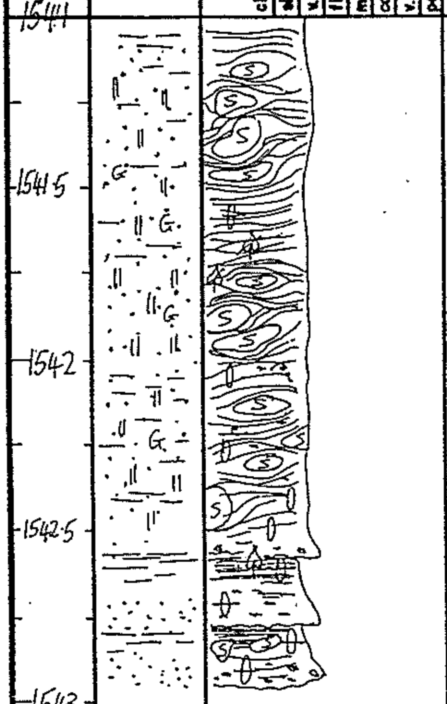
The nodules display 3 main colour zonations:



WELL NAME: ELDER#1 **COMPANY:** WMC **DATE LOGGED:** / /1988 **SCALE** 1:20

CORE No.: 2 **INTERVAL FROM** 1536.2 **TO** 1545.5 **m** **RECOVERY** 74 **%** **LOGGED BY:** K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles	CORE DESCRIPTION	FACIES	ENVIRON.



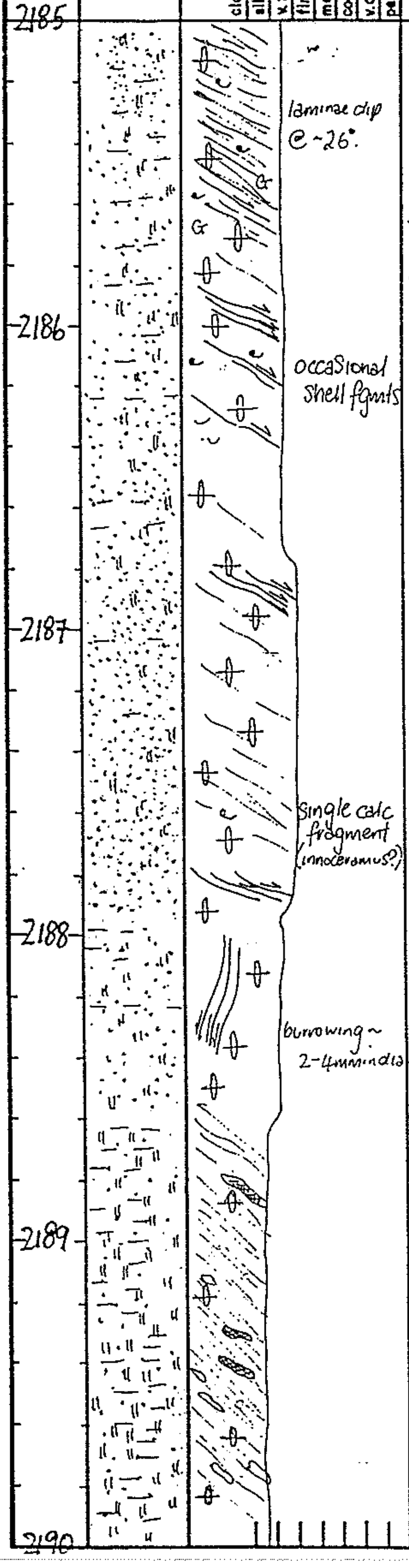
Below 1539m there is an increase in abundance of quartz and feldspar grains ranging in size from crse - small pebbles. The feldspars are possibly weathering to kaolin. There is also a general increase in abundance of sparry calcite. Burrows are infilled by calcite & siderite cemented clyst. There are also rr recrystallised shell fragments (bivalves & brachiopods).

BASE OF CORE = 1543.05m.

1 of 2

WELL NAME: Emma #1	COMPANY: OCCIDENTAL	DATE LOGGED: 6 / 6 /1988	SCALE 1:20
CORE No.: 3	INTERVAL FROM 2185 TO 2194·3 m	RECOVERY %	LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES	CORE DESCRIPTION	FACIES	ENVIRON.



2185-2185·6m Slty SSt qtzitc; lt bnsh gy - med gy, mottled, vf-f grd, subang-subrnd, mod srtd, abdt arg mtx, silica cement, non calc, occ calc fragments (bivalves and brachiopods); trace glauc, trace pyrite, mod bioturbated (burrows upto 2-4mm in diam). dip ~26°; nil observable porosity.

2185·6-2186·45m Slty SSt dom^n qtzitic, lt bnsh gy - med gy, mottled, silt - very fine grnd (occ fine), subang-subrnd, mod-prly srtd, dom sil^c cement, mod calc, occ shell fgmts rimmed by isopachus pyrite, ext bioturbated, low angle ~25° fault cross-cuts core @ 2186m.

2186·45-2188·6m SSt dom^n qtzitic, lt gy - lt bnsh gy, mottled, silt-vf grnd (pred vf), subang-rnd, mod argill, mod sorted, ext bioturbated, (burrows 2-6mm in diam), dom sil^c cement, mod calc, mod glauc, single bivalve shell @ 2187·66m, mod abdt post compaction faults @ 40-55°. Nil vis intergran. porosity.

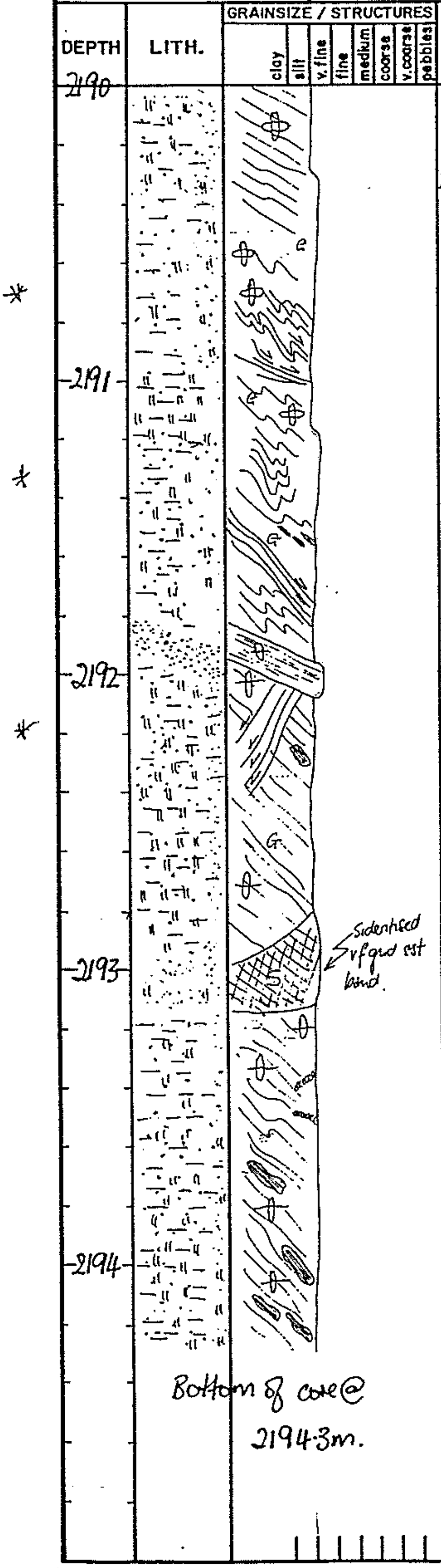
2188·6-2190m Sandy Sltst, dom qtzitic, lt olgy - lt bnsh gy, vf-fine grained, ang-subang, mod-poorly sorted, abdt elongate matrix supported sandstone clasts, (1-2cm in diam). silc cmtd, mod calc, mod-ext bioturbated, extensive sideritized burrows. nil visible intergranular porosity.

2 of 2

WELL NAME: EMMA # 1 | COMPANY: OCCIDENTAL | DATE LOGGED: 6 / 6 /1988 | SCALE 1:20

CORE No.: 3 | INTERVAL FROM 2185 TO 2194.3 m | RECOVERY % | LOGGED BY: K. WULFF

CORE DESCRIPTION	FACIES	ENVIRON.



2190.45-2190.65m Sandy Sltst lt gy - lt ol gy, mottled, vf-f gnd, mod srtd, abdt argill mtx, dom sil^c cemt^d, mod calc, ext biot, slumped, sft sed faulting, mod micaceous, nil vis φ.

2190.65-2191.93m. Sndy Sltst - lt ol gy - lt gy, mottled, mod argill, poorly sorted, abdt matrix supported sandstone clasts, ext bioturbated, slumped, high dip 40-60°, non calc, silc cement, mod micaceous, nil vis porosity.

2191.93-2192.12m SSt: lt gy - v lt gy, vf-f gnd gdg to silt, subang-subrnd, mod-well srtd, silc cement^d, non calcareous - v sl calcareous, very faintly planar laminated, tite, nil vis intergran porosity.

2192.12-2192.85m Sandy Siltstone: dom qtzitic, lt ol gy - lt gy - lt bn gy silt - vf gnd, poorly - mod srtd, mod abdt sst clasts, (0.5-2 cm diam) non calc, sil^c cemt^d, abdt post compactional normal faults. High dip laminae @ 45-50°; abdt slumping, mod bioturbated? nil vis porosit

2192.8-2193.18m Sideritised Sndy Sltst. - lt gy - lt bnsh gy, vf-f gnd, (occasionally fine grained) mod srtd, gen massive, faint lam @ 30-55°. dom sil cemt^d, sl calc, mod gluc, occ pyr,

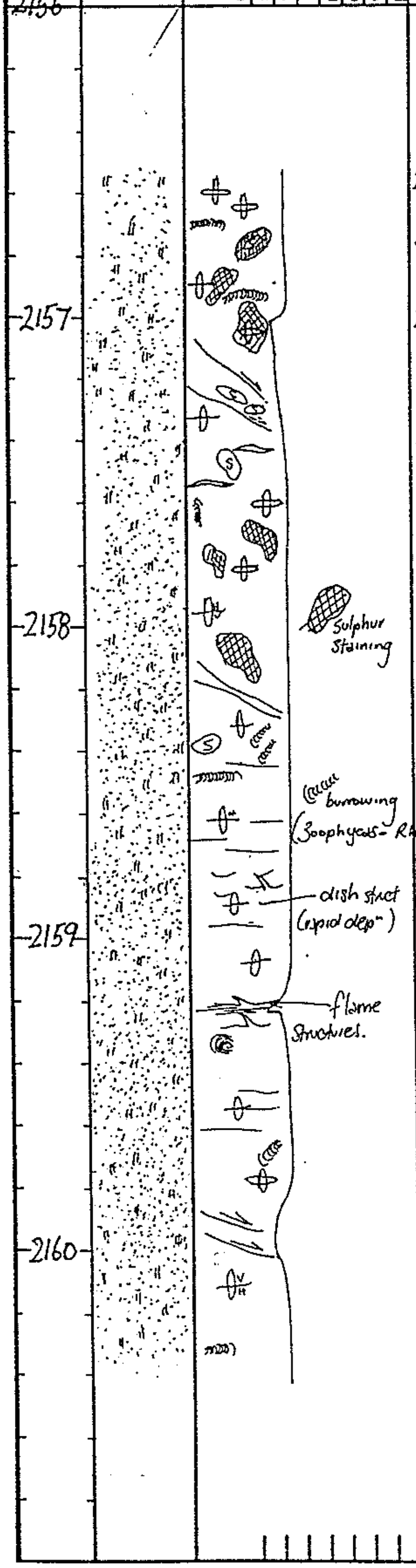
2193.18-2194.3m Sandy Siltstone, dom qtzitic, lt ol bn - lt bnsh gy - lt gy - v lt gy, vf-silt, ang-subang, mod-prly srtd, occasional lge (1-2cm in diam) sst clasts, dom sil^c cmt, mod calc, mod bioturbated, (burrow 2-4mm in diam) mod micromicaceous, tight, nil vis porosity.

1 of 1

WELL NAME: GEORGETTE-1 | COMPANY: OCCIDENTAL | DATE LOGGED: 12/6 /1988 | SCALE 1:20

CORE No.: 1 | INTERVAL FROM 2156 TO 2160 m | RECOVERY % | LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES clay silt v.fine fine medium coarse v.coarse pebbles	CORE DESCRIPTION	FACIES	ENVIRON.



2156.5-2156.98m SSt lt gy-lt bnsh gy, silt-vf gnd, subang (occ rnd^d), silc cmt, non calc, ext bioturbated) glauc, sub hzntal, (burrows upto 4mm in diam), sucrosic texture, nil-poor vis porosity, mod abdt sid nodules.

2156.98-2157.3m Arg SSt lt gy-lt bngy-olgy, mottled, silt-vf gnd, subang-subrnd, mod srtd, sil cmt, non calc, ext bioturbated, sulphur staining around siderite nodules and burrows.

2157.3-2158.75m SSt qtzitic, lt gy-lt bn gy, silt-vf gnd (occ fine) subang, mod srtd, mod sph, ext silc cmt, non calc, abdt sulphur staing around siderite nodules. extensively bioturbated, both hzntal + vertical, upto 3mm in diam. nil sed struct; siderite nod upto 15mm in diam, sucrosic texture, poor vis porosity.

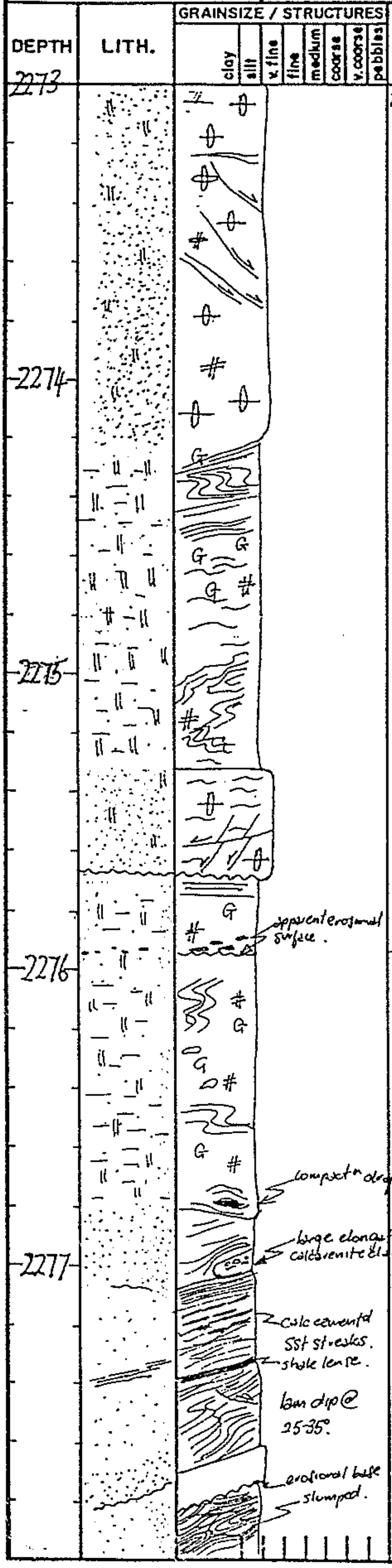
2158.75-2159.88m SSt v lt gy-lt gy-lt bn gy, mottled silt-vf grained (pred vf), subang-rnd (pred subrnd) mod sph, sil cmt, non calc, mod-prly srtd, ext biot, nil primary sed structures, burrows upto 4-5m in diam. rr dish and flame structures. (rapid dep^n + dewatering). minor pyrite, nil glauc, nil-mnr vis porosity.

2159.88-2160.05m Slty SSt - lt mdgy-lt bngy, silt-vf gnd, mod-prly srtd, subang-subrnd, mod sph, ext bioturbated, nil primary sedimentary structures, tce pyr, nil glauc. tite.

2160.05-2160.56m Slty SSt lt gy-lt bngy-med gy mott, silt-vf gnd (pred vf), subang-rnd, mod-prly srtd, mod abdt sid nodules, ext sil cement, tce calc, extensively bioturbated, (burrows 4-5mm diam) dom hzntal, mod glauc nil-trace intergran porosity.

WELL NAME: GEORGETTE 1 | COMPANY: OCCIDENTAL | DATE LOGGED: 14/ 6 /1988 | SCALE 1:20

CORE No.: 2 | INTERVAL FROM 2273 TO 2281·45m | RECOVERY % | LOGGED BY: K. WULFF



CORE DESCRIPTION | FACIES | ENVIRON.

2273-2274·22m SSt lt gy - lt bn gy vf f gnd, subang-subrnd (occ rnd), mod srtd, dom sil cmt, mod calc, well cmtd, tce glauc, mod dissem pyr, μmicaceous, extensively bioturbated, nil observable primary sed structures, abdt fractures orientd @ 50-65° to core axis. nil visible intergranular porosity.

2274·22-2275·32m Sndy Sltst, med-lt gy - med dk gy, qtzitic, silt - vf gnd, subang, abdt arg mtx, mod calc, mod glauc, trace pyrite, laminations @ 10-20° to core axis. mod biot. occ calcisiltite clasts (elongate, upto 15mm long axis). Nil vis ϕ.

