Sedimentation of the Barrow Group, Exmouth Plateau, Northwestern Australia

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BACKGROUND

The Exmouth Plateau is a major promontory of the north-western Australian continental shelf and ranges from longitude 111°E to 117°E throughout southern latitudes 16° to 21° (Figure 1). This plateau has an aerial extent of approximately 150,000 square kilometers and local water depths range from 700 metres to 2000 metres at the plateau margins.

Past research in the area indicates that the Exmouth Plateau is an isolated block of continental crust which was created by rifting during the breakup of India and Australia, (Von Rad and Exon, 1983). The plateau is bounded to the north, west and south by margins which were created as a result of rifting and shearing associated with this major tectonic event. (Figure 2).

Sedimentation on the Exmouth Plateau has varied substantially over time, reflecting the different environments which were encountered throughout the rifting process. Early Triassic sediments are fluvial-deltaic in origin but are unconformably overlain by deposits which show a steadily increasing marine influence (Figure 3). This generalized stratigraphic sequence reflects the fact that the plateau has undergone progressive subsidence since it was first exposed to the sea by the breakup of Gondwanaland.

In this thesis, the continental margin deposits of the Barrow Group are examined in detail. This major unit is

Figure 1.

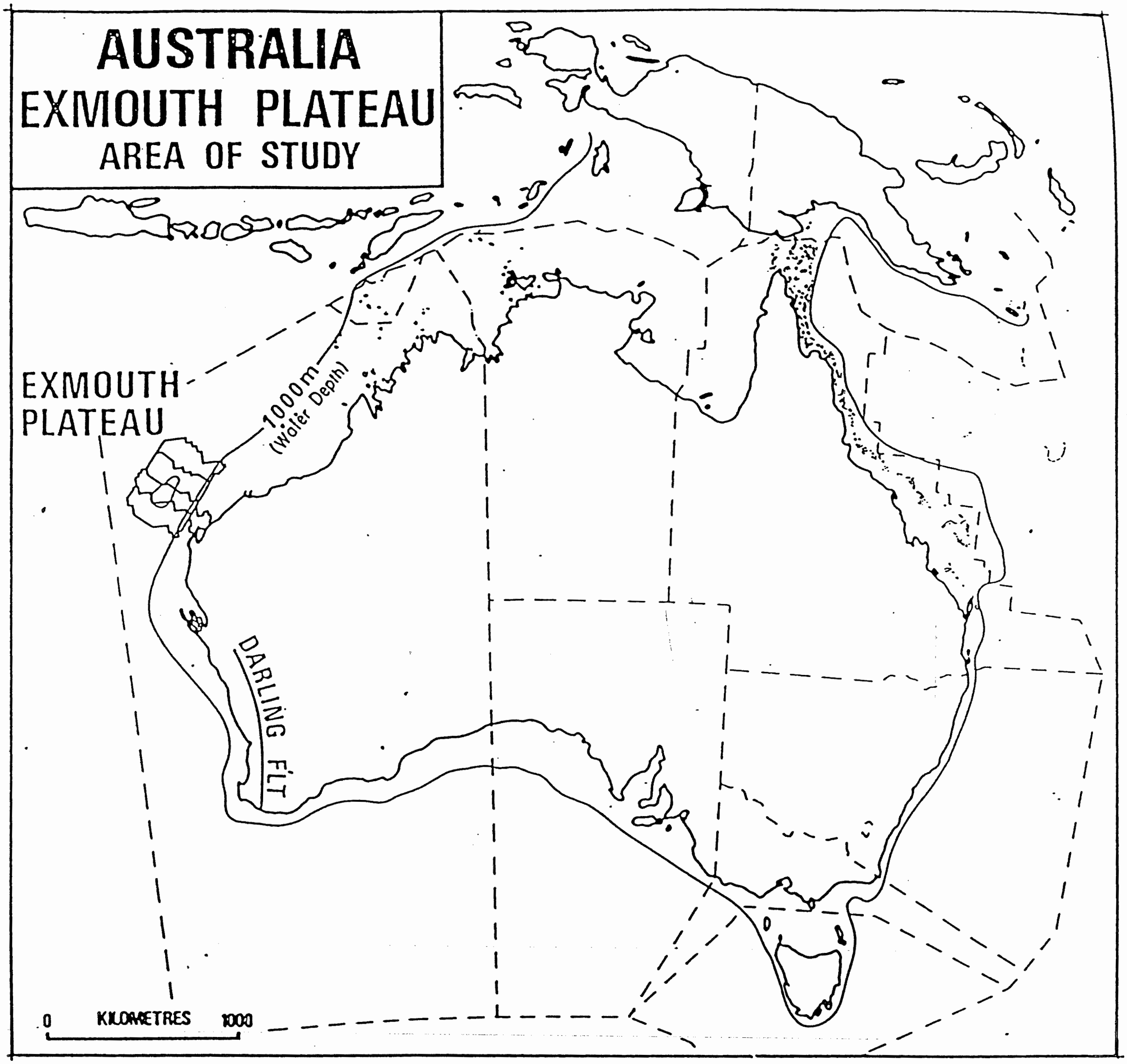
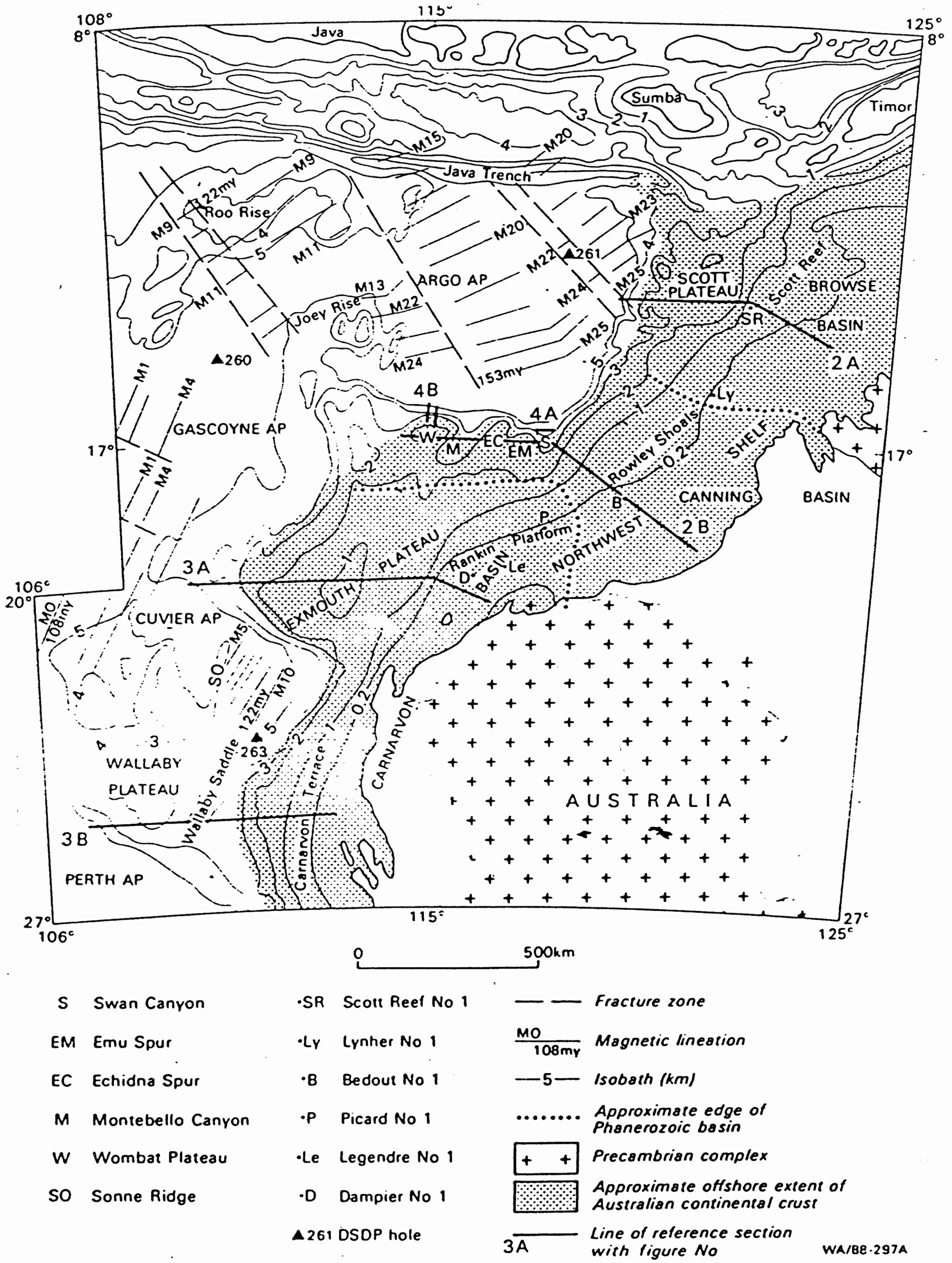

AUSTRALIA
EXMOUTH PLATEAU
AREA OF STUDY
EXMOUTH PLATEAU
1000m (Water Depth)
DARLING FLT
0 KILOMETRES 1000

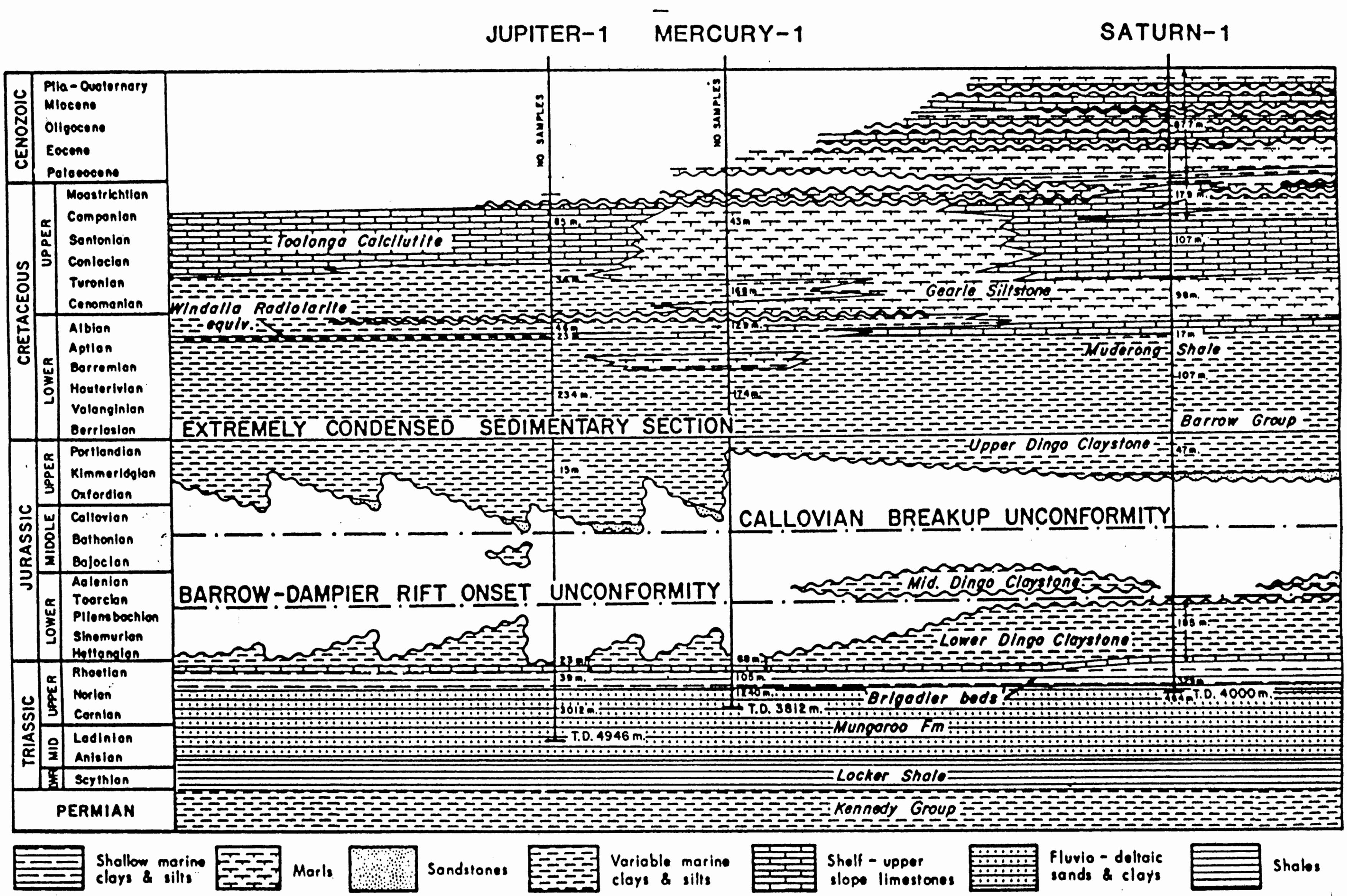
Figure 2. Tectonic Setting of the Exmouth Plateau.



The Exmouth Plateau is found within the Carnarvon Basin of NW Australia. The Australian mainland lies to the SE while the northern, western, and southern margins of the plateau have all formed by rifting and shearing.

(VonRad and Exon, 1983)

Figure 3 Stratigraphic Section



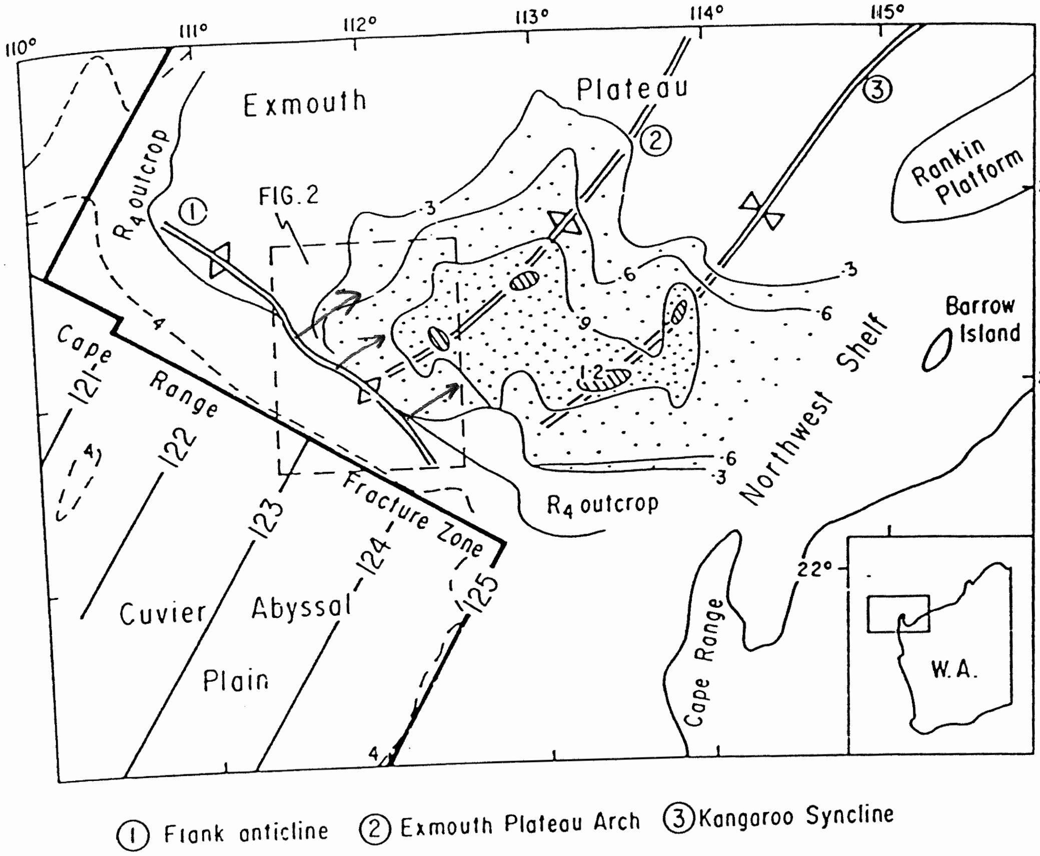
(Barber, 1982)

Tithonian-Hauterivian in age and represents the progradation of an entire continental shelf complex into a shallow marine basin which formed as a result of crustal attenuation, (Boote and Kirk, 1989). The geology of the Barrow Group is unique in that the progradation of the continental shelf takes place over the subsided continental crust of the Exmouth Plateau rather than onto oceanic crust as is usually the case in coastal settings.

Because the plateau is composed of continental crust, it sits at a much higher level than would a similar block of oceanic crust. For this reason, the seas which covered the plateau during Barrow sedimentation were extremely shallow and the entire coastal margin was compressed into a vertical section of several hundred metres rather than the usual three to four kilometers. Despite its vertical limitations, the prograding continental margin of the Barrow Group contains all of the typical coastal facies, ranging from alluvial plain to deep sea fan.

The objective of this study is to examine the depositional history of the Barrow Group, using seismic and well log data, in order to draw conclusions regarding the source area, the environments of sedimentation, and the extent of Barrow Group deposition. In particular, this study will focus on the issue of sediment source area and the direction of progradation of the Barrow Group. This problem hes been addressed in the past by Veevers and Powell (1979), who proposed that Barrow Group sedimentation was caused by the formation of a rim basin along the south western margin of the Exmouth Plateau as a result of its interactions with the Greater Indian Plate, (figure 4).