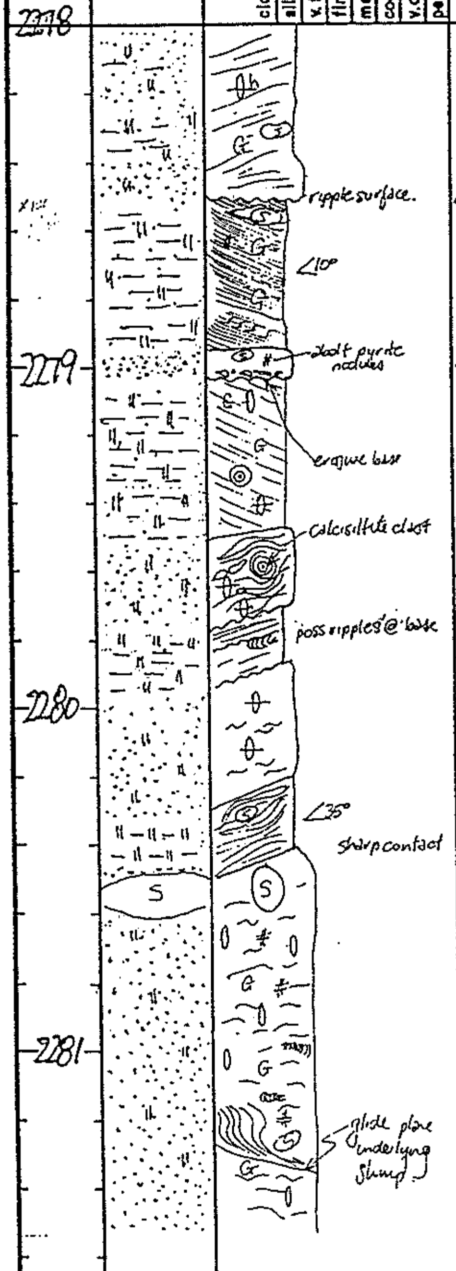
2275·32-2275·69m SSt, lt gy - lt brnsh gy, silt - vf gnd, well srtd, silc cmtd, abdt qtz overgrowths. gen mass, tce glauc, tce lithics, weakly planar laminated, x cutting fractures @ 75° to core axis. Sharp erosional basal contact.

2275·69-2277·05m Sndy Sltst, qtzitic, med-lt gy - md dk gy, abdt argillaceous matrix, abdt calcisiltite and calcarenite intraclasts. (<3mm in diam). abdt sft sed deformn features (slumps) nil vis intergranular porosity.

2277·05-2278m Sltst med dk gy - med gy - ol gy silt - vf gnd qtz, abdt arg mtx, silc cmtd, mod calc, planar lam @ 35° to hzntal, occ ext slumped, abdt calcisiltite intraclasts. SSt interbed @ 2277·68-2277·78m, med-lt gy, vf gnd, mod srtd, mass, silc cement, non calc, sharp erosive base, nil vis ϕ.

WELL NAME: GEORGETTE#1	COMPANY: AUST OCCIDENTAL	DATE LOGGED: 12/ 6 /1988	SCALE 1:20
CORE No.: 2	INTERVAL FROM 2273 TO 2281·45 m	RECOVERY %	LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES clay · silt · v.fine · fine · medium · coarse · v.coarse · pebbles	CORE DESCRIPTION	FACIES	ENVIRON.



2278-2278·5m Sandy Siltst. lt gy-lt ol gy-lt bn gy, dom qtz, silt-vf gnd, ang-subrnd (pred subang), mod srtd, matrix supported, silc cmt, non calc, tce glauc • pyrite, gen wavy lam @ ~10-15° to hzntal, occ rnd sid nodules upto 2cm in diam, horizontal bioturbated?

2278·5-2278·92 Siltst. med gy-ol gy, silt-vf qtz, subang-subrnd, glauc arg mtx, silc cement, non calc, vr calc spicules, vr pyr nodule planar lam dips @ 10°. lge sid nodule (4cm diam) w̄ 'press sol shadow' orientd // to depn dip.

2278·92-2278·98m Siltly Sandstone (as for 2278-2278·5m) with sharp erosive basal contact, and lag deposit consisting of elongate (0·4-0·8cm) rextallised silty sst.

2278·98-2279·52m (AS for 2278·5-2278·92m).

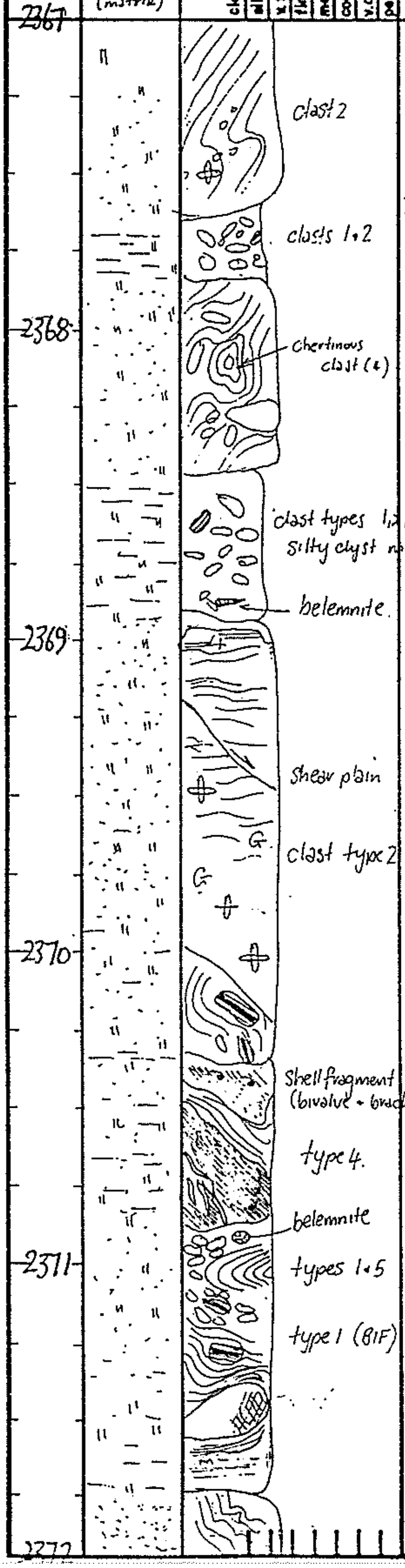
2279·52-2280·3m Slty SSt, dom qtzitic, lt ol gy-med gy, silt-vf gnd, (occ f gnd), gen poorly sorted, laminated, dips @ 10°. Abdt arg mtx, (3 apparent depn cycles with erosn scour bases @ 2279·18m, 2279·82m and 2280·3m.) mod abdt silc cmt siltite clasts, sl biot, increase in abundance of qtz).

2280·3-2280·46m Sndy Sltst, med gy-med dk gy, dom qtzitic, subang-subrnd, abdt arg mtx, dom silc cement, sl. calc, lam dip @ 35°. erosion ctc @ base, contains large siderite nodule (4cm diam) oriented parallel to dip.

2280·46-2281·55m SSt lt gy-med gy, vf-f gnd, ang-subang, mod sph, mod srtd, silc cemtd, sl calc, mod glauc, pyritic, mod arg mtx large sid nodule @ 2281·3m, wavy lam, mod biot, tite, nil-poor vis porosity.

WELL NAME: SOUTH PEPPER-1.
COMPANY: WMC
DATE LOGGED: / /1988
SCALE 1:20
CORE No.: 8
INTERVAL FROM 2367 **TO** 238534**m**
RECOVERY %
LOGGED BY: K. WULFF

DEPTH	LITH. (matrix)	GRAINSIZE / STRUCTURES (clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles)	CORE DESCRIPTION	FACIES	ENVIRON.



2367-2367·48
Clast type 2.

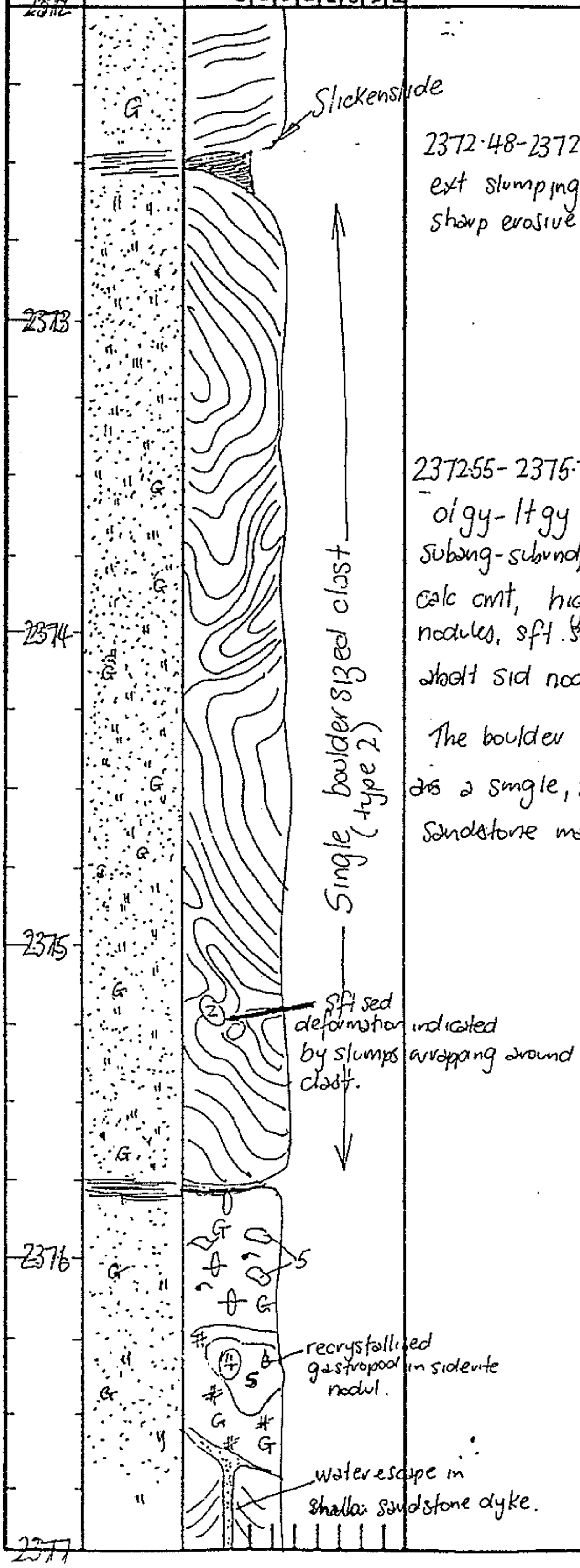
2367·48-2367·8. abundant type 1 and 2 clasts with a glauconitic silty cl mtx. abdt grnule-pbl size clasts, very poorly sorted randomally oriented Silc cement, non calc.

2367·8-2371·72 - Massive slump consisting of type 1,2,4+5 clasts within a silty clyst mtx.

2371·72-2372·48m. A single massive type 2 clast.

WELL NAME: SOUTH PEPPER	COMPANY: WMC	DATE LOGGED: 28/9 /1988	SCALE 1:20
CORE No.: 8	INTERVAL FROM TO m	RECOVERY %	LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES clay silt v.fine fine medium coarse v.coarse pebbles	CORE DESCRIPTION	FACIES	ENVIRON.



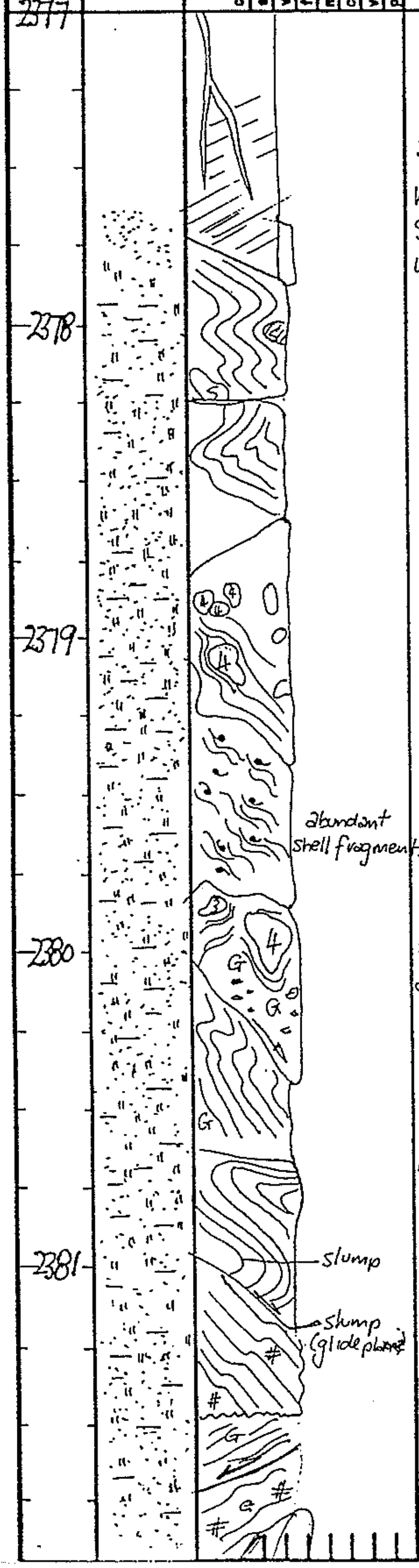
2372·48-2372·55m Slty Clyst. dk gy-ol gy, ext brg, ext slumping. mod abdt glauc, mnr pyrite, sharp erosive base.

237255-2375·7m Arg SSt: mass boulder sized clast. ol gy-lt gy-gnshgy, vf gnd siltstone gdg to silty sst. subang-subrnd, mod srtd, abdt glauc, dom sil cemt. mnr calc cmt, high angle slumps with mod abdt siderite nodules, sft sediment deform^n, nil faulting.
abdt sid nodules (4), vf gnd sst and abdt glauc (2)

The boulder sized clast appears to have been deposited as a single, semiconsolidated unit. The argillaceous sandstone matrix displays nil vis porosity.

WELL NAME: SOUTH PEPPER #1	**COMPANY:** WMC	**DATE LOGGED:** 28/9/1988	**SCALE** 1:20
CORE No.: 8	**INTERVAL** FROM 2367 TO 2385·4m	**RECOVERY** %	**LOGGED BY:** K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES clay silt v.fine fine medium coarse v.coarse pebbles	CORE DESCRIPTION	FACIES	ENVIRON.



2377-2379·78m
Section is extensively slumped with abdt sideritic clyst clasts (pebbles-boulders) within a matrix grading from argillaceous sandstones to silty clyst. Core displays multiple periods of slumping with sharp contacts @ 2378·25m, 2378·7m, 2379·2m and 2379·7m.

2379·78-2380·25m <u>Arg SSt</u> gysh green, olgn, -olgy, qtzitc, (qtz is clr, mlky, occ frostd), mod srtd, abdt arg mtx, dom sil cmt, occ pyr cmt, abdt glauc, mnr weathered feld, abdt, type 1 clasts, large type 4 clast @ 2380m
Whole section represent mass flow with faulted base @ 75° to hzntal.

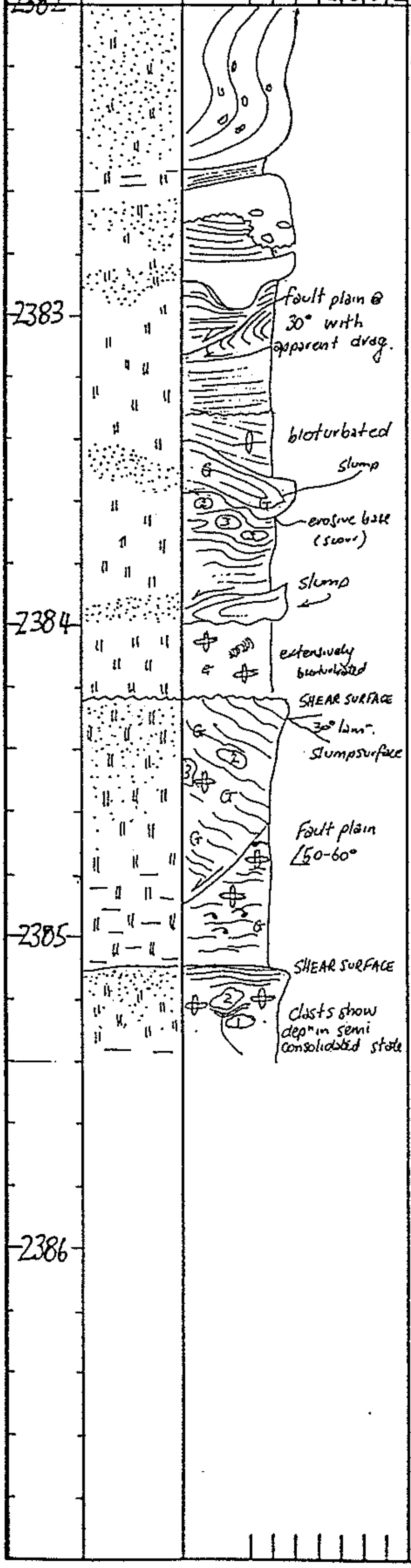
2380·25-2382·0m Arg <u>Sltst gdg to silty sst</u> med gy-gnsh gy, mass slumped arg SSt gdg to sndy sltst, slump contacts @ 2381m, 2381·4m, 2381·8m. Soft sediment deformation, mod abdt ripup shale clasts upto 12cm long with silty SSt mtx. mod abdt glauc-pyr, sil cmtd, minor carb, nil-vis porosity.