Figure 4 Rim Basin Model



Arrows indicate direction of sediment transport

(Veevers and Powell, 1979)

According to these authors, the uplifted edge of the plateau provided a source for sediments which were carried to the north east, forming the progradational wedges of the Barrow Group.

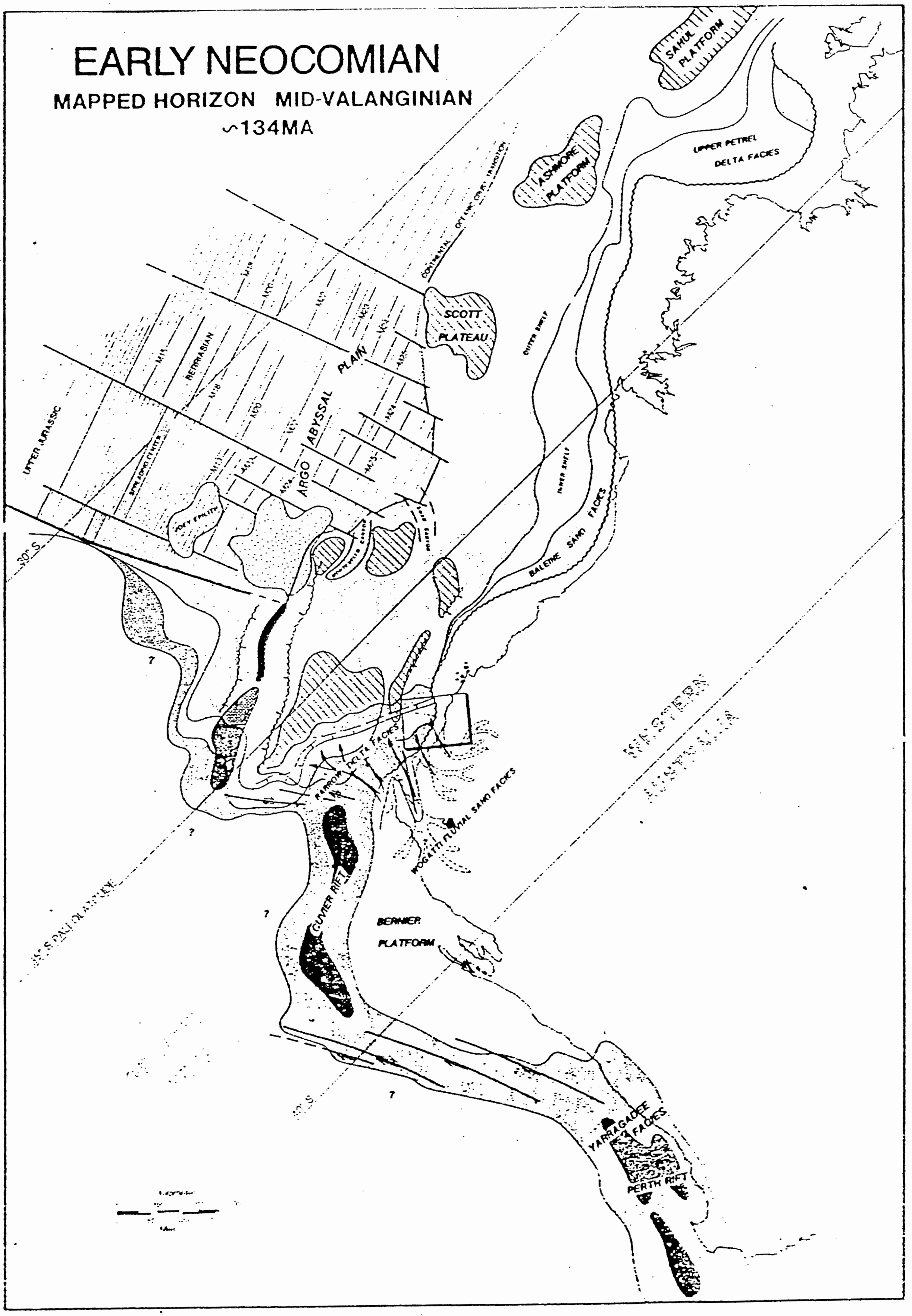
Boote and Kirk (1988), dispute this theory, proposing instead that Barrow Group sediments were supplied from the Australian mainland to the south where uplift associated with the rifting event initiated erosion, (figure 5).

In this thesis, the direction of Barrow Group progradation will be assessed from seismic data, thereby providing evidence which can be used to determine conclusively which of these two theories is valid.

DATA

The primary sources of data for this study were multi-channel seismic reflection lines obtained from the G.S.I. 1976 Group Shoot, (WA76 2,4,9,18,20,22) and the ESSO 1978 survey, (X78A and X79B series).Seismic data was unmigrated with ESSO data shot 48 fold and GSI data shot 24 fold. Record lengths were generally six seconds with quality being very good to excellent in the upper three seconds, (the approximate depth of the lower Barrow Group reflector). In addition to the seismic data, well logs were used from the Vinck-1, Investigator-1, Eendracht-1, Resolution-1, Zeepaard-1, Zeewolf-1, Serius-1, Jupiter-1, Mercury-1, and Saturn-1 drillsites.

Figure 5 Continental Sediment Source Model



(Boote and Kirk, 1989)

Geological Development

Paleozoic:

During the Paleozoic, the northern and northwestern coastlines of present day Australia bordered the Tethys Sea from the south, (Exon et al. 1981). At this time, the Exmouth plateau was part of an intracontinental downwarp called the Northern Carnarvon Basin which intermittently served as a shallow southward extension of the Tethys Sea, (Barber, 1982). Towards the end of the Permian, rifting began to effect the northern regions of Gondwanaland and small continental blocks began to separate from the landmass and move northward as isolated fragments surrounded by oceanic crust, (Boote and Kirk, 1989).

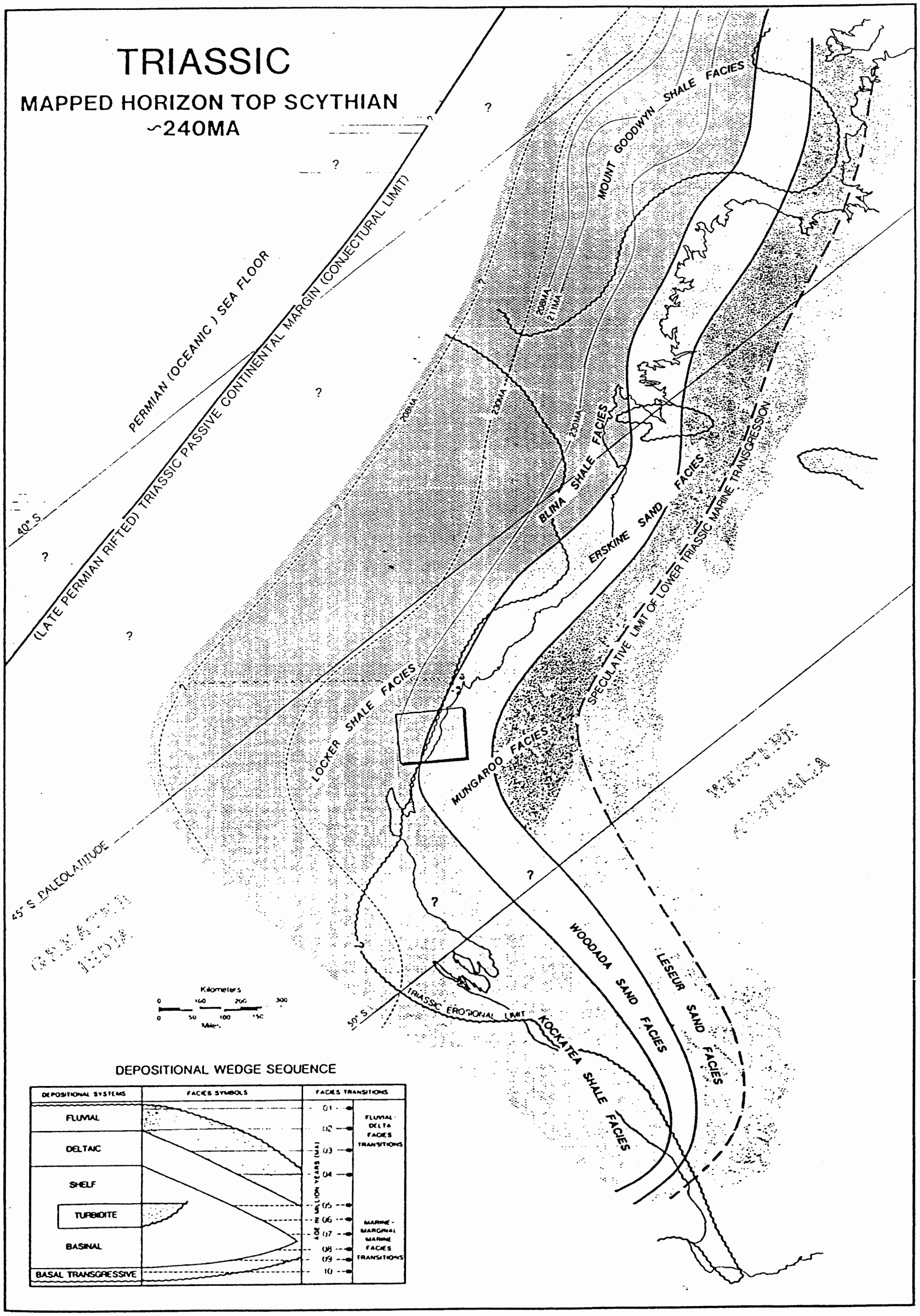
Triassic:

Near the Permian-Triassic boundary, rapid subsidence began to effect the Carnarvon Basin resulting in a transgressive-regressive sequence as sea level rose within the basin and later lowered as sediment influx began to exceed subsidence rates, (Barber, 1982). This transgression and later regression are recorded in the marine Locker Shale unit and the fluvio-deltaics of the Mungaroo Formation respectively, (figure 6) . The Mungaroo Formation was deposited as a prograding deltaic complex which advanced to the northwest as the seas retreated from the craton, (Barber, 1982).

Jurassic:

In the early Jurassic, the gradual attenuation of the

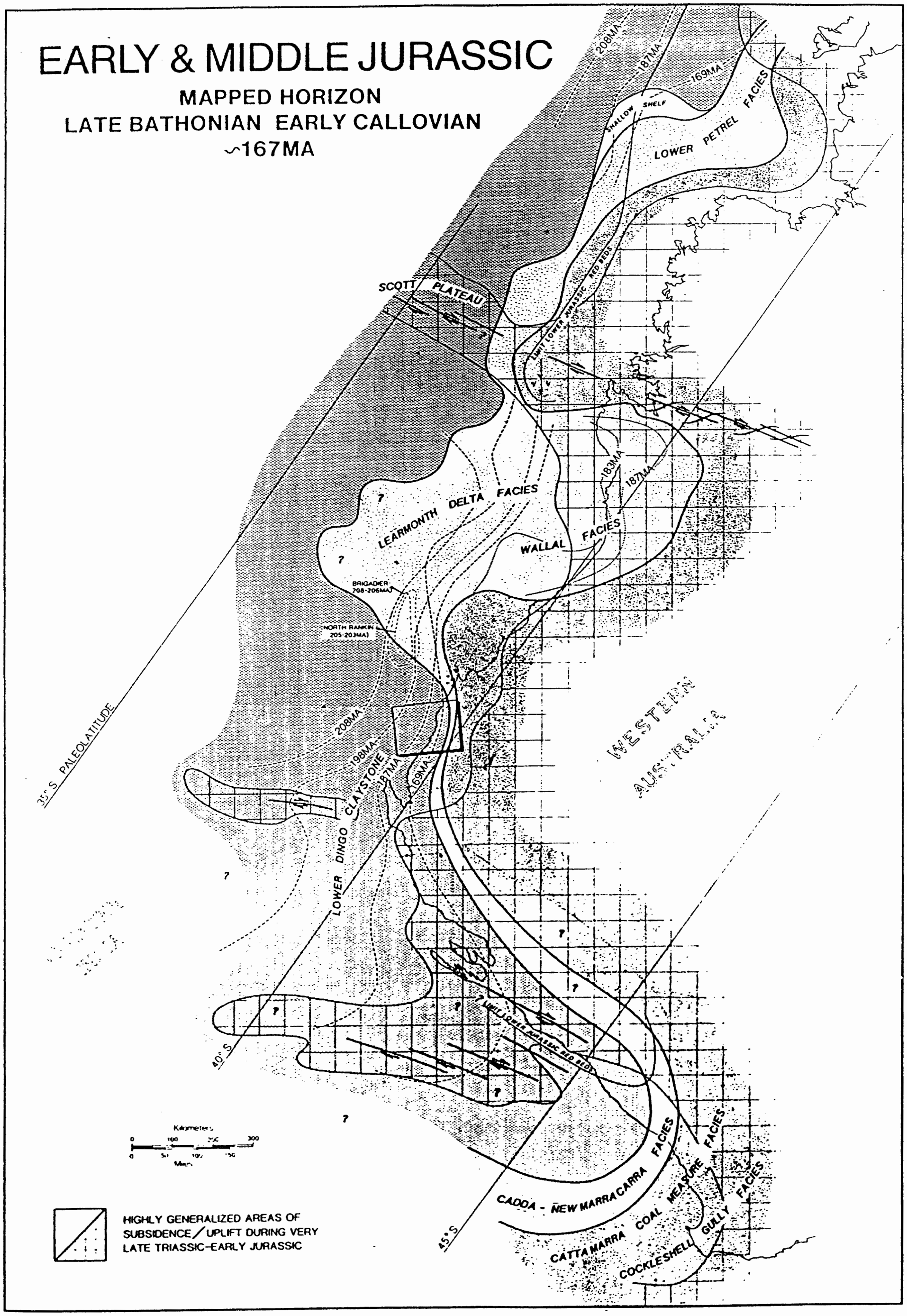
Figure 6



During the Triassic, the entire coastline of Gondwanaland was involved in a major transgressive - regressive event which resulted in the deposition of the Locker Shale Formation and the fluvio - deltaics of the Mungaroo Formation. (Boote and Kirk, 1989) continental crust became apparent in the continued subsidence of the Carnarvon Basin which again resulted in a major transgression of the region (Boote and Kirk, 1989). As a result of this transgression, deposition of the Mungaroo Formation was halted and the calcareous claystones of the Dingo Formation were laid down in the Exmouth region (figure, 7).

As regional extension continued into Callovian-Oxfordian times, continental breakup began to affect the Exmouth Plateau area. Regional northeasterly striking faults formed throughout the Carnarvon Basin and movement along these faults resulted in a great deal of localized uplift and subsidence. To the immediate northwest of what is now the Exmouth Plateau, a zone of regional uplift developed along a northeast trending axis (figure 8). As a result of this doming trend, much of the northwestern Exmouth Plateau was aerially exposed and subject to erosion, while further south, the Exmouth block remained submerged and deposition continued uninterrupted. Sedimentation on the southern margin of the plateau was influenced by the formation of the Kangaroo Trough, a northeast trending graben structure. This depression formed within the Exmouth block and served as a trap for sediments supplied from the continent to the south, effectively preventing any large amount of Jurassic sediment from advancing farther northwest across the plateau.

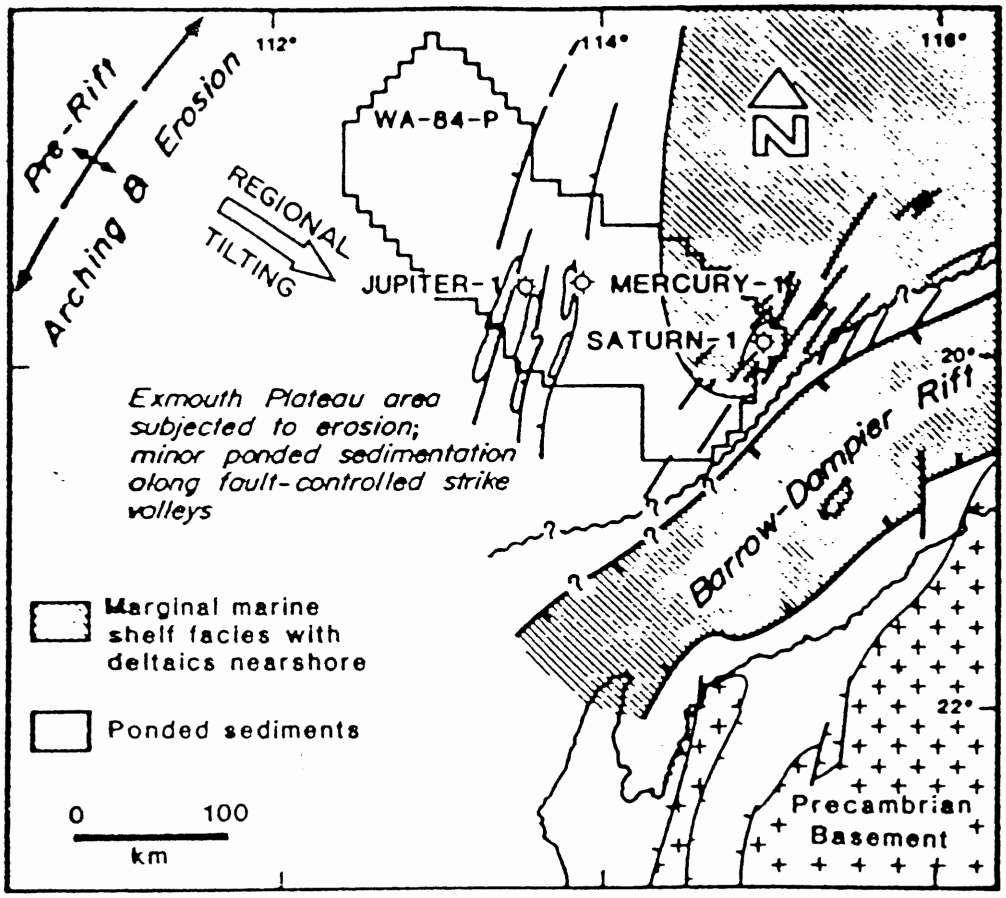
To the southeast of the Exmouth Plateau, a north easterly trending rift graben was formed during Callovian times (figure 9). This graben subsequently underwent a great deal of subsidence, effectively isolating the Exmouth block from the



During the Early Jurassic, a transgression of the Exmouth region led to the deposition of the Dingo Claystone. (Exmouth Plateau is in boxed region.)
(Boote and Kirk, 1989)

Figure 8

Exmouth Plateau During the Mid Jurassic.