ENTIRE CORE IS WITHIN A MASSIVE SLUMP. ZONE

WELL NAME: SOUTH PEPPER # 1 | COMPANY: WMC | DATE LOGGED: 28/ 9 /1988 | SCALE 1:20

CORE No.: 8 | INTERVAL FROM 2367 TO 2385·4m | RECOVERY % | LOGGED BY: K. WULFF

DEPTH	LITH.	GRAINSIZE / STRUCTURES (clay, silt, v.fine, fine, medium, coarse, v.coarse, pebbles)	CORE: 4" CORE DESCRIPTION	FACIES	ENVIRON.



2382- 2382·55m Argillaceous Sandstone. med gy-gysh gn, vf gnd, mod-prly srtd, abdt pebble sized clasts, (calcsiltite), sil cmt, abd+ glauc, abdt arg mtx, slump @ 70-80°.

2382·55 - 2384·2m (as for 2380·25-2382m)

2384·2-2385:08m. Silty glauconitic sandstone -gysh gn-olgy, silt-very fine gnd, ang-subrnd, mod srtd, dom sil cement, w secondary pyrite cement. rr calc cmt, abdt arg mtx, feldsphathic, abdt glauc. occ bivalve fgmts, mod bioturbated, occ type I, II + 3 clasts, clasts are freq sideritised, faint lam @ 30°. High angle fault (50-60°) with mod throw. Upper contact at 23842m is sharp and erosive.

2385·08- Argillaceous Sandstone: gysh gn, silt-very fine gnd, subang-subrnd, mod-well srtd, abdt arg mtx, dom silica cement, mod abdt feldspar, glauc and bivalve fragments. Occ type 1 clasts. nil observable porosity.

Bottom of core @ 2385·4m

CLAST TYPES

① pebble-cobble sized lithic and chertinous clast (Banded Iron formation and quartzite.

② pebble-cobble sized very fine-fine grained sandstone with variable amounts of dk gy argillaceous laminae.

③ pebble-cobble sized, rounded, elongate, calcareous and sulphurous claystone with abundant fractures infilled by calcite.

④ pebble-boulder sized claystone grading to sandy siltstone clast, extensively sideritized and mod glauconitic. abundant slumps.

⑤ mass claystone pebble-cobble sized clasts

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 21

DATE LOGGED: ? **INTERVAL:** ?

No depths are marked on the core and many pieces are missing. Gross lithological units only are discussed.

Total length of core present ~56 cm.

20 cm sandstone, quartzose, greyish yellow, medium - coarse, occasionally very coarse grained, round - subrounded, moderately sorted, silica cemented, non calcareous, quartz grains are clear -milky, translucent, contains rare detrital lithic? fragments, rare glauconite, occasional large pink feldspar grains, generally massive, poor visual porosity.

30 cm dusky yellow green - greyish grain. Very fine - coarse grained, (occasionally very coarse), subangular - round, predominantly subrounded, poorly sorted, consisting of 70% quartz -clear - milky, fine - coarse, occasionally very coarse, subrounded -round, very poorly sorted, silica cemented, occasionally conchoidal fracture. 10% detrital grains, dark greenish grey - greenish black, fine - medium, occasionally coarse, subangular - subrounded, frequent conchoidal fracture, possibly tourmaline, glauconite and lithic fragments. 20% cement and minor argillaceous matrix. Non calcitic. Rock has been moderately bioturbated. Burrows have been infilled by argillaceous and micromicaceous matrix. Nil visual porosity.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 22

DATE LOGGED: 11/10/88 **INTERVAL:** FROM 6682 ft TO 6700 ft

The core is unmarked - the precise depth is unknown. The arrangement of the core is not continuous and therefore no detailed logging can be undertaken.

Core present ~3.2 m (11').

GENERAL CORE DESCRIPTION

The core displays a generally monotonous sequence of intensely bioturbated argillaceous fine grained sandstone. Occasional pebble sized sideritic nodules are scattered throughout the core. A thin, massive medium grained sandstone lens is present near the 'top'? of the core and contains a single vertical burrow that has been infilled by argillaceous matter (burrow diameter ~2-3 mm). The core contains abundant belemnites up to 4 mm in diameter and 15 mm long.

A minor increase in relative quartz grain size (average medium) occurs towards the base of the core? with a thin (4" (9 cm)) massive sandstone lens that displays no bioturbation.

Below the sandstone lens a 10 cm thick unit of interlaminated fine -medium sandstone and clay laminae displays major contortion of the laminae and later, post deposition (before major compaction) sharp faulting (soft red deformation). The base of the core? (10 cm) returns to the bioturbated argillaceous sandstone and siltstone with abundant belemnites.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 23

DATE LOGGED: 11/10/88 **INTERVAL:** FROM 6741 ft TO 6759 ft

The core is unmarked and is no longer in any identifiable order. The core therefore cannot be studied in regard to grain size variations, and facies distribution but can only be described in general.

The lithology is dominantly very fine grain argillaceous sandstone grading to sandy siltstone and silty claystone. The sandstone is dominantly quartzose very fine - fine grained, subangular - subrounded, moderately sorted, very slightly calcareous with porosity choked by clays. Minor visual porosity. The very fine grained sandstone is slightly friable and grades upward into occasional argillaceous laminae. An interlaminated sequence at 6750 ft has not been bioturbated nor contorted in any way apart from a minor normal fault (displacement ~3 mm) post compaction.

Apart from this minor laminated sequence the remainder of the core is the very fine grained argillaceous sandstone. In the basal part of the core? the very fine grained sandstone is interlaminated with claystone. However the clay laminae show distortion due to dewatering (flame - volcano structures) as well as moderate bioturbation. (Burrows are subvertical and up to 4 mm in diameter.)

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 24

DATE LOGGED: 11/10/88 **INTERVAL:** FROM 6760 ft TO 6778 ft

The core is unmarked and in no identifiable order. Adjacent pieces do not conform and must therefore be considered to be anomalous. The core cannot be used for grain size or facies variation studies.

The core is dominantly very fine - fine grained argillaceous sandstone with occasional zones of concentrated dark argillaceous laminae. These argillaceous laminae have been extensively bioturbated and the laminae are discontinuous and undulose associated with both the bioturbation and dewatering associated with compaction.

The sandstone is very fine - fine, occasionally medium grained, angular - subangular, (occasionally subrounded), moderately sorted, generally sideritic cemented . Very slightly calcareous, moderately abundant detrital lithics, glauconite, weak subparallel alignment of grains. Very tight - no visual porosity.

The basal 3-4 ft of the core is marked by major change to very argillaceous, intensely bioturbated (obliterates all primary red structures) sandy - siltstone - silty - claystone.

Contains rare - occasional belemnites throughout argillaceous zones.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 25

DATE LOGGED: 12/10/88 **INTERVAL:** FROM 6778 ft TO 6793 ft

The core is not marked and is no longer in an identifiable order. Neither the top nor the bottom has been marked. No grain size or facies distribution study may be undertaken, only general core description may be carried out.

The entire core is a single intensely bioturbated argillaceous sandstone. The original rock was probably interlaminated (mm scale), however the intense burrowing (dominantly subhorizontal) has resulted in obliteration of primary sedimentary structures. The burrows, up to 4 mm in diameter however, are dominantly ~2 mm diameter. The rock also contains abundant belemnites. The sandstone is dominantly quartz and is very fine - fine grained, subangular - subrounded, occasionally round, moderately - well sorted, silica cemented, nil calcite.

The burrows are probably Zoophycos.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 26

DATE LOGGED: 12/10/88 **INTERVAL:** FROM 6793 ft TO 6805 ft

Core 26 is dominantly an very fine grained argillaceous sandstone with two fine grained sandstone lenses ~5" (12 cm) thick at 6796' and 6799'.

The bioturbation in the argillaceous sandstone has obliterated primary sedimentary structures and argillaceous laminae are discontinuous and contorted. The laminae occasionally show dewatering structures (namely dish, rare flame structures). The sandstone is very fine to fine grained, subangular - subrounded, moderately - well sorted, non - very slightly calcareous and silica cemented. The burrows are infilled by argillaceous matter. The burrows are up to 5 mm in diameter and display a pattern typical of Zoophycos.

Within the argillaceous sandstone there appears to be three weakly fining upward cycles with possible erosive bases at ~6796 and 6799'. These cycles are marked by clean massive, very fine - fine grained sandstone at the base grading up to interlaminated very fine argillaceous sandstone and claystones which have been intensely bioturbated.

Occasional belemnites are present scattered throughout the more argillaceous intervals.

The basal 2' of the core is very poorly sorted and appears to fine upward into a more homogenous fine grained bioturbated argillaceous sandstone sequence. The basal unit contains quartz grains up to 1 mm, detrital feldspars? and lithic fragments. Intense bioturbation has also occurred within this unit attesting to the original abundance of argillaceous matrix.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 27

DATE LOGGED: 12/10/88 **INTERVAL:** FROM 6805 ft TO 6823 ft

Core 27 is continuous from Core 26. The core is unmarked and generally lacks continuity.

Core 27 contains three distinct lithological types:

i) extensively bioturbated very fine grained argillaceous sandstone with occasional sandstone and claystone clasts.

ii) generally massive, very weakly laminated, very fine grained sandstone.

iii) massive, hard, micromicaceous dehydrated claystone.

i) The bioturbated very fine - fine grained argillaceous sandstone has been extensively burrowed obliterating any primary sedimentary structures. Burrows are both oblique and subhorizontal and range in diameter from 1 mm to 6 mm. Trace burrows are <u>Zoophycos</u> and <u>Nereites</u>? The unit is dominantly quartzose, very fine - fine grained, subangular - subrounded, moderately sorted. Frequent rounded and flattened clasts (up to small pebble size) also occur disseminated throughout. These clasts have been frequently burrowed and are often difficult to distinguish from the sediment. The burrows are frequently rimmed by argillaceous matter and infilled by very fine grained quartzitic sediment.

ii) The generally massive, very fine - fine grained sandstone is weakly laminated with generally planar orientation of quartz horizontal axis. Occasional thin argillaceous laminae occur near the top of the units. The sandstone is very tight. The sandstone lenses are between 10 cm and 50 cm thick. In one case the top of one sandstone unit has been eroded by a coarser massive sandstone. This basal unit of the overlying sandstone is medium grained and contains abundant lithic and feldspathic grains. This basal unit grades upward into massive fine - very fine grained sandstone.

iii) A 30 cm (1 ft) unit of massive micaceous claystone occurs within the upper bioturbated sandstone. This claystone unit is extensively hard and contains slickenslides indicating soft sediment deformation while in a semi-consolidated state. The claystone has also been intersected by a thin (3 mm wide) calcareous dyke? Minor, extremely small (< 1 mm) dendritic burrows were noted on the surface of the split cores. These trace burrows appear to be <u>Chondrites</u>.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 28

DATE LOGGED: 13/10/88 **INTERVAL:** FROM 6823 ft TO 6841 ft

Core 28 is not marked up and a significant proportion of the core is missing (10 ft present, 8 ft missing). This core does however, appear to be in a reasonable continuity and therefore some facies variations may be described with some reliability.

The top ~2' of the core is a continuation of the massive fine grained sandstone seen in the base of Core 27. The sandstone however, grades down into a medium - occasionally coarse, poorly sorted sandstone. The grains are subrounded - round, occasionally subangular, of moderate sphericity and poorly - moderately sorted. Abundant detrital lithic and feldspar grains are present as well as occasional small pebbles of limonitic claystone. No apparent bioturbation is present. A minor 6" argillaceous bioturbated sandstone lens with a sharp upper contact underlies the medium -coarse grained base of the overlying sandstone unit. This argillaceous sandstone was originally overlain by a lower energy deposit with climbing ripples? which was in turn eroded by the initially high, then waning energy, depositional cycle responsible for the fining upward. Below the 6" argillaceous zone the core is a massive fine - medium grained sandstone, subangular - subrounded, moderate sphericity with occasional limonitic claystone pebbles. The pore throats appear moderately choked with clays and silica cement. This second sand unit is ~4 ft (1.2 m) thick. Below ~6830' is the intensely bioturbated argillaceous sandstone with oblique, vertical and subparallel burrows. The burrows range from 1 mm-4 mm in diameter and are predominantly argillaceous lined and infilled by very fine quartzitic sandstone. Occasional large belemnites (3-4 cm long and 0.75 cm wide) occur within the argillaceous sandstone. Flattened pebble size clasts occur scattered throughout the core.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 29

DATE LOGGED: 13/10/88 **INTERVAL:** FROM 6841 ft TO 6859 ft

The core is predominantly rubble and is unmarked. Only the gross lithological units may be distinguished.

Core 29 consists dominantly of massive fine - medium grained slightly argillaceous sandstone with occasional minor argillaceous laminae. The laminae are generally planar except where bioturbation has contorted the laminae. The laminae also display occasional dish shaped structures and rare flame structures indicative of rapid dewatering. The sandstone is identical to the massive sandstone described in Core 28.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 30

DATE LOGGED: 13/10/88 **INTERVAL:** FROM 6859 ft TO 6877 ft

Core 30 contains no distinguishable markings and many pieces of the core appear jumbled and discontinuous. The core may therefore be used only for gross lithological purposes with any confidence.

Core 30 consists dominantly of fine - medium (dominantly fine) grained sandstone with occasional lenses of bioturbated very fine grained argillaceous sandstone. The massive sandstone is generally not bioturbated and very weakly laminated associated with the orientation of the quartz crystals long axis. Occasional elongate limonitic very coarse - very small pebble clasts occur disseminated throughout. Occasional large belemnites (up to 1 cm in diameter) are present within the bioturbated units. The bioturbated argillaceous sandstones rarely attain thicknesses > 1' (30 cm).

The contact between the argillaceous units and the overlying massive sandstone are sharp indicating rapid change in depositional energy. Occasionally the laminae are planar and have not been disturbed by burrowing. These laminae are mm scale and subhorizontal. Burrowing typical of Zoophycos and Rhizocorrallium are present.

The massive quartzitic sandstones are generally tight with little or no porosity. The pore throats appear choked by clays and silica cement. The sandstones are slightly calcareous. The sandstone is also quite friable. One large sideritic nodule had formed and the iron discolouration had permeated into the adjacent sandstone.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 31

DATE LOGGED: 13/12/88 **INTERVAL:** FROM 6877 ft TO 6895 ft

Core 31 is unmarked and core pieces are discontinuous. Only a general lithological summary is therefore discussed.

The core is dominated by two facies types, 1) bioturbated fine grained, argillaceous sandstone, and 2) generally massive fine grained sandstone. The bioturbated argillaceous sandstone contains contorted argillaceous laminae, subparallel and oblique burrows, rare - occasional limonitic pebble size claystone clasts and rare sandstone clasts. The burrows are between 1 and 3 mm in diameter and are rimmed by argillaceous matrix and infilled by quartzose sandstone.

The sandstone lenses are typically upwards of 6-8 ft (1.8-2.4 m) thick and are generally massive with no apparent bioturbation. Occasional large sideritic small cobble size clasts are present. One clast is rimmed by dark argillaceous matter while the second may be authigenic in origin and derived 'in situ' (in which case it would be nodular rather than a clast).

The contact between the massive fine grained, moderately sorted sandstone and the overlying bioturbated argillaceous sandstone is gradational (not sharp as was seen in Core 30). This contact suggests a general fining upward sequence is present in Core 31.

A significant proportion of the core is missing or rubble [i.e. >7' (2.1 m)]. A single piece of core (<1" thick) contained extremely poorly sorted, matrix supported, fine - very coarse grained quartz with coarse grained lithic fragments as well as shell debris (bivalves). No similar or related core was observed and it is unknown whether or not this belongs to Core 31 or is an extraneous section of core.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 32

DATE LOGGED: 14/10/88 **INTERVAL:** FROM 7732 ft TO 7745 ft

Core 32 contains 'no' legible depth markings. The core is however, in reasonable continuity and can be described with reference to grain size and facies variation.

7732-7742'

The section is generally a very fine - fine grained feldspathic sandstone - greywacke. The core has been intensely bioturbated obliterating primary sedimentary structures. The argillaceous sandstone/greywacke is brown grey, very fine - fine grained, subangular - subrounded, moderately sorted and contains occasional large pebble sized sideritic claystone clasts (type 2). Contorted laminae and weak grain orientation dips at ~5-10°. The rock is very slightly calcareous, with apparent dissolution of feldspars.

A small reverse fault at ~7738' displaces burrows by ~1 cm and suggests the unit has undergone compression post compaction. An increase in abundance of clasts below 7740' suggests a rapid transition from the underlying 'conglomeritic' matrix dominant mass flow unit. The presence of sideritic nodules with compaction drape of the laminae around the nodules suggests early diagenesis.

7742-7745'

This section is dark red brown - greyish red purple conglomerate with large cobble - pebble sized clasts within a silty claystone matrix. The reddish colour attests to the presence of iron rich cements (siderite). Clast types include: rounded bioturbated argillaceous sandstone/greywacke, sideritised silty claystone clasts and sideritic nodules with zoning showing transition in iron content.

Clast types include:

1) bioturbated very fine grained argillaceous sandstone.

2) sideritised claystone.

3) mass sideritic nodules.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 34

DATE LOGGED: 14/10/88 **INTERVAL:** FROM 7872 ft TO 7889 ft

There are no legible depth markings on Core 34. The core does however appear to be continuous, consequently relative grain size and facies variations may by outlined.

The core is red brown - greyish and contains abundant pebble -boulder sized clasts within a silty claystone matrix.

There are three clast types:

1) rounded bioturbated greywacke (very argillaceous, very fine grained sandstone).

2) sideritic silty claystone clasts.

3) sideritic nodules with zoning indicating variation in concentration of cement.

The matrix is silty claystone grading to sandy siltstone and contains contorted argillaceous laminae which have undergone bioturbation and compaction. The reddish colour attests to the dominance of sideritic cements. The matrix is extremely tight and contains no reservoir properties. The core is intensely fractured subhorizontally making identification of gross units difficult. However, a single boulder sized clast (up to 1.5 m, (5')) in diameter may be present.

The core represents typical high energy mass flow deposition with clasts derived from reworking of semi-compacted sediments higher on the shelfal areas.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 36

DATE LOGGED: 14/10/88 **INTERVAL:** FROM 8520 ft TO 8526 ft

No depth markings are legible on the core.

Core 36 is a massive, dark brownish grey, silty claystone sequence that contains high angle (20-30°) depositional microlaminae. This high angle has caused the core to fracture along these laminae. A high angle (50°) normal fault cross cuts the core at ~8523'.

The silty claystone is highly indurated and is extremely brittle. No observable primary sedimentary structures apart from the laminae were observable.

WELL NAME: Barrow 1 **COMPANY:** WAPET **CORE No:** 37

DATE LOGGED: 14/10/88 **INTERVAL:** FROM 9297 ft TO 9304 ft

The core is poorly preserved and no depth markings are obvious on the core.

Core 37 is a massive, dark brownish grey - greyish black, horizontally laminated carbonaceous claystone. The claystone is moderately soft - hard (not brittle), flakes along the horizontal laminae and is micromicaceous.

WELL NAME: Flag 1 **COMPANY:** WAPET **CORE No:** 4

DATE LOGGED: 17/10/88 **INTERVAL:** FROM 9820 ft TO 9844 ft

Core 4 consists dominantly of fine - medium grained, bioturbated, argillaceous sandstone with occasional interbeds of generally massive, off white - light brownish grey sandstone with abundant glauconite.

The bioturbated argillaceous sandstone consists of ~80% of the cored interval. The unit contains weak laminations at ~20-30°. The sandstone is moderately - poorly sorted with common large coarse quartz grains and limonitic? claystone clasts scattered throughout. The poor sorting may be either depositional in origin or associated with the intense bioturbation. Fauna includes Chondrites burrows and possibly Zoophycos? or Rhizocorallium.

The generally massive sandstone interbeds occur dominantly toward the base of the core. No basal contacts are present, however it is likely that they are sharp. The sandstone is dominantly fine - medium grained, occasionally coarse, subangular - subround, with authigenic quartz overgrowths. Remaining interstitial pore space has been infilled by secondary calcite cement. The upper contacts between the sandstone and the overlying bioturbated unit are generally transitional (except in one case where a fault has resulted in a sharp contact).

The sandstone shows a distinct graded bedding, fining upwards and contains abundant ferruginous claystone coarse grained clasts occasionally larger rounded limonitic clasts towards the base.

Both the sandstone and the bioturbated unit contain frequent bioclasts.

The core has minimal visual porosity and negligible permeability.

WELL NAME: Flinders Shoal 1 **COMPANY:** WAPET **CORE No:** 5

DATE LOGGED: 14/10/88 **INTERVAL:** FROM 4903 ft TO 4926 ft

Core 5 is a pale brown - greyish brown, massive bioturbated argillaceous sandstone. Quartz grains are very fine - fine, occasionally medium, subangular - subrounded, occasionally round, moderately sorted. Primary sedimentary texture has been obliterated by bioturbation.

Mineralogy is typically quartzose with minor feldspar. The abundant clay matrix (kaolinite) is partly authigenic in origin and is attributed to the breakdown of feldspars. Moderate glauconite occurs disseminated throughout and appears in pelloidal form. Minor quartz overgrowths are present.

The core contains large sideritic nodules which appear to partially replace detrital grains. Within these concretions are preserved bivalve and belemnite shell fragments. The sideritic nodules attest to the abundance of iron rich cements responsible for reddish colour. The bioturbation appears to be dominantly chondrites form. The core appears to have minor reservoir potential (porosity <10-15%) however permeability would be minimal due to abundant clay matrix.

Bivalve fragments are typically <0.5-0.75 cm in diameter, however rare larger 1 cm diameter whole shell are present which suggests they are in situ.

APPPENDIX II
THIN SECTION DESCRIPTIONS

BAMBRA-1, core 2, 2716.75m.

BAMBRA-1, core 2, 2722.05m.

BAMBRA-1, core 2, 2721.19m.

BAMBRA-1, core 2, 2723.05m.

EMMA-1, core 3, 2185.3m.

EMMA-1, core 3, 2187.05m.

DORRIGO-1, core 3, 1604.4m.

DORRIGO-1, core 3, 1605.1m.

DORRIGO-1, core 3, 1609.94m.

GEORGETTE-1, core 1, 2156.6m.

GEORGETTE-1, core 2, 2278.8m.

GEORGETTE-1, core 2, 2275.26m.

GEORGETTE-1, core 2, 2278.98m.

SOUTH PEPPER-1, core 8, 2327.9m.

CHERVIL-1, core 7, 1785.04m

BAMBRA-1, CORE 2, 2716.75 m

ROCK NAME Feldspathic quartzite

MINERALOGY

	Average %
Quartz.	55
Rhombohedral dolomite?/Sideritic cement	15
Argillaceous matrix.	10 (sericitized).
Feldspar - plagioclase.	5
Muscovite.	5
Glauconite.	5
Organic matter.	2
Zircon?	Trace.
Bioclastic detritus.	Trace.
Chert.	Trace.

TEXTURE

- Grains frequently rimmed by isopachus dolomite (or aragonitic) cement.

- Authigenic overgrowths interlock slightly with the adjacent grains and thus are demonstrably authigenic.

- Small siderite crystals infill pore space (possibly replace quartz at boundaries).

- Siderite crystals infilling pore spacing was either syndepositional or early diagenetic formation evident by appearing as inclusions within the authigenic overgrowths.

- Horizontal burrows (2 mm diameter) infilled by subangular anhedral very fine grained quartz and feldspar crystals within sideritic cement matrix and sericitic matrix. Rare - occasional vertical burrow infilled by argillaceous matrix (0.25 mm in diameter).

- Organic matter concentrated along argillaceous laminae.

- Quartz grains 0.1 mm in diameter, no visual porosity, extensive authigenic overgrowth, rare - occasional sutured grain contacts indicating pressure solution.

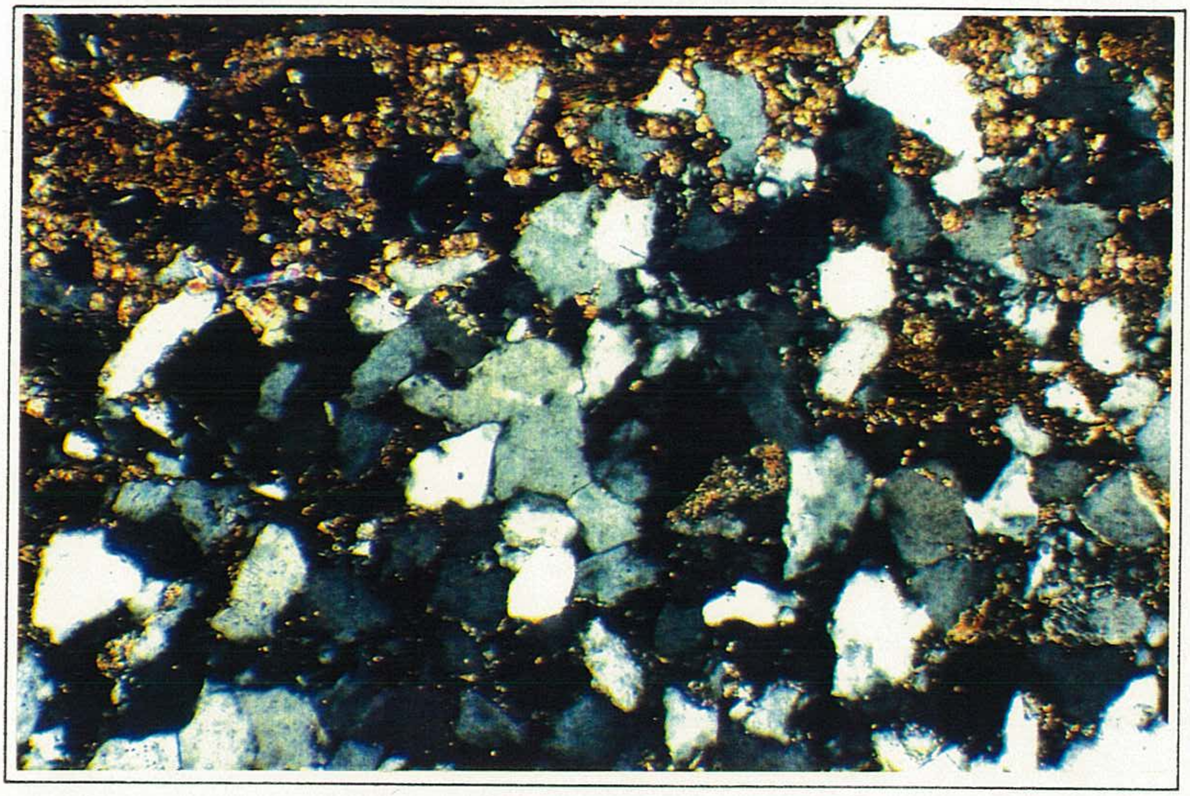
- Rock is both chemically and physically immature indicated by quartz grains, relative abundance of unaltered feldspars, argillaceous matrix.

- Glauconite appears 'squeezed' between quartz and feldspar crystals indicating compaction of the glauconite whilst still hydrated?

DEPOSITIONAL ENVIRONMENT

The extremely fine grain size suggest a low energy depositional system. Combined with the physical and chemical immaturity of the section suggests deposition within a low energy submarine regime, possibly the distal localities of a submarine fan system or outer shelfal environment. Diagenetically the sideritic bitumen concentrated along boundary cement occluding much of the pore space appears very early formation prior to further porosity destruction by authigenic overgrowths of the quartz grains.

Within the argillaceous laminae the clay matrix appears to have restricted further cementation and the areas between the quartz grains are almost entirely clay choked. The organic matter is also concentrated along these laminae. Later calcareous cement, probably dolomite completely infilled any remaining void space and represents the last phase of precipitate cementation.



Bambra-1, 2716.75m, cross-polars, 100x magnification.

Mod-well sorted, vf-f grained, with extensive quartz overgrowths, frequent triple point grain contacts. Horizontal burrow (2mm in diametre) has been infilled by sideritic cement which has also partially corroded quartz boundaries. Rock displays nil-minor intergranular porosity.

BAMBRA-1, CORE 2, 2722.05 m

ROCK NAME Feldspathic quartzite.

MINERALOGY

	Average %	Upper %	Lower %
Quartz.	60	70	50
Feldspar.	10	10	10
Siderite.	10	2	30
Calcite/dolomite cement.	5	5	5
Argillaceous matrix.	5	5	Trace.
Glauconite.	5	10	Trace - 2
Muscovite.	3	5	Trace.
Organic matter.	2	4	Trace.
Chert.	Trace.	Trace.	Trace.
Tourmaline.	Trace.	Trace.	Absent.

TEXTURE

The slide is divided into two separate lithological units. The boundary is marked by a compacted, sideritised and bitumen infilled burrow that separates an overlying feldspathic quartzite from the underlying extensively sideritic cemented, extremely - very fine grained orthoquartzite. Glauconite also occurs preferentially along argillaceous bedding contact.

The extensive early diagenetic sideritic cement in the lower layer has occluded most of the pore space. Secondary authigenic silica overgrowths and calcite cementation has infilled the remaining void space. The upper section contains very little (<2%) argillaceous matter. The quartz in the lower layer is extensively pitted by the siderite and the authigenic quartz overgrowths post date the early diagenetic siderite cementation. There is a very faint orientation of crystals parallel to the horizontal burrow however, it appears that the early sideritic cementation inhibited the compaction of this lower layer due to the lack of marked orientation of the grains and pressure solution at boundary contacts.

The upper layer contains a marked decrease in sideritic cement and pore space has been dominantly occluded by authigenic overgrowths with secondary calcite cement. The upper layer also contains a significantly higher proportion of muscovite. The layer shows extensive compaction and orientation of the crystals as shown by the contorted muscovite crystals and pressure solution boundaries between quartz grains and squeezed glauconite. Sericitised organic rich laminae are orientated parallel to the long axis of the crystals and argillaceous band marking the boundary between the units. The upper feldspathic sandstone also contains a significantly higher amount of glauconite.

The argillaceous and micaceous infilled burrow is very marked and shows an extensive degree of compaction and contortion as observed in the muscovite crystals. There is also a concentration of bituminous organic matter along the laminae marking the boundary. This argillaceous layer probably marks a period of non deposition in a very low energy, anoxic environment. This hiatus may have resulted in conditions conducive for the extensive sideritic cementation observed in the underlying sequence.

DIAGENETIC HISTORY

1 Deposition of very fine - fine grained feldspathic - orthoquartzite.

2 Early diagenetic sideritic cement occluding majority of pore space.

3 Minor syntaxial quartz overgrowths.

4 Late calcite cement infilling remaining void space (very minor).

5 Hiatus - deposition of thin argillaceous, micaceous and bituminous layer.

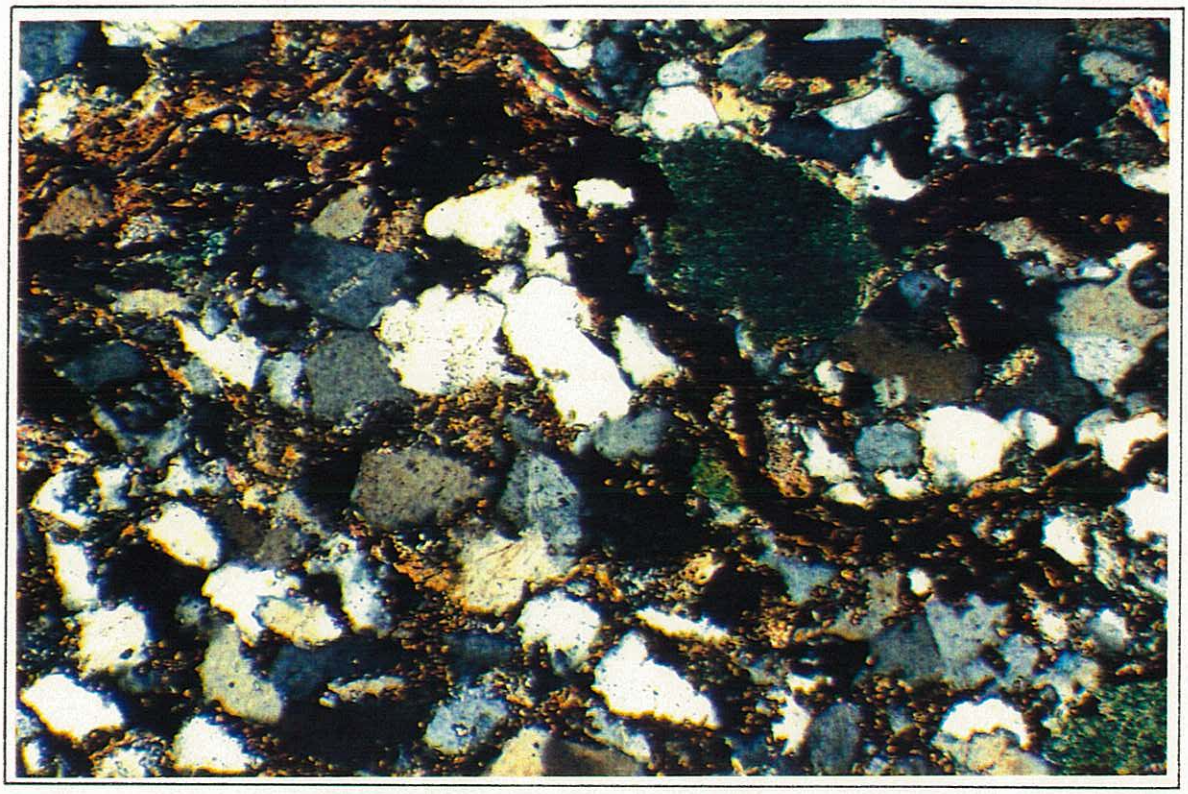
6 Rapid deposition of feldspathic and glauconitic quartzite.

7 Relatively rapid compaction with extensive penecontemporaneous authigenic silica overgrowths.

8 Secondary calcitic cementation infilling void space and sericitisation of glauconite and argillaceous matrix.

DEPOSITION ENVIRONMENT

Deposition probably occurred within a marine (indicated by glauconite), relatively anoxic environment conducive for the preservation of organic matter and sideritic cementation. The abundance of quartz and relative lack of argillaceous matter suggests deposition in a distal location on the outer lobe of a submarine fan complex with periods of lobe switching resulting in non deposition or condensed depositional sequences.



Bambra-1, 2722.05m, cross-polars, 100x magnification.