Doming in the Northwest and rifting in the southeast cause SE tilting of the Exmouth Block.

(Barber, 1982)

continental mainland to the south. This subsided graben is bordered on the mainland side by the Pilbara Block, and on the Plateau side it is bounded by the uplifted Rankin horst. Figures 10a and 10b illustrate the present level of subsidence in this rift valley; note, however that during the Jurassic, the graben would not have shown this much relief and sediment fill would be proportionally less.

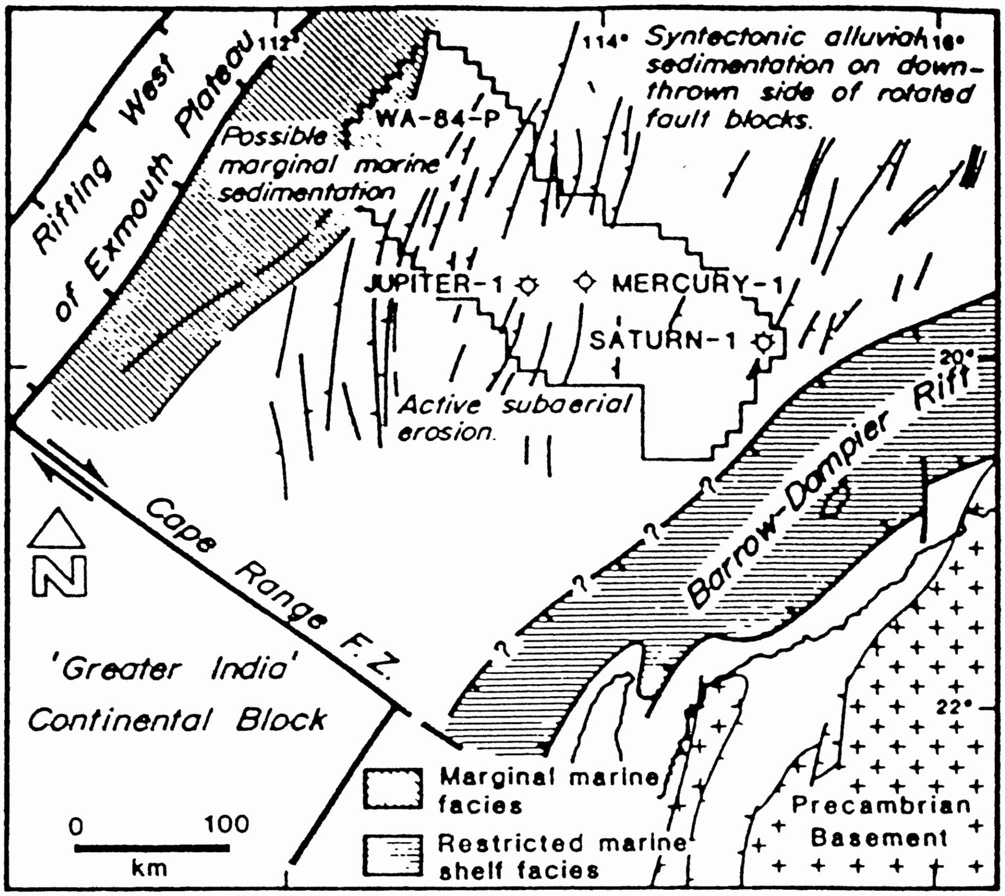
When the zone of uplift to the northwest of the plateau began spreading during the lower Callovian it did so by a combination of rifting along northeasterly trending faults and shearing along northwesterly trending transform faults, (Exon et al, 1981). In order to accommodate spreading on the western margin of the plateau, the Cape Range transcurrent fault zone formed, thereby creating a physical separation between the plateau and the Greater India block to the west (figure 9) . As crustal spreading to the northwest progressed, oceanic crust began to infill the rift and the Argo Abyssal Plain was formed.

On the Exmouth Plateau itself, NE-SE trending listric faults developed enabling the crust to accommodate extension by fault block rotation (Barber, 1982). Within the valleys on the downthrown sides of the fault blocks, syntectonic deposition of marine sediments took place producing a draped Jurassic cover over the tilted underlying Triassic fault blocks.

From the lower Callovian to the end of the Jurassic, the Rankin Trend remained a positive feature of relief, projecting above sea level, while the rest of the plateau subsided beneath encroaching seas, (Barber, 1982).

Figure 9

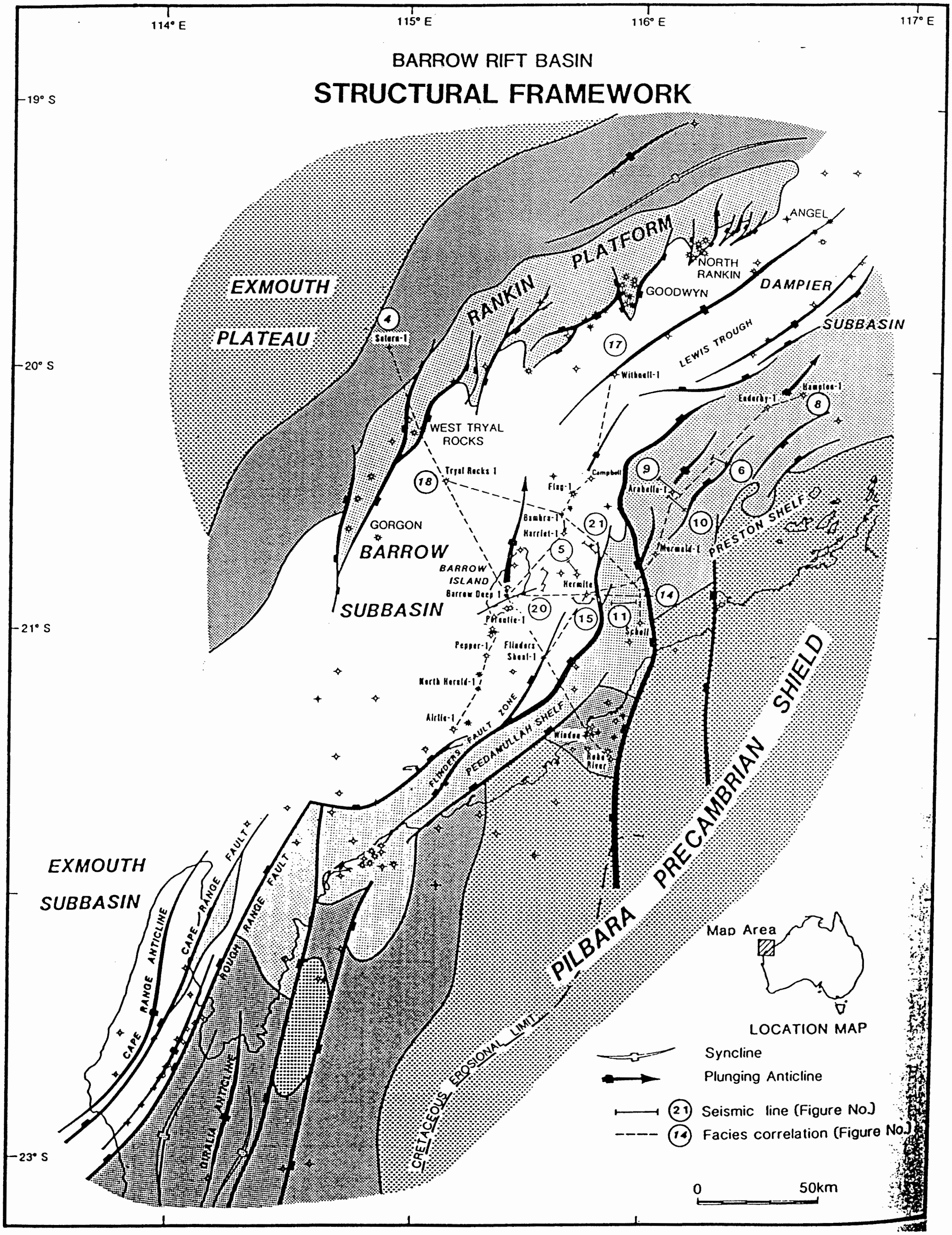
Callovian Breakup on the Exmouth Plateau.