Slide displays large bitumen and siderite infilled burrow within a very fine grained sideritic cemented sandstone. The quartz displays early diagenetic syntaxial quartz overgrowths. Rounded, fine grained glauconite pellet displays moderate sideritization. Slide displays nil-minor intergranular porosity

BAMBRA-1, CORE 2, 2721.19 m

ROCK NAME Quartzitic Greywacke.

MINERALOGY

	Average %
Argillaceous matrix (sericite).	40
Quartz.	30
Siderite.	10
Feldspar.	5
Muscovite.	5
Organic matter.	5
Glauconite.	Trace - 3
Calcite.	Trace - 2
Zircon.	Trace.
Chert.	Trace.

TEXTURE

The rock is a laminated, extremely fine grained quartzitic greywacke. The quartz (0.1-0.4 mm) show extensive authigenic overgrowths and intergranular pore space is infilled by sideritic cement and sericitised brown clay matrix. Nil intergranular porosity remains. There is also a moderate concentration of opaque bituminous matter which appears enclosed by silica overgrowths. The organic matter is concentrated along contorted laminae. The siderite cement is early diagenetic, however it appears that the authigenic overgrowths outpaced the sideritic cement and is the principal porosity occluding cement. Siderite rhombi appear as inclusions in the syntaxial quartz overgrowths.

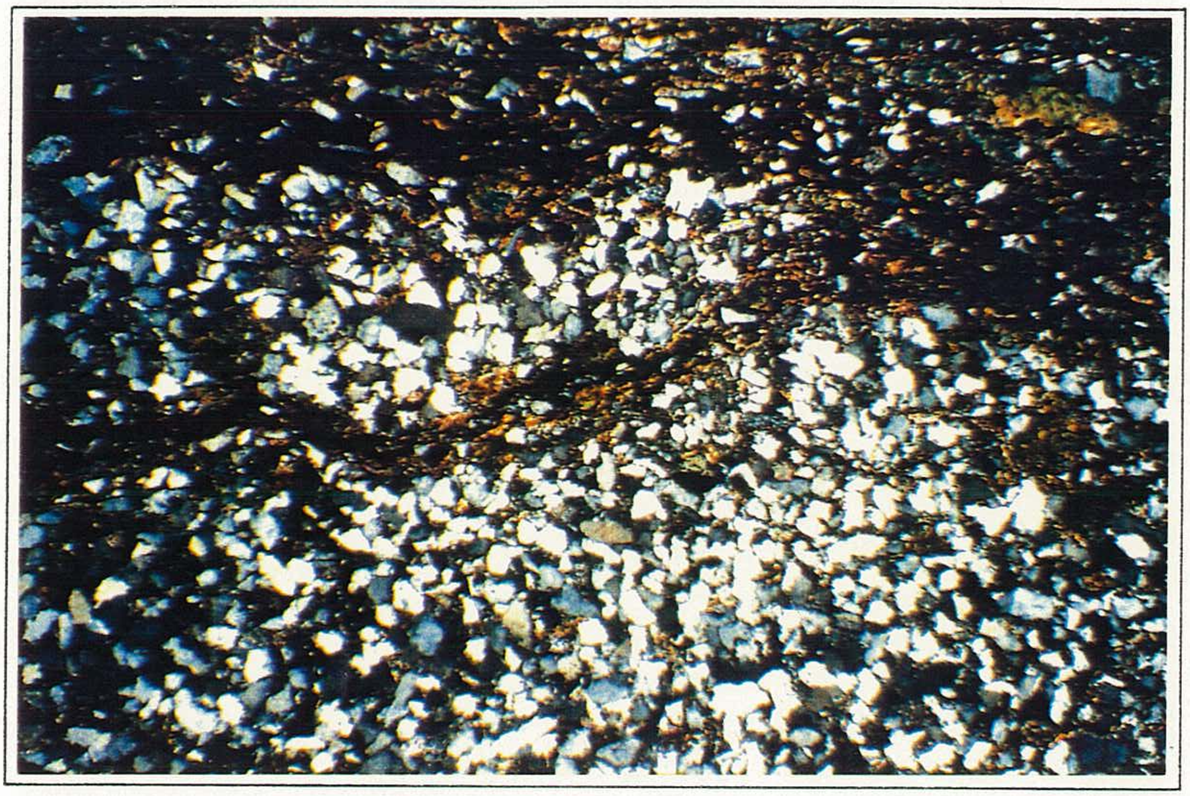
The sericitised argillaceous laminae display a degree of contortion due to compaction and contain an abundance of bituminous and micaceous (muscovite and biotite) matter. Frequent glauconitic pelloids appear 'squeezed' and orientated parallel to the laminae. These glauconitic pelloids have undergone an extensive degree of sericitisation. The quartz within the argillaceous layers display minimal quartz overgrowths and a higher degree of pitting of the grain surface by the seriticitic matrix. Within the argillaceous bands are laminae consisting almost exclusively of brown clay matrix which has been weakly sericitised. These laminae are up to 1.5 mm in diameter and probably represent infilled horizontal burrows where bioturbation has been concentrated along organic rich, argillaceous laminae.

DIAGENETIC HISTORY

Early diagenetic sideritic cement within the quartz rich bands was halted due to rapid development of authigenic quartz overgrowths. This may be due to a relatively rapid burial or conditions being more conducive for silica cementation. The cementation within the argillaceous laminae was inhibited by the predominance of clays, however fairly extensive sideritic cementation is present. Secondary calcite cementation is extremely limited in this unit due to the lack of porosity/permeability associated with the argillaceous nature of the rock.

DEPOSITIONAL ENVIRONMENT

The depositional environment was likely very low energy, disaerobic to very slightly oxic, deep submarine outer neritic - upper bathyal environment. The presence of feldspars within the quartzitic laminae suggests fairly rapid deposition and mode of transport due to the relative chemical instability of feldspars. Combined with the very fine quartz grains it may suggest deposition on the very distal areas of submarine fans or ramp sands on the margin of outer shelfal - foreslope sediments.



Bambra-1, core 2, 2721.19m, 25x magnification.

Slide display homgeneous nature of the very fine grained feldspathic quartzite with occasional 0.5-1.5mm sub-horizontal burrows infilled by bitumen and sideritic cement

BAMBRA-1, CORE 2, 2723.82 m

ROCK NAME Feldspathic Quartzite.

MINERALOGY

	Average %
Quartz.	60
Feldspar.	10
Kaolinitic/sericitic matrix.	10
Siderite.	5
Glauconite.	5
Organic matter.	5
Muscovite.	5
Siderite.	Trace - 2
Chert.	Trace.
Calcite cement.	Trace.
Tourmaline.	Trace.

TEXTURE

The rock is massive, very fine grained (0.1-0.2 mm), subrounded, moderately well sorted, with faint orientation of crystal axes. Feldspars include plagioclase with typical carlsbad twinning and microcline with cross hatched (polysynthetic) twinning. The grains show a faint preferred orientation, however extensive authigenic overgrowths prior to significant compaction inhibited orientation of the crystal axes. The general lack of compaction is also obvious by the organic matter which is globular within the pore throats and does not exhibit any obvious squeezing. Glauconite has a pelloidal shape and only occasionally shows any degree of compaction.

Cementation is dominated by syntaxial quartz overgrowths with only minor early diagenetic sideritic cement. Sericitised argillaceous matrix is relatively infrequent. Quartz and feldspar boundaries display no degree of pressure solution.

DIAGENETIC HISTORY

1 Deposition in a moderate energy environment whereby conditions were not conducive for the deposition of argillaceous matrix.

2 Early diagenetic formation of microcrystalline sideritic cement within pore space.

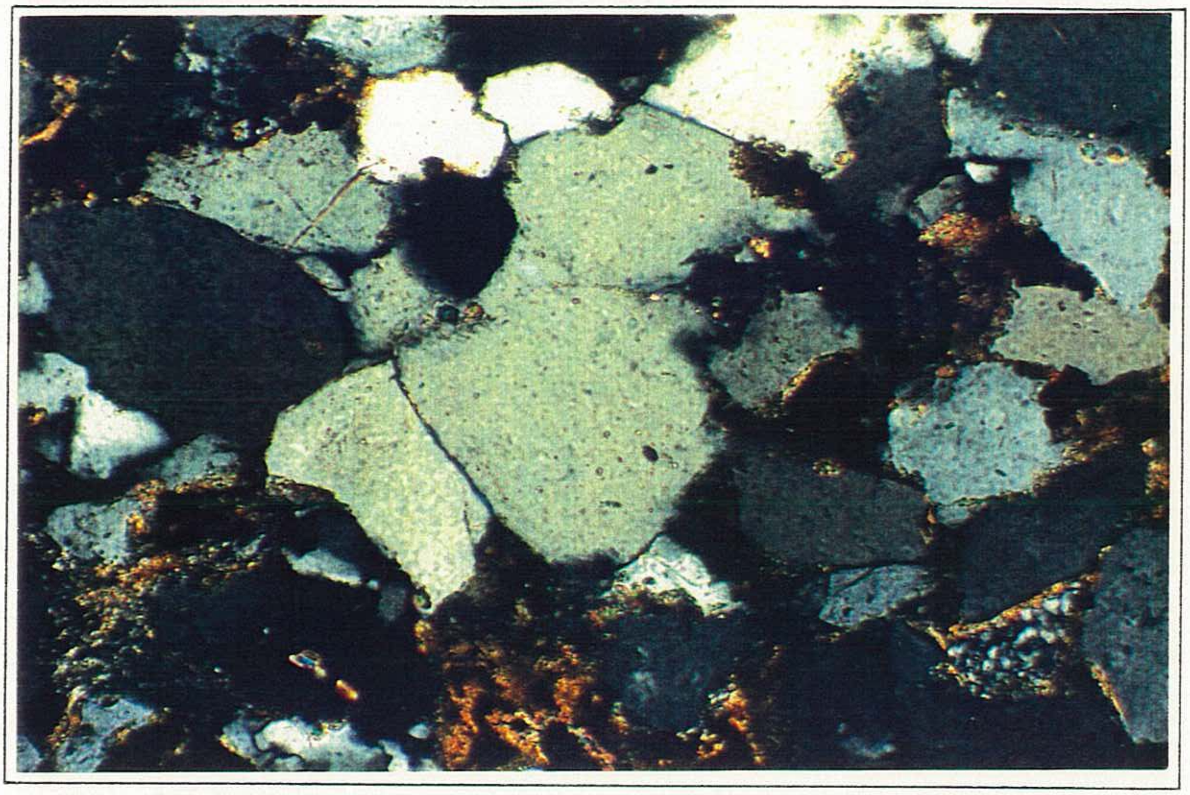
3 Rapid authigenic quartz overgrowths inhibiting further sideritic cementation.

4 Authigenic breakdown of feldspars into kaolinite booklets further occluding porosity.

5 Very late, minor carbonate cementation infilling remaining void spaces.

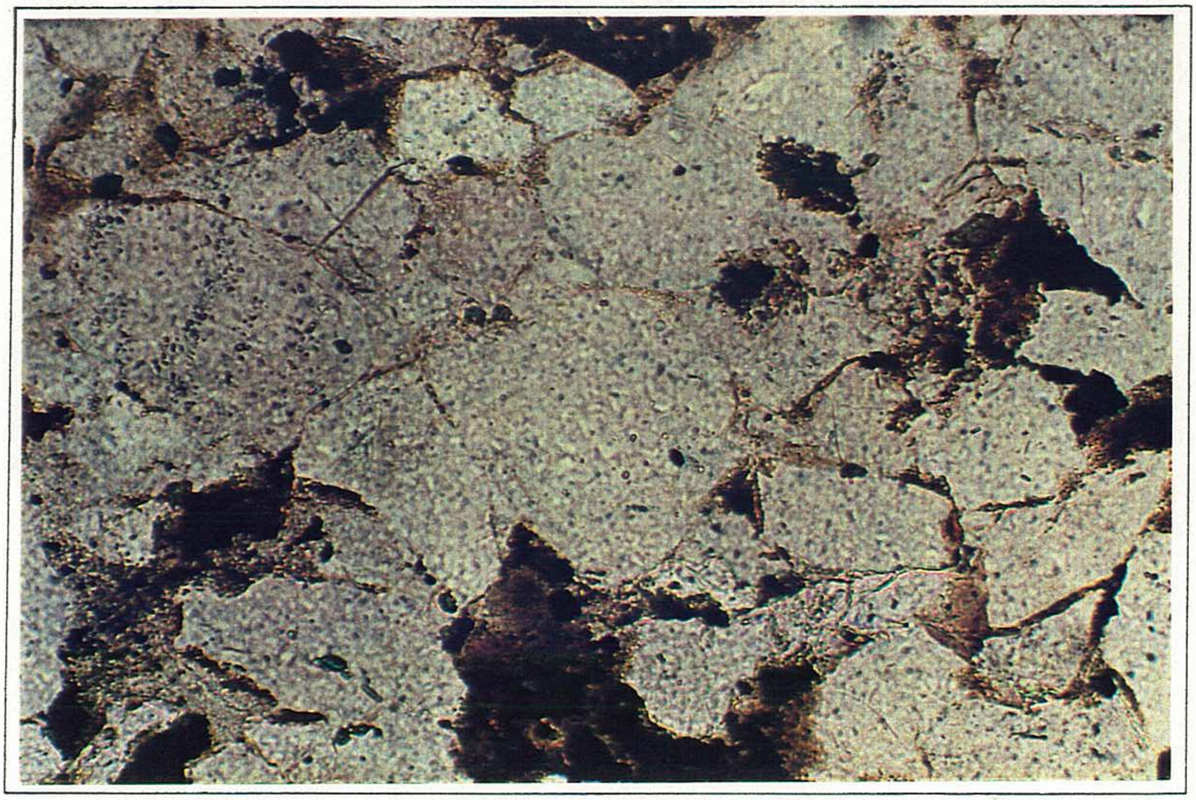
DEPOSITIONAL ENVIRONMENT

Deposition occurred in a low - moderate energy marine environment. Probably moderate - deep water as a result of gravity flow processes that resulted from reworking of shelfal marine sands with moderately abundant glauconite by storm activity, tectonic activity or eustatic sea level changes. This resulted in deposition of shelfal sediments into the basin by means of turbidite deposition. The lack of argillaceous matter (apart form that derived from the chemical breakdown of feldspar) indicates that deposition was not in the most distal area of a fan lobe or turbidite sequence.



Bambra-1, core 2, 2723.82m, cross-polars, 200x magnification.

Slide displays the extensive syntaxial quartz overgrowths that has significantly occluded intergranular porosity. The original quartz grains are rounded and the grain boudaries are marked by fluid inclusions(?).The slide also displays minor chert, glauconite, and mior sericitic matrix. Intergranular porosity is infilled by opaque, globular bitumen(?).



Bambra-1, core 2, 2723.82m, plane-polars 200x magnification.

Slide displays intergranular porosity infilled by sideritic cement and globular bitumen

EMMA-1, CORE 3, 2185.3 m

ROCK NAME Feldspathic greywacke - argillaceous protoquartzite.

MINERALOGY

	Average %
Quartz.	50
Feldspar.	10
Muscovite.	10
Sericite.	5-10
Kaolinite.	5
Glauconite.	5
Siderite.	5
Bitumen.	5
Chert.	Trace.
Organic matter.	5

TEXTURE

The rock is dominantly quartzitic, very fine grained (0.08-0.2 mm), moderately sorted with extensive argillaceous and poorly definable, planar laminae. The laminae have been contorted by compaction and water expulsion. The dark brown argillaceous matrix consist dominantly of sericitised clays with moderate amounts of muscovite, minor bituminous matter and angular silt sized quartz. The quartzitic units dominate the rock and consist of quartz with authigenic overgrowths, feldspar, minor siderite and moderate amounts of bitumen infilling void space. It appears that oil migrated through the rock after authigenic overgrowths, sideritic cement and authigenic clay generation had occluded most of the pore space. This resulted in choking of the remaining pore space by bituminous material and a general lack of pervasive bitumen throughout. It is apparent that the rock had also undergone a degree of compaction prior to hydrocarbons migrating into available pore space. Clay laminae have been contorted by bioturbation.

DIAGENETIC HISTORY

1 Early diagenetic microcrystalline sideritic cement.

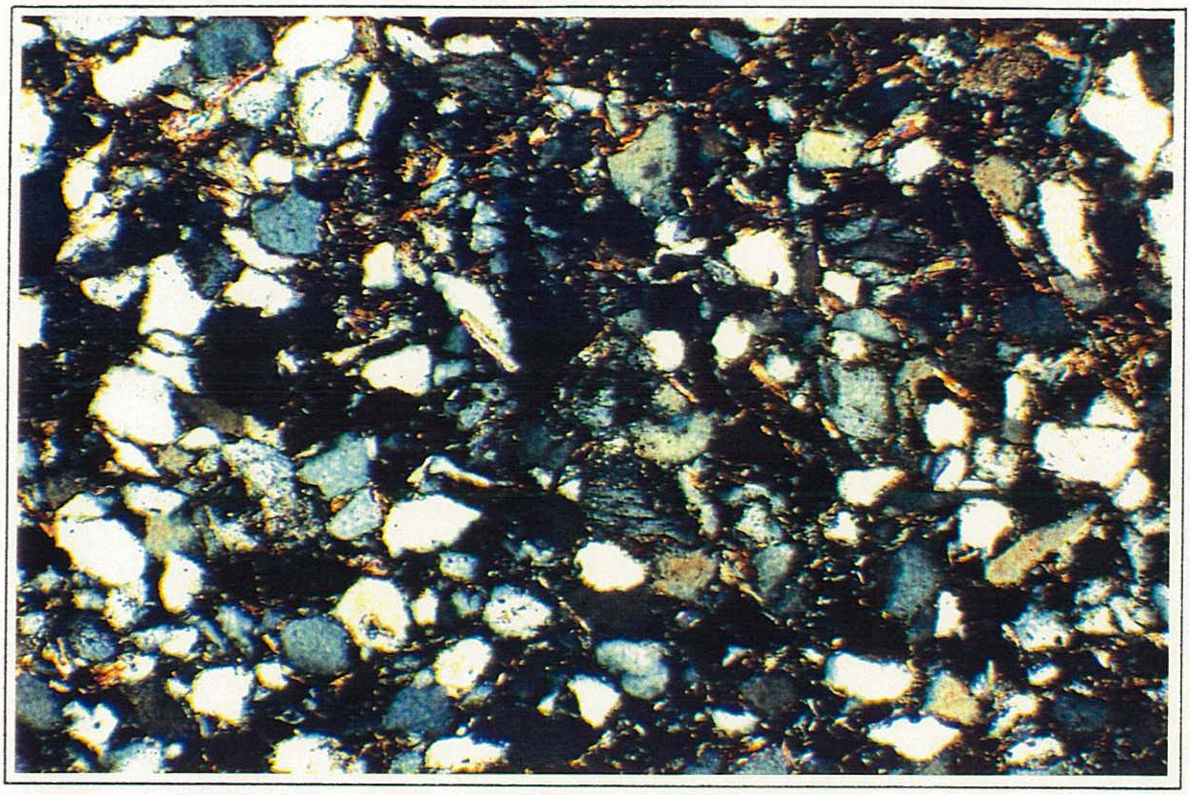
2 Authigenic quartz overgrowths.

3 Kaolinitisation of feldspars and sericitisation of brown clay matrix.

4 Migration of hydrocarbons into remaining pore space.

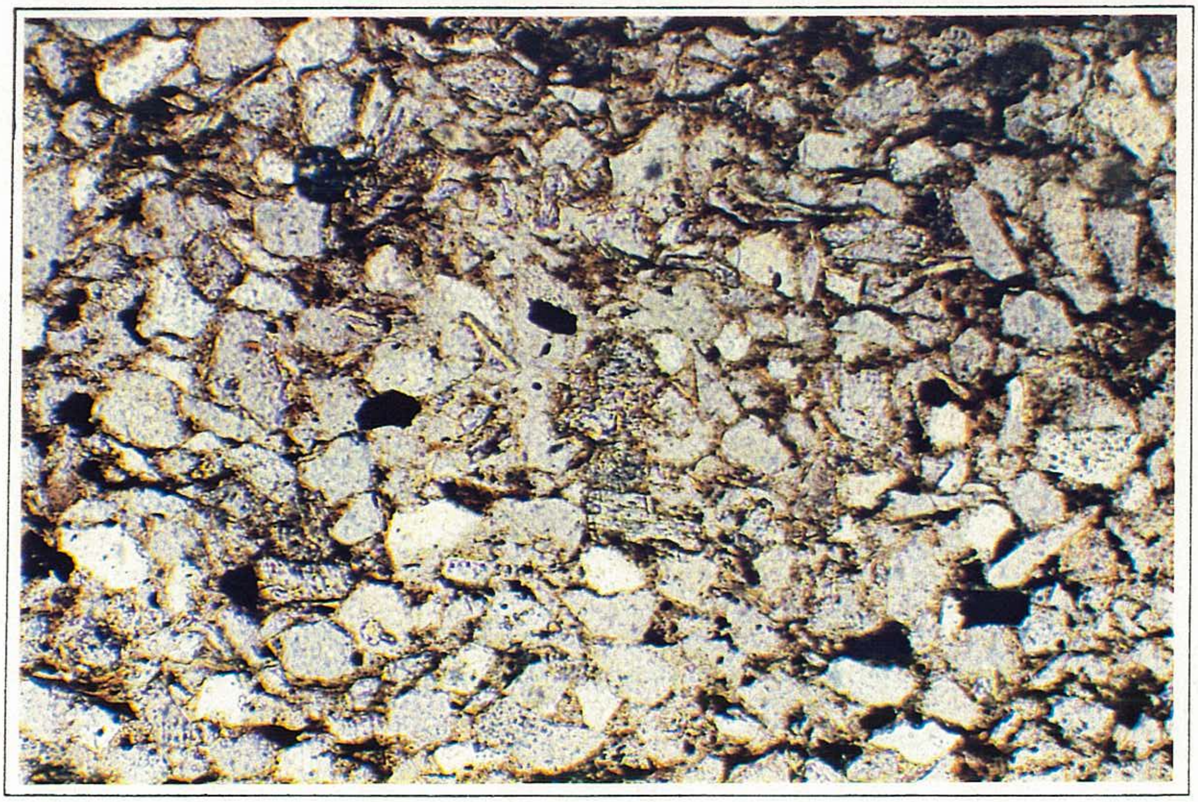
DEPOSITIONAL ENVIRONMENT

Depositional environment is a moderate - low energy, slightly oscillating energy system conducive for deposition of extremely fine grained quartz with argillaceous laminae. The preference of glauconite along the argillaceous laminae suggest in situ generation of glauconite from alteration of micaceous material or from faecal pellets due to the preferential bioturbation of the more organic rich argillaceous laminae. Extensive bioturbation has disturbed the laminae and primary sedimentary structures are difficult to distinguish. Deposition probably occurred in outer shelfal (below wave base) - bathyal associated with redistribution and reworking of shelfal sediments by density flow means.



Emma-1, core 3, cross-polars, 100x magnification. 2185.3m

Slide displays moderately -well sorted, very fine grained sandstone with abundant detrital clay matrix which has restricted authigenic quartz overgrowths. Rock contains abundant muscovite laths, sericitic matrix and opaque, glogular bitumen infilling intergranular porosity



Emma-1, core 3, plane-polars, 100x magnification. 2185.3m

Slide displays muscovite laths generally planar orientated and wrapping around the quartz grains. The quartz grains rarely display grain-grain contacts. Minor intergranular porosity infilled by globular bitumen.

EMMA-1, CORE 3, 2187.05 m

ROCK NAME Bioturbated Subgreywacke.

MINERALOGY

	Average %
Quartz.	35
Micritic matrix.	30
Sideritic cement.	10
Feldspar.	5
Calcite.	5
Calcite cement.	5
Sericite.	5
Glauconite.	Trace - 2
Organic matter.	Trace - 2
Biotite.	Trace.
Chert.	Trace.
Muscovite.	Trace.

TEXTURE

The rock is a highly bioturbated subgreywacke. The burrowing is oblique - subparallel to the orientation of crystals axes. The burrows are infilled by micritic matrix with microcrystalline sideritic and carbonate cement. Minor, extra fine, angular quartz crystals occur scattered within the burrows. The micritic matrix infilling the burrows has been weakly sericitised in part, however retains much of its low birefringence and high relief. The quartz is very fine grained (0.1-0.2 mm), subangular - subrounded, low sphericity, and moderately sorted. The quartz shows minor authigenic overgrowths and boundaries have been significantly pitted by sideritic cementation and micritic matrix. Carbonate cement has also replaced? quartz at some boundary contacts. The micritic matrix has inhibited significant authigenic quartz overgrowths. Secondary micro-sparry carbonate cement has infilled remaining pore space. Primary sedimentary structures have been obliterated by the intensive bioturbation.

DIAGENETIC HISTORY

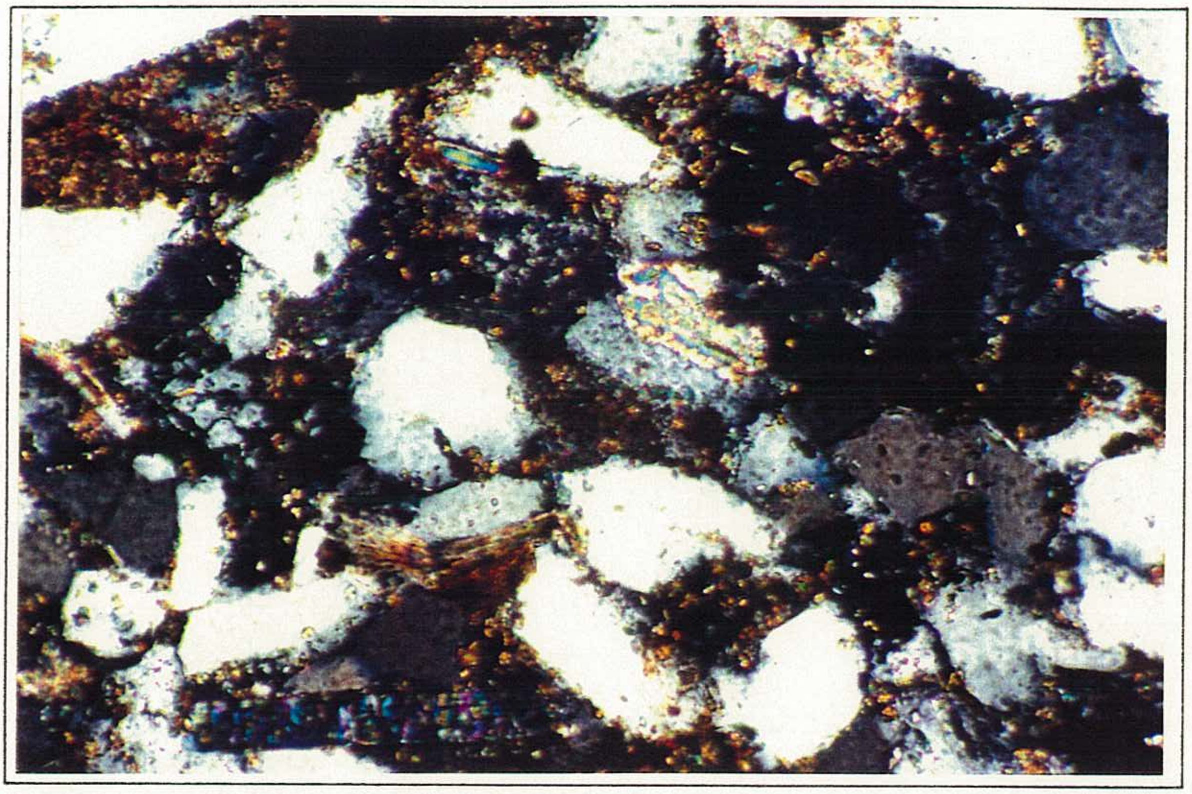
1 Early authigenic overgrowths.

2 Early diagenetic microcrystalline siderite cementation infilling burrows.

3 Moderate early carbonate cement infilling remaining pore space.

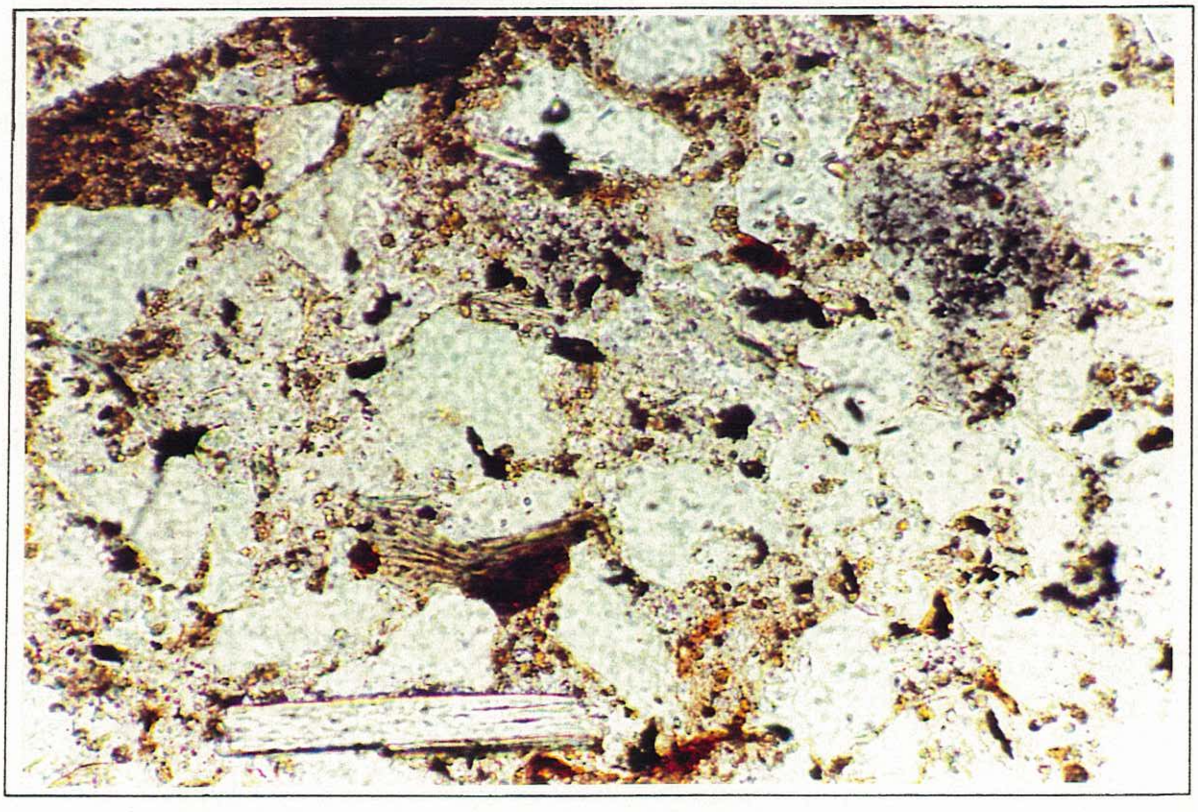
DEPOSITIONAL ENVIRONMENT

Relative low energy, below wave base, aerobic depositional environment allowing intensive bioturbation to occur.



Emma-1, core 3, 2187.05m, cross-polars, 200x magnification.

The slide displays extensively sericitised quartz and chert grains. Tabular muscovite laths upto 0.5mm long are orientated sub-parallel however the orientation of the quartz grains are generally random. The rock displays nil-very minor intergranular porosity



Emma-1, core 3, 2187.05m, plane-polars, 200x magnification.

The slide displays extensive sideritic matrix whch has inhibited authigenic quartz overgrowths. Intergranular porosity has been infilled by microsparry calcite cement and the muscovite laths display a moderate degree of compaction

DORRIGO-1, CORE 3, 1604.4 m

ROCK NAME Quartzitic subgreywacke.

MINERALOGY

	Average %
Quartz.	50
Micritic matrix.	20
Siderite.	15
Feldspar.	5
Muscovite.	5
Calcite microspar.	Trace - 5
Organic matter.	Trace - 5

TEXTURE

The rock is an argillaceous subgreywacke which has been extensively bioturbated by subhorizontal burrowing obliterating primary sedimentary structures. The very fine - silt sized quartz (0.08-0.25 mm) is angular - subrounded (predominantly subangular) and the long axis of the crystals are generally orientated parallel to the laminae. The quartz is relatively poorly sorted with the larger crystals (0.25 mm) being frequently subhedral and subrounded. The smaller crystals (~0.08 mm) are relatively angular and show no crystal faces. The variation in quartz grain size shows a bimodal distribution, the larger grains being confined to the quartzose laminae while the finer, more angular grains occur both within the quartzose and argillaceous laminae. The quartz boundaries show quite extensive pitting by siderite cementation and contain frequent inclusions of microcrystalline siderite. Glauconite has been noted in one area to have slightly replaced muscovite. The micritic matrix typically has a translucent reddish brown, iron stained colour due to the finely intergrown sideritic cement. Muscovite up to 0.4 mm long occurs dominantly within the quartzitic laminae.

DIAGENETIC HISTORY

1 The principal pore occluding matter is the argillaceous matrix with intergrown, early diagenetic sideritic cement.

2 The quartz grains show minor authigenic overgrowths, however the grains are rimmed by argillaceous matter which appears to have inhibited significant overgrowth formation.