Crustal spreading during the Callovian was accompanied by rifting of the western plateau margin and shearing of the southern margin.

(Barber, 1982)

Figure 10a

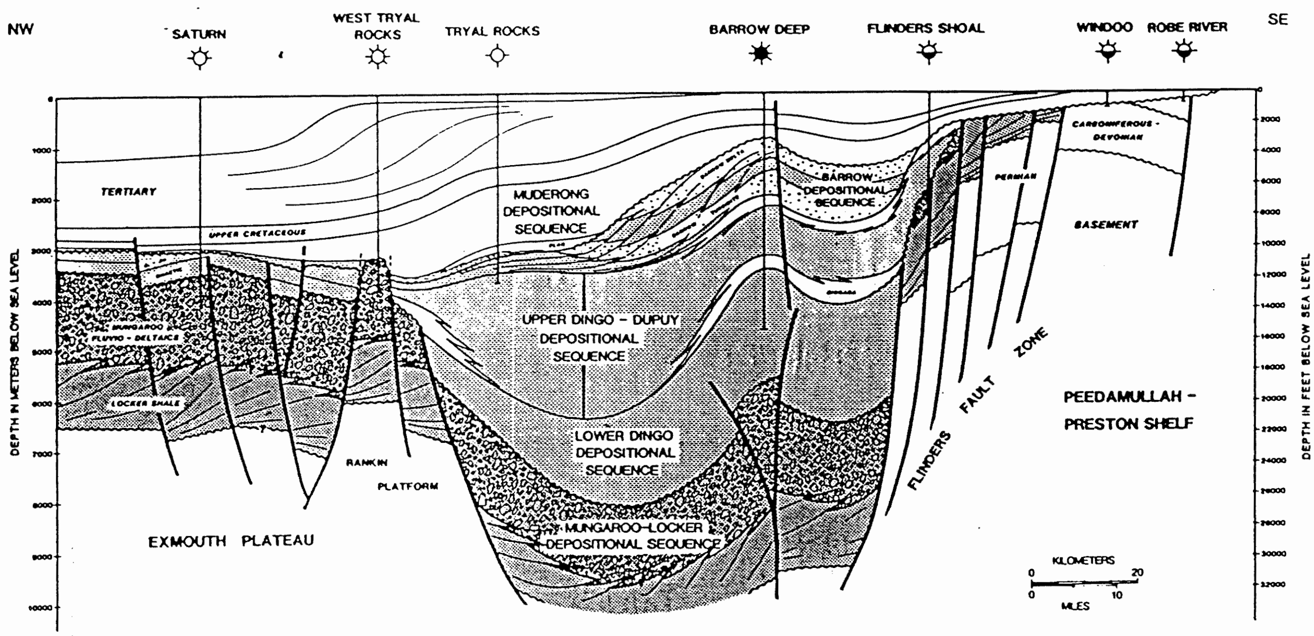


On its southern eastern margin, the Exmouth Plateau is separated from the continental mainland by a failed rift basin.

(Boote and Kirk, 1989)

Figure 10b

Quaternary Cross - Section of Barrow Rift Basin.



The Rankin Platform has remained a structural high throughout the subsidence of the Barrow Rift Basin.

(Boote and Kirk, 1989)

Cretaceous:

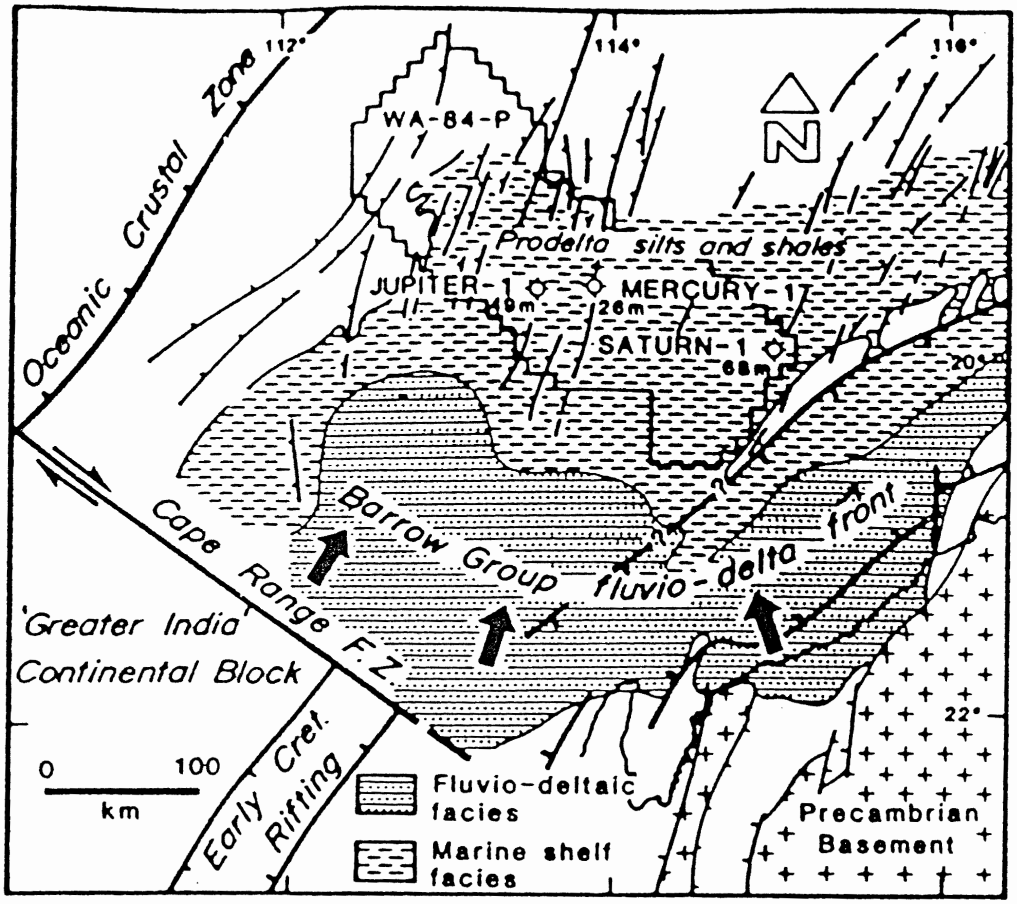
With the beginning of the Neocomian, tectonic activity on the eastern flank of the Carnarvon Platform caused uplift in the region of the Cape Range Fault Zone, and possibly on the Australian mainland to the south figure 11 (Boote and Kirk, 1989). Erosion of these uplifted regions provided sediment which was carried northward and deposited to form the Barrow Group.

The Barrow Group sediments were deposited rapidly as the continental margin prograded northward throughout Tithonian to Hauterivian times, (Boyd,1987). Within the Barrow unit three distinct phases of progradation can be discerned, each one displaying the characteristic morphology of an advancing continental margin. The existence of three separate depositional phases suggests that periodic transgressions by the sea may have halted the progradation of the continental shelf, forcing it to retreat for a time before renewing sedimentation on top of the previously deposited units.

Towards the end of the Lower Cretaceous, rifting began to take place to the south of the Exmouth Plateau, creating the beginnings of the Cuvier Abyssal Plain, figure 11, (Barber, 1982). This rifting event was merely the local expression of a regional spreading event which reached its culmination during the mid Necomian when Greater India completed its separation from Australia. At this time the sediment supply for the Barrow deltas was cut off and marine shelf conditions developed all across the subsiding Exmouth block, (Barber, 1982). With the

Figure 11

The Neocamian on the Exmouth Plateau.



Uplift in the Cape Range Fault Zone provides an elevated source from which Barrow sediments are derived.

(Barber, 1982)

initiation of rifting in this region came the injection of volcanics along the zones of crustal weakness, (these volcanics are quite evident at the southern extremity of line 78A-51). Boyd (1987) proposes that these volcanic injections may explain why this region has not undergone subsidence since the Neocomian rifting event and is still arched in the subsurface.

With its southern and western sediment sources cut off, deposition on the Exmouth Plateau slowed down considerably. As a result of continued subsidence and transgression, restricted marine conditions developed throughout the region and the Murderong Shale unit was deposited ubiquitously across the plateau. Continued transgression of the Australian mainland to the south decreased the supply of clastic sediment to the plateau region, allowing open shelf conditions to prevail, (Barber, 1982). It was under these open shelf conditions that the Gearle Siltstone unit was deposited during the Upper Cretaceous, (Barber, 1982).