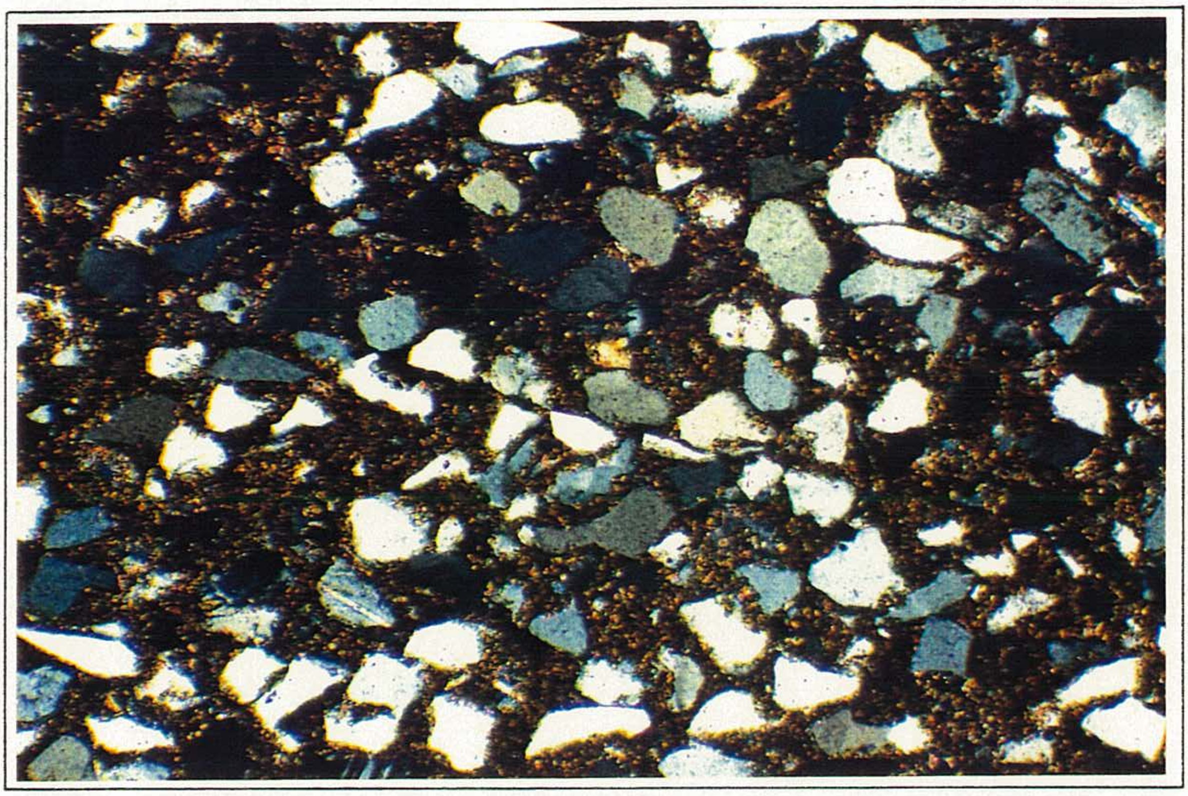
3 Secondary carbonate cement (probably dolomite) has infilled void space in

the quartzitic laminae.

4 Microsparry calcite cement has infilled any remaining void space and is a late stage diagenetic cement.

DEPOSITIONAL ENVIRONMENT

The rock consists predominantly of detrital material. The physical and chemical immaturity of the sediment suggests relatively rapid burial. However, the very fine grain size and argillaceous interlaminated nature of the sediment suggest deposition in an oscillating, very low energy environment. This suggests deposition in below water base, relatively deep marine environment.



Dorrigo-1, core 3, 1604.4m, cross-polars, 100x magnification

Slide displays matrix supported greywacke with angular - subangular very fine grained quartz and minor feldspar(micocline). The matrix has been extensively sideritised which has in part corroded the Quartz boundaries.. The rock displays no intergranular porosity

DORRIGO-1, CORE 3, 1605.1 m

ROCK NAME Argillaceous protoquartzite - subgreywacke.

MINERALOGY

	Average %
Quartz.	50
Argillaceous matrix.	25
Siderite.	15
Muscovite.	5
Feldspar.	Trace - 2
Chert.	Trace.
Glauconite.	Trace.
Opaque detrital grains (Magnetite?).	Trace.
Organic matter.	Trace.

TEXTURE

The rock displays a distinct fining upward fabric from very fine grained (~0.2 mm) to extremely fine grained (<0.08 mm). The larger quartz grains are subangular, generally moderately - poorly sorted, and are roughly orientated parallel to laminae. The quartz fines upward and grades into predominantly argillaceous matrix with scattered, silt sized quartz grains. The basal coarser grained section contains abundant very fine - fine grained plagioclase and opaque anhedral grains. The argillaceous micritic matrix rims the quartz grains and inhibits quartz overgrowths. The change in grain size is gradational and marks a relative waning in depositional energy. Large sideritic nodules occur within the basal quartzose layer and may represent sideritic cement infilling large subhorizontal burrows. Smaller horizontal burrows (~1-2 mm in diameter) occur in abundance within the upper argillaceous matrix and are infilled by microcrystalline sideritic cement. The matrix has a tan-brown colour and may be associated with intergrown cryptocrystalline sideritic cement. This cementation and staining of the matrix is a diagenetic feature. Late diagenetic microsparry carbonate cement has infilled remaining primary void space or replaced leached out argillaceous matrix?

DIAGENETIC HISTORY

1 Rarely developed syntaxial quartz overgrowths. May not have developed in situ.

2 Cryptocrystalline sideritic cementation infilling burrows.

3 Early diagenetic sideritic microcrystalline cementation.

4 Leaching of argillaceous matrix and dissolution of feldspars.

5 Late stage microsparry calcareous cement infilling remaining void space.

DEPOSITIONAL ENVIRONMENT

Relatively low and oscillating energy in a deep marine environment were responsible for deposition of the sediments. The trace of glauconite infers marine conditions. Abundance of argillaceous matrix supports low energy, below wave base conditions. The fining upward nature of the unit and the presence of feldspars in the lower unit suggest relatively rapid deposition from provenance in a depositional environment with waning energy.

DORRIGO-1, CORE 3, 1609.94 m

ROCK NAME Argillaceous sandstone - sublabile greywacke.

MINERALOGY

	Average %
Quartz.	45
Argillaceous matrix.	30
Siderite.	10
Biotite/Muscovite/Kaolinite.	5
Calcite.	5
Feldspar (dominantly plagioclase, Trace microcline).	5
Organic matter (Bitumen?).	Trace - 2

TEXTURE

The rock is an argillaceous very fine grained sandstone - sublabile greywacke with undulose and discontinuous laminae. The quartzitic laminae, consisting dominantly of quartz with subordinate feldspar, is very fine grained (<0.8 mm), subrounded, moderately - well sorted, with extensive authigenic silica overgrowths. The quartz and feldspars show a very faint grain orientation subparallel to the laminae boundaries. The quartz grains also show occasional sutured grain contacts (indicating pressure solution due to compaction) however the dominant porosity occluding fabric is the authigenic overgrowths. The detrital feldspars are frequently partially altered along cleavage planes to a high birefringent, spicular mica. The quartz grains contain abundant very small inclusions of high relief, rhombic crystals, possibly dolomite or siderite. The quartz crystals also have been rimmed by clay matrix. Secondary microsparry carbonate cement has infilled remaining pore space.

The argillaceous laminae are matrix supported and contain angular -subangular, very fine (<0.15 mm) quartz grains. The argillaceous matrix is dominantly detrital in nature and has been stained brown by either intergrown sideritic cement or by some other iron staining means. The quartz have been orientated with their long axis parallel to the laminae. Also intercalated with the argillaceous laminae are occasional rhombic calcite crystals which are of probable detrital origin. Muscovite and biotite occur as elongate tabular crystals which have frequently been bent and contorted around quartz and feldspar grains due to compaction but which are still generally orientated parallel to the laminae. Organic matter is also present in moderate abundance within the argillaceous laminae and appear to have been squeezed with their long axis parallel to depositional laminae. Nil primary porosity exists within the argillaceous laminae.

Frequent bioturbation oblique to the laminae cross cut both the argillaceous and quartzitic laminae. The diameter of the burrows are <0.08 mm. The burrows have been infilled by microsparry calcitic cement and micritic matrix.

DIAGENETIC HISTORY

1 Extensive authigenic overgrowth on quartz and feldspar grains, early diagenetic sideritic cementation. Overgrowths may however have not been generated in situ and be detrital.

2 Alteration and breakdown of unstable detrital feldspar grains.

3 Possible intergrown sideritic cementation within argillaceous matrix.

DEPOSITIONAL ENVIRONMENT

The sediments must have been deposited under very low, slightly oscillating depositional energy conditions. The presence of chert and feldspars suggest reworking of relatively rapidly accumulated sediments possibly from shelfal or near shore areas. The depositional environment responsible for deposition of this sediment may have been below wave base, low energy outer shelfal - slope environment.

NB: General lack of siderite in contrast with other samples.

GEORGETTE-1, CORE 1, 2156.6 m

ROCK NAME Argillaceous Sandstone / Subgreywacke.

MINERALOGY

	Average %	
Quartz.	50	
Calcite cement.	15	
Clay matrix.	25	(Sericite, muscovite and kaolin in equal abundance.)
Siderite.	10	
Feldspar.	5	(Predominantly plagioclase and microcline.)
Organic matter.	5	
Muscovite.	5	
Chert.	Trace.	
Glauconite.	Trace.	

TEXTURE

The rock is an argillaceous sandstone (subgreywacke) with occasional undulose clay laminae and organic matter disseminated throughout. The rock is dominated by extremely fine grained (~0.05 mm) angular -subangular, occasionally subrounded, moderately well sorted, quartz and subordinate feldspar. Detrital clay matrix has rimmed the quartz grains restricting authigenic overgrowths. The clay matrix infills pore space between the quartz grains and appears intergrown with a diagenetic, calcite cement. The clay laminae appear discontinuous and contorted related to subhorizontal and oblique bioturbation generally pervasive throughout the rock. No evident orientation of grains is apparent which may be related to the bioturbation. Alteration of feldspars along cleavage planes to sericite/kaolinite? is occurring in many of the feldspar grains. Some acicular inclusions (sillimanite?) occur occasionally within quartz crystals. The quartz crystals contain relatively abundant, extremely fine, rhombohedral inclusions. The microsparry calcite cement is intergrown with the clay matrix and has corroded quartz boundaries. Glauconite is only just beginning to replace muscovite and biotite.

DIAGENETIC HISTORY

1 Minor carbonate cementation intergrown with detrital argillaceous matrix. Infilling void space. Alteration of micas to glauconite.

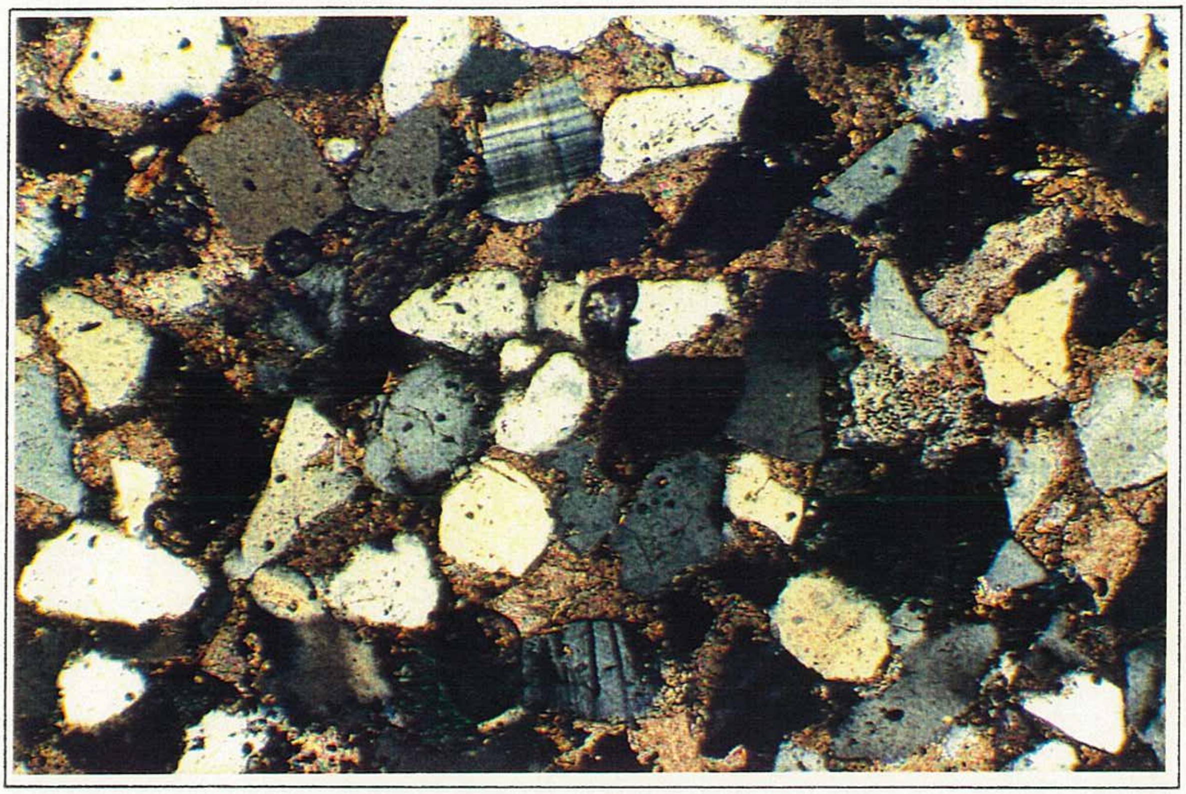
2 Generally no authigenic overgrowths due to rimming of quartz and feldspar crystals by detrital clay matrix. Compaction and contortion of muscovite

tabular laths and water expulsion.

3 Alteration of feldspars and unstable grains. Usually along cleavage planes.

DEPOSITIONAL ENVIRONMENT

The depositional environment must have been very low energy submarine environment. Little further can be said due to the obliteration of primary sedimentary structures by intense bioturbation.



Georgette-1, core 1,2156.6m, cross-polars, 100x magnification.

Slide displays mod-well sorted, subrounded-rounded, matrix supported sub-greywacke. Early diagenetic calcite cement has partially replaced detrital argillaceous matrix. The quartz and feldspars grains rarely display grain-grain contacts. The glauconite has been extensively sericitised. Opaque globular bitumen(?) occurs disemminated throughout the slide. The rock displays no intergranular porosity

GEORGETTE-1, CORE 2, 2278.8 m

ROCK NAME Subgreywacke.

MINERALOGY

	Average %
Quartz.	50
Sericitic matrix.	30
Siderite.	10
Feldspar.	5
Muscovite.	5
Organic matter.	5
Chert.	3
Calcite.	2

TEXTURE

The rock shows a generally chaotic fabric with only a very weak preferred orientation of crystals. The rock is extremely fine grained, quartz grains are generally <0.08 mm and angular - subangular. The rock is poorly sorted and displays a bimodal grain size distribution.

The slide shows an erosive contact between two separate depositional cycles. The overlying cycle is dominated by extremely fine grained crystals (<0.05 mm), subangular - angular, moderately sorted with a weak grain orientation within an argillaceous matrix. The underlying cycle consists of poorly sorted quartz grains ranging from 0.05-1.5 mm within a matrix supported fabric. The argillaceous matrix is identical to the underlying unit. Both units have undergone fairly intensive subhorizontal bioturbation with the diameter of the burrows generally <0.08 mm. Large burrows cross cut the underlying poorly sorted sequence and are up to 0.25 mm in diameter. These burrows have been infilled by microsparry calcitic cement and authigenic clays derived from the breakdown of unstable grains.

The organic matter frequently occurs disseminated within the argillaceous matrix and appears as rounded detrital clasts. Under higher magnification the individual organic matter globules show a cellular configuration (honeycomb-like). This organic matter was probably derived in the shallower areas which was reworked and deposited by mass flow means in a deeper environment.

DIAGENETIC HISTORY

1. Very minor authigenic quartz overgrowths generally inhibited by clays rimming quartz crystals.

2. Early diagenetic sideritic cementation intergrown with the argillaceous matrix.

3. Infilling of burrows by equant microsparry calcitic cement and faecal pellets?

DEPOSITIONAL ENVIRONMENT

The initial depositional environment was a mass flow of a matrix supported sediment resulting in poorly sorted sediments generally chaotically oriented within an argillaceous matrix. The rapid deposition of this mass flow sequence rapidly ceased and was followed by deposition of further matrix supported quartzose sediment but in a slower and generally less chaotic cycle.

GEORGETTE-1, CORE 2, 2275.26 m

ROCK NAME Feldspathic subgreywacke.

MINERALOGY

	Average %			
Quartz.	45	CLAST COMPOSITION:	Siderite	40%
Argillaceous matrix.	20		Calcite	30%
Sideritic cemented clasts.	10		Quartz	25%
Chert.	5		Pyrite	10%
Feldspar.	5		Feldspar	5%
Kaolinite.	5			
Muscovite.	5			
Pyrite.	5			
Organic matter.	Trace.			
Equant sparry calcite.	Trace.			

TEXTURE

The rock is dominantly matrix supported with abundant detrital quartz and subordinate feldspars with the grain size showing a poorly developed gradation (or may have been affected by bioturbation). Occasional large (up to 1 cm in diameter) calcitic clasts and very coarse quartz grains also are present. These clasts appear detrital in nature and are rimmed by dark brown argillaceous matrix.

The quartz and feldspar within the brown argillaceous matrix is very fine grained (0.05-0.125 mm) angular - subround, moderately - poorly sorted and very weakly oriented subparallel to depositional laminae observable on the slide. The feldspar shows alteration to kaolinite along cleavage planes and may contribute to the authigenic clay abundance. The quartz contain abundant acicular inclusions of (?siliminite or rutile) as well as rhombohedral sideritic crystals? The matrix is a reddish brown and may contain intergranular sideritic cement. The rock displays a weak graded bedding.

The calcitic - sideritic clasts are and very coarse quartz grains are rounded to sub-rounded. The clasts are dominated by sideritic and equant sparry calcite cement. Burrows up to 0.6 mm in diameter appear subparallel to the weak alignment of the quartz grains. These burrows have been infilled by sideritic cement. Sparry and microsparry calcite dominate the interstitial cement between the quartz grains.

The relative abundance of organic matter has been replaced by authigenic pyrite. Pyrite is also partially replacing matrix and is also occurring as inclusions within the quartz. Pyrite generally has a globular form but occasionally displays its characteristic cubic habit.