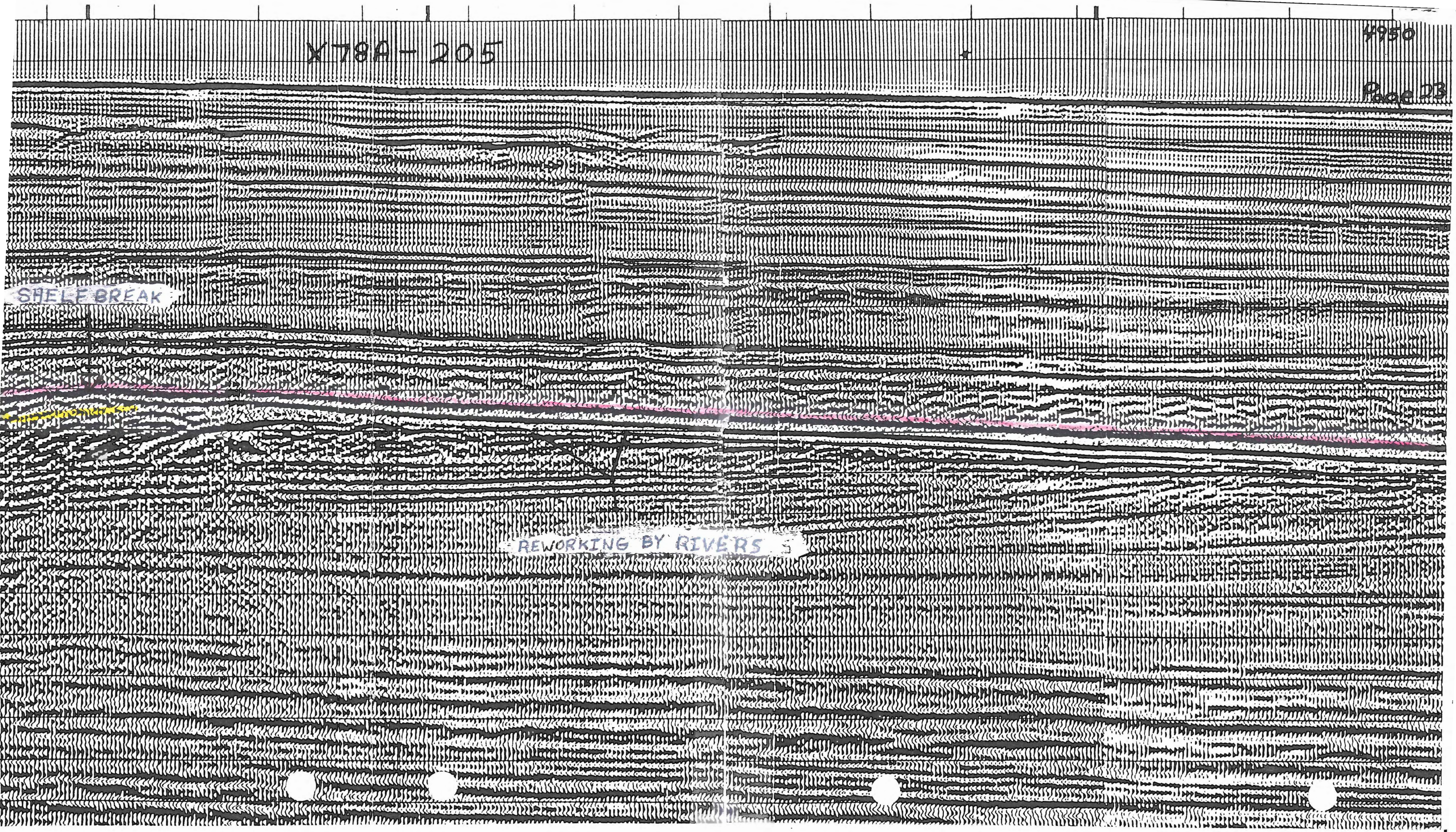
3.5 Post Cretaceous

Sedimentation of the Exmouth Plateau since the Cretaceous has been characteristic of an open shelf or upper slope environment, dominated mostly by carbonates, marls and calcareous oozes, (Boote and Kirk, 1989). Subsidence of the Exmouth Plateau has continued on into the Cenozoic as it maintains isostatic equilibrium with the cooling oceanic crust around it, (Barber, 1982).

Methods

All of the conclusions of this study are based on results obtained from the analysis of seismic records and well log data obtained from drillsites within the region. In order to accurately assess the lateral extent of the Barrow unit from seismic data, it is essential that three seismic horizons be picked accurately throughout the study area, these three horizons are; 1 The top of the Barrow Group,(pink reflector), 2 The top of the Jurassic,(grey reflector), 3 The top of the Triassic basement, (red reflector), (see figure 12).

When examining the Barrow Group, it is necessary to pick both the Jurassic and Triassic reflectors because of the uneven nature of the basement in the area. As mentioned previously, the Jurassic sediments of the Dingo Formation were deposited contemporaneously with the faulting of the Triassic basement and as a result of this the Dingo sediments are often found as valley fill on the downthrown side of basement fault blocks. In addition to this, a great deal of Jurassic sediment which was deposited on the northern part of the Exmouth Plateau was removed during the Callovian uplift. For these reasons, it cannot be simply assumed that the Barrow Group will overlie either the Triassic or the Jurassic, but rather will be bound on the bottom by an unconformity surface which may truncate both.