DIAGENETIC HISTORY

1 Early diagenetic microcrystalline sideritic cementation intergrown with argillaceous matrix.

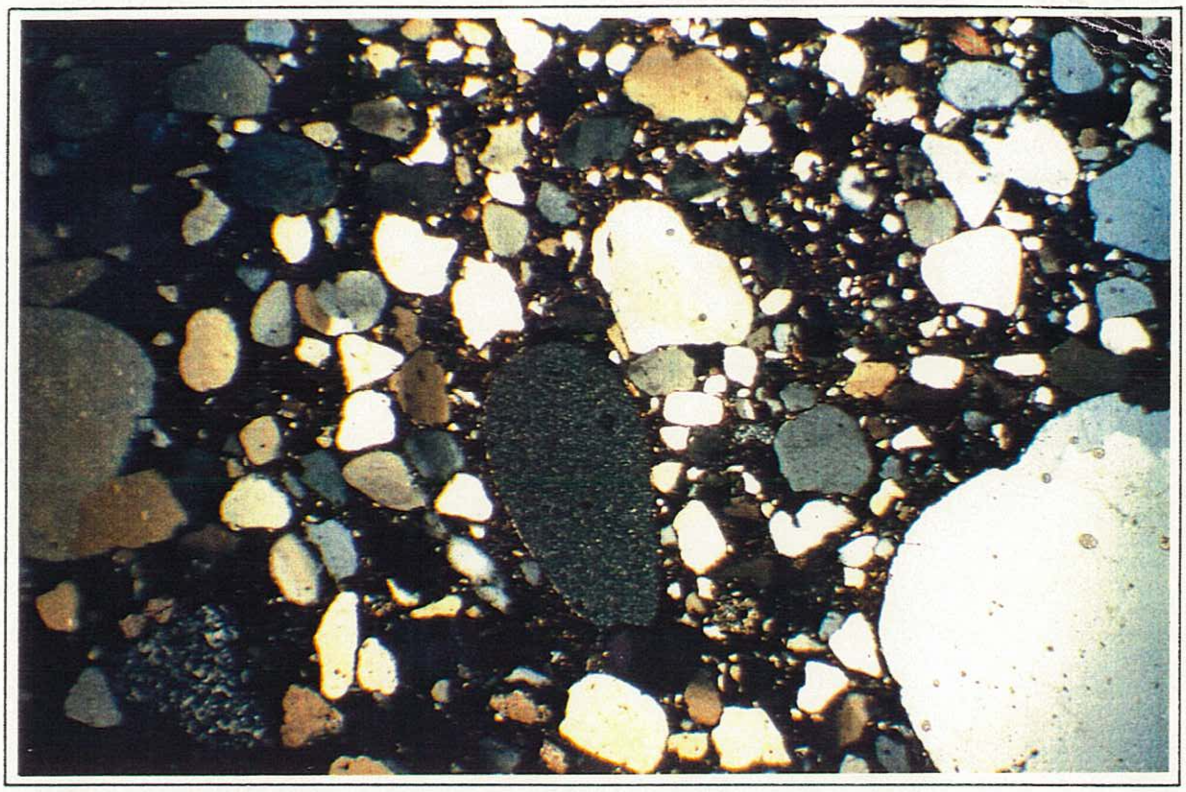
2 Sericitisation / kaolinisation of feldspars along twin planes.

3 Generation of authigenic pyrite by degradation of organic matter.

Clasts were cemented prior to reworking and transportation. The relative roundness and lack of obvious compaction testifies to the clasts homogeneity prior to deposition.

DEPOSITIONAL ENVIRONMENT

The sediment has been deposited in a relatively rapid, high energy depositional environment obvious from presence of detrital clasts within fine grained ground mass. The sediments were reworked from a marine sediment and deposited by mass flow submarine processes with a rapidly waning fluidised flow not allowing sorting processes to develop.



Georgette-1, core 2, 2275.26m, cross-polars, 100x magnification.
Slide displays poorly sorted quartz and subordinate chert and feldspars. the grainsize distribution is bimodal in nature with very fine-fine grained, subrounded quartz within a brownish argillaceous matrix. The rounded, very coarse(0.5-2mm in diametre) occurs disseminated throughout the rock. The quartz grain boundaries are sharp and display no authigenic quartz development due to the detrital clay matrix. The rock displays no intergranular porosity.

GEORGETTE-1, CORE 2, 2278.98 m

ROCK NAME Subgreywacke

MINERALOGY

	Average %
Quartz.	40
Argillaceous matrix.	30
Siderite.	20
Feldspar.	5
Organic matter.	5
Muscovite.	2-5
Pyrite.	Trace - 2
Chert.	Trace.
Rutile/Zircon?	Trace.

TEXTURE

The slide displays a homogeneous very fine grained (<0.15 mm), angular - subangular, moderately - well sorted fabric with the long axis of the quartz grains oriented subparallel to argillaceous laminae. The rock is dominantly matrix supported with rare grain-grain contacts. Subparallel argillaceous laminae are common, frequently appearing discontinuous and contorted possibly associated with dewatering and compaction or the moderately intense bioturbation. Common organic matter is disseminated throughout the slide and displays compaction and a moderate degree of maturation evident by its blackness and opacity. Authigenic pyrite is occasionally seen to replace the organic matter.

The quartz grains have weakly developed authigenic overgrowths however the argillaceous matrix inhibited significant overgrowth formation. Early diagenetic sideritic cementation is intergrown with the argillaceous matrix and has given it the brown colour. Traces of rounded very fine chert grains associated with the quartz attests to the reworking of detrital sediments. The quartz contains relatively abundant rhombohedral yellowish brown (in plain light) inclusions which may be siderite. The feldspars have undergone intense kaolinisation? concentrated along twin planes or along the margins of the crystals. The quartz boundaries are frequently pitted and are replaced by the siderite cement and argillaceous matrix.

DIAGENETIC HISTORY

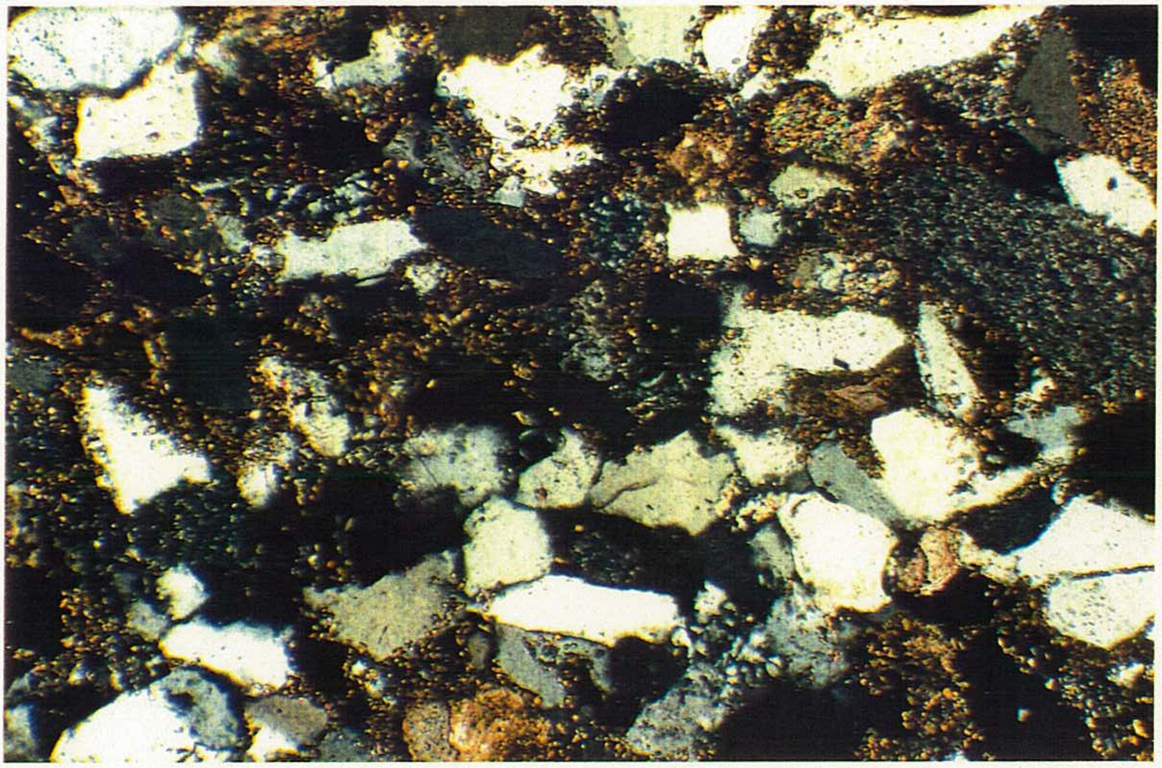
1 Early diagenetic quartz overgrowth.

2 Early diagenetic sideritic cementation intergrown with matrix and occurring as inclusions within the syntaxial quartz overgrowths.

3 Alteration and breakdown of unstable grains, e.g. kaolinisation of feldspars, along cleavage.

DEPOSITIONAL ENVIRONMENT

The depositional environment was a weakly fluctuating, very low to low energy system, most likely marine and well below storm wave base. The rhombohedral micro-cryptocrystalline siderite crystals within the argillaceous matrix suggest a relatively early diagenetic cementation processes prior to significant compaction. The authigenic alteration of organic matter to pyrite suggests a very reducing environment, however this may well have occurred post-burial. The presence of thin, subparallel trace burrows (<1 mm in diameter) suggests that the sea floor conditions at time of deposition most likely had some degree of oxygenation.



Georgette-1, core 2, 2278.98m, cross-polars, 100x magnification.

Slide can be subdivided into a lower very fine grained quartzite with extensive early diagenetic quartz overgrowths development. Syn-diagenetic growth of siderite crystals occur as inclusions within the overgrowths. The upper half of the slide displays extensive development of early diagenetic siderite cement rimming the randomally orientated quartz crystals. Large pelletal glauconite is moderately sericitised.The rock displays no intergranular porosity

Georgette-1, core 2, 2278.98m, plane-polars, 100x magnification.

The slide displays the abundant, high relief,very small(<0.001mm) siderite crystals rimming the quartz grains.The quartz grains display a weak orientation of crystal axis.

SOUTH PEPPER-1, CORE 8, 2327.9 m

ROCK NAME Feldspathic Subgreywacke

MINERALOGY

	Average %
Quartz.	50
Calcite cement.	20
Feldspar.	10
Glauconite.	5 - 10
Chert.	5
Kaolinite.	5
Organic matter.	Trace - 2
Augite?	Trace.
Pyrite.	Trace.

TEXTURE

Based on core descriptions, this rock is part of a boulder sized clast that was deposited during a massive mass flow episode. This rock therefore yields no information as to the final depositional environment but does indicate the shelfal marine sediments from which these massive clasts are derived.

The quartz, chert and feldspar grains are very fine grained (0.08-0.3 mm) subangular - round, generally subround, moderately sorted and generally randomly orientated. Occasional, very coarse grained (1-1.5mm) rounded quartz grains occur disseminated throughout the slide. These grains display minor corrosion at grain boundaries. The very fine quartz grains display extensive authigenic overgrowths and frequently have embayed contacts with adjacent grains. The feldspar displays both polysynthetic thinning (plagioclase) and cross hatched twinning (microcline). The feldspars frequently show alteration to kaolinite? along cleavage planes as well containing very small (<0.1 mm) rhombohedral, high relief inclusions? Abundant pelloidal glauconite occurs interstitially and has been compacted and squeezed while still in a hydrated state. Interstitial pore space has been infilled by microsparry calcite cement. Minor argillaceous matrix appear to rim the detrital grains. Rare pleochroic high relief (yellow - brown) subhedral detrital grains occur randomly within the rock. Calcite cementation also appears to replace the quartz and feldspar at grain boundaries.

DIAGENETIC HISTORY

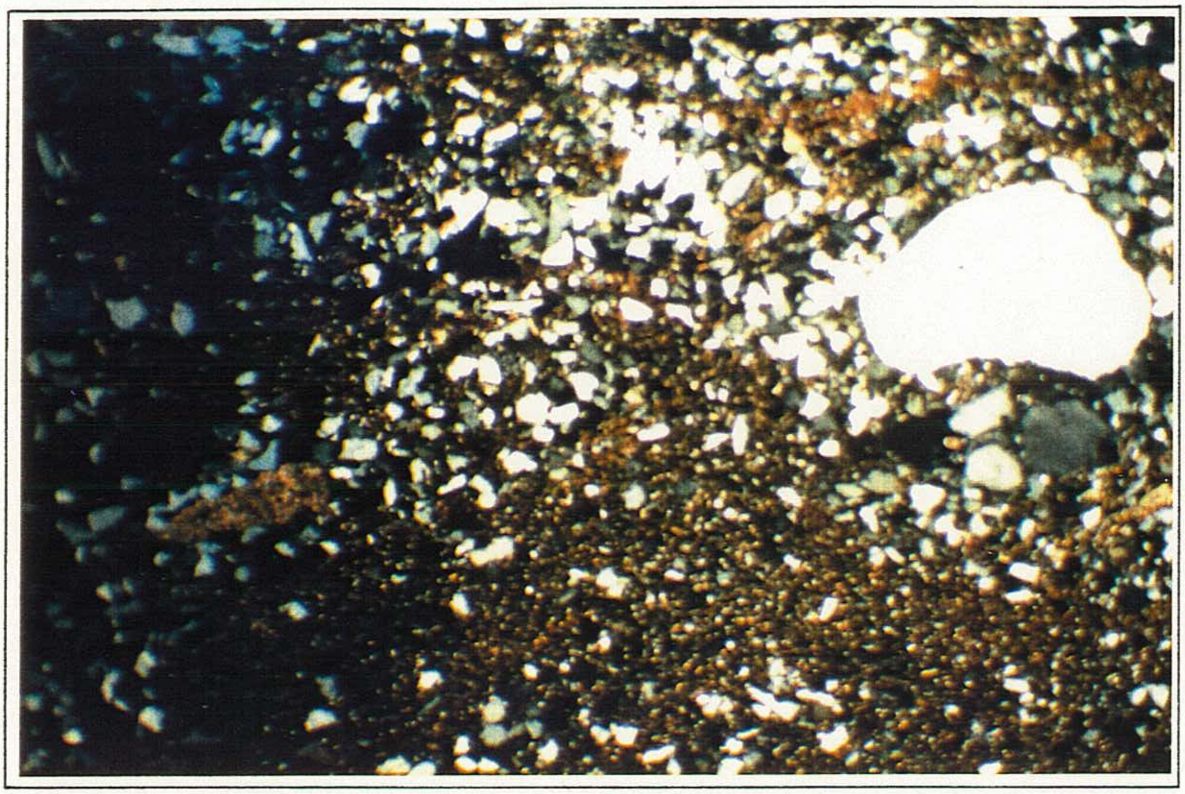
1 Authigenic quartz overgrowths.

2 Calcite cementation infilling interstitial porosity.

3 Minor kaolinisation of feldspars.

DEPOSITIONAL ENVIRONMENT

The depositional system was most likely a moderate energy, relatively shallow marine environment, still influenced by wave motion (due to the lack of argillaceous matter). The rounded and moderately sorted nature of the grains suggest that the grains have been reworked and the presence of chert and feldspar in abundance combined with detrital clinopyroxenes suggest moderately close proximity to provenance and rapid deposition due to the chemical immaturity of the sample.



South Pepper-1, core 8, 2327.9m, cross-polars, 25x magnification.

The slide displays the poorly sorted nature of the rock ranging from brownish argillaceous matrix, very fine grained - silt sized quartz and coarse grained, rounded quartz grains. The slide displays nil intergranular porosity.

CHERVIL-1, CORE 7, 1785.04 m

ROCK NAME Feldspathic quartzite.

MINERALOGY

	Average %
Quartz.	40
Calcite grains.	20
Calcite cement.	10
Feldspar.	10
Sericite/kaolinite.	10
Chert.	5
Glauconite.	Trace - 5

TEXTURE

The slide is extremely poor quality and is only useful in isolated areas. Where identifiable, the rock is extremely tight and quartzitic with extensive syntaxial quartz overgrowths and strongly embayed grain boundaries. The quartz, feldspar and chert grains are very fine grained (0.15-0.45 mm), subrounded - round, moderately -poorly sorted and generally lacking orientation. The principal porosity occluding process is authigenic overgrowths on the quartz grains however secondary equant microsparry calcite cement has infilled any remaining interstitial void spaces. Large detrital calcite grains with rhombohedral cleavage up to 0.5 mm in diameter also occur associated with the detrital quartz, chert and feldspar. The calcite grains appear fractured and are occasionally altered to quartz? The quartz contains abundant rhombohedral high relief inclusions as well as occasional needle-like acicular silliminite/or rutile inclusions.

DIAGENETIC HISTORY

1 Syntaxial quartz overgrowths.

2 Equant microsparry calcite cement.

3 Compaction inducing embayed and rare sutured grain contacts.

4 Alteration of feldspars along cleavage plains to kaolin(?).

DEPOSITIONAL ENVIRONMENT

The presence of glauconite supports a marine deposition process. When combined with the relatively poor degree of sorting, relative abundance of feldspars, chert and calcite grains and lack of detrital argillaceous matrix, suggests a rapid mode of deposition under moderate energy conditions. The depositional environment may therefore be a storm derived turbidite, depositing shelfal sediment rapidly into a low energy environment. It is highly unlikely that these sediments were deposited in above wave base conditions due to the chemical immaturity of the sediments (i.e. the abundance of feldspars and calcite).