X78A - 205
4950
Page 23
SHELF BREAK
REWORKING BY RIVERS

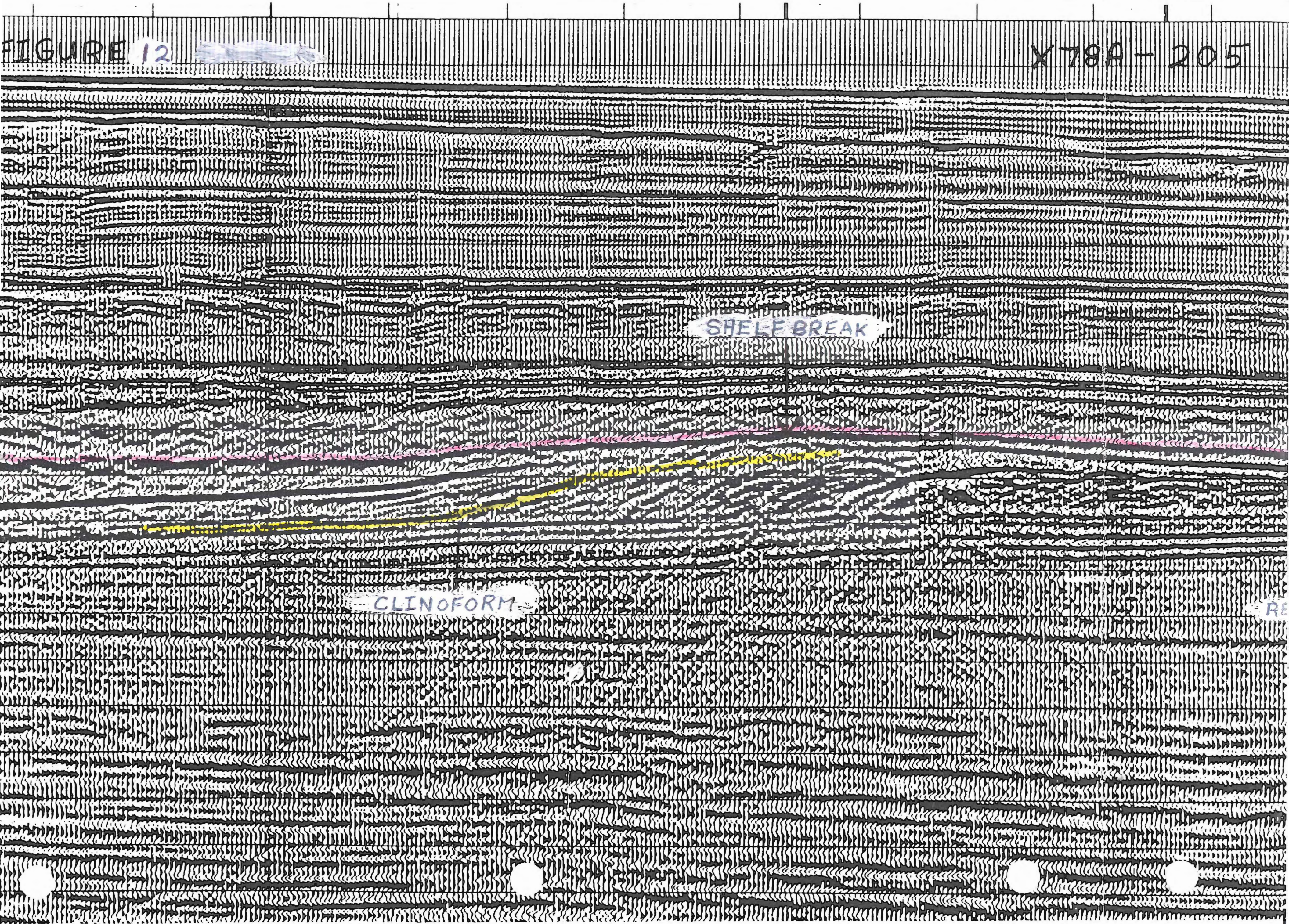


FIGURE 12
X78A-205
SHELF BREAK
CLINOFORM

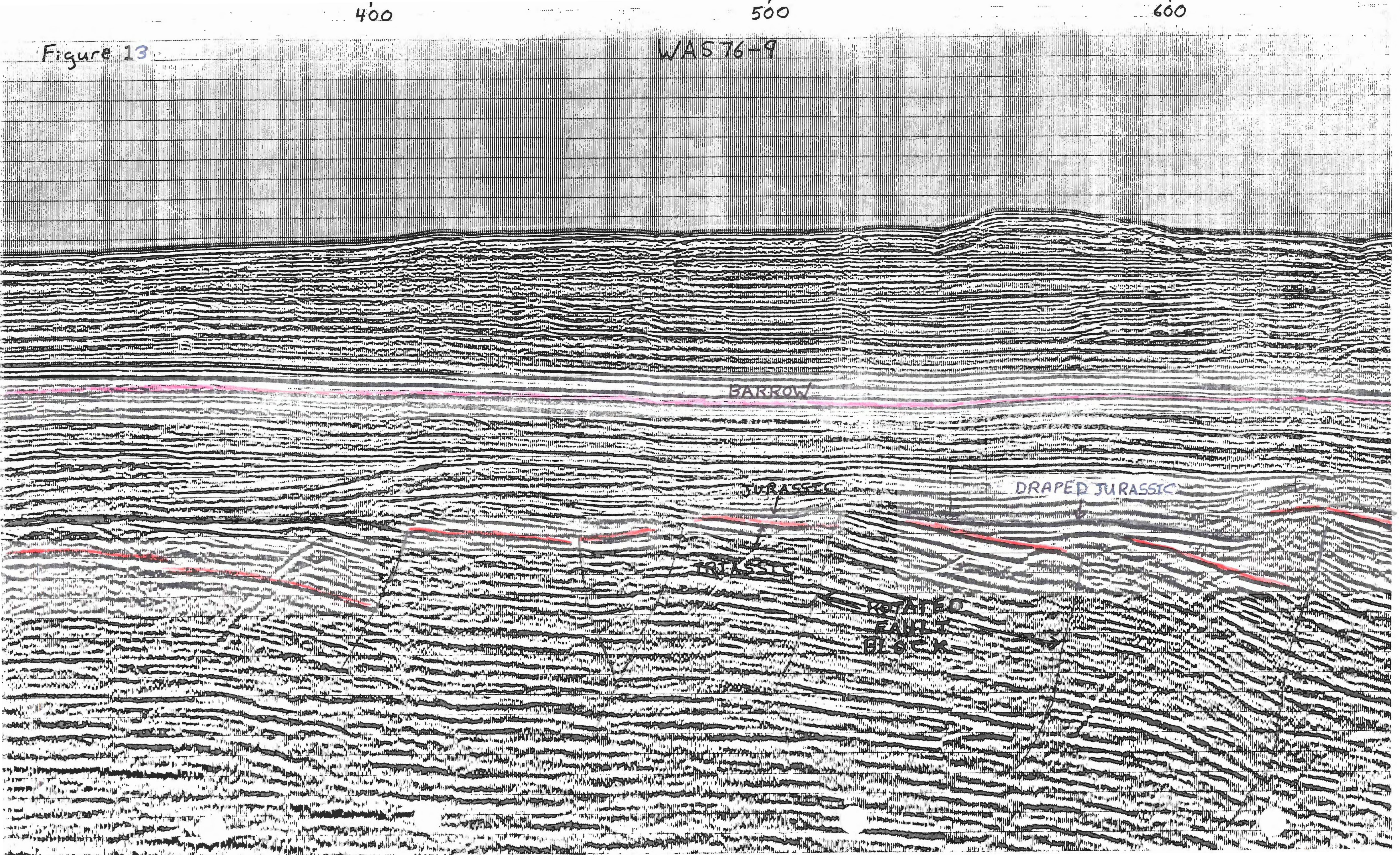

400
500
600
WAS76-9
BARROW
JURASSIC
DRAPED JURASSIC
TRIASSIC
ROTATED
FAULT
BLOCK

Figure 13

3.1 Well Correlations:

In order to accurately pick these seismic horizons initially, well data was used. From each well report, a graph was constructed in which actual depth was plotted as a function of seismic travel time (Figure 13 enclosed in pocket). By using this graph one can simply read off the seismic travel time which corresponds to the actual depth in metres to any given horizon, and thereby locate that horizon on a seismic line passing through that drillsite.

3.2 Seismic Stratigraphy:

Having located the relevant seismic horizons at wellsite locations, it then remained to trace these reflectors laterally throughout the study area. Seismic horizons were traced by considering the geology of the units involved and relating this to the character of the seismic reflections. The work of Vail (1977), was consulted in the identification of various seismic features which characterize the Exmouth Plateau deposits.

3.3 Mapping:

Having traced the Barrow Group across all of the seismic lines available, it was then necessary to construct an isopach map of the unit. Isopach values were chosen so as to provide an overview of regional depositional trends, with anomalies only being chosen if they could be traced from line to line with certainty. The isopach values were posted on a base map and contoured with a contour interval of .2s.

In addition to the isopach values, several other features of interest were plotted on this map including;

1) The limit of progradation for the upper and lower sediment lobes, based on the final location of the shelf break as seen in the seismic data.

2) The extent of erosion of the Barrow Group on the southern Exmouth Plateau

The map showing wellsite locations and seismic coverage of the study area, is included in the pocket on the back cover, along with, the isopach map overlay.

3.4 Progradational Vectors:

In order to gain a better understanding of the history of Barrow deposition, progradational vectors were obtained from the lobate sedimentary units. The directions of maximum progradation were obtained at the points of intersection between seismic lines, wherever a specific continental margin feature could be seen on both seismic lines. The vertical and horizontal dimensions of the dipping reflector were measured and converted into actual distances. Based on well log data, it was calculated that a seismic velocity of 2200m/s was an appropriate estimate for the rocks of the Barrow Group, while horizontally, a scale of 1cm =660m was used on the full scale records and on half scale records the scale was 1cm=1200m.

Having calculated the vertical (Y), and horizontal (X), dimensions of these reflectors, the apparent dip angles could be determined by using the formula:

$$Y/X = \tan Z$$

where z is the angle of the apparent dip in the plane of the seismic line. Having calculated two apparent dips, the true strike and dip of the surface in question can be determined by using the following procedure outlined by Billings (1972).

1) The orientations of the two seismic lines are determined and they are drawn as two rays, O-A, and O-B, which radiate from a point source. (Figure 14)

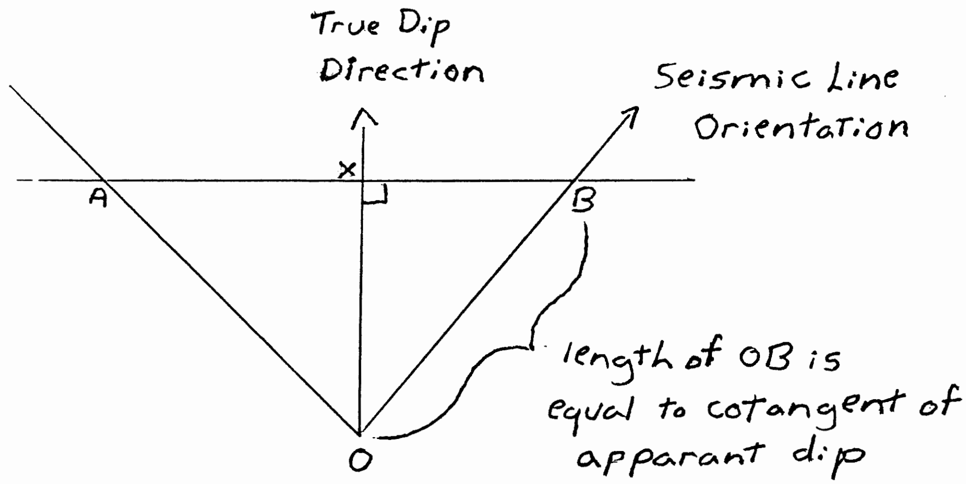
2) The lengths of these lines are calculated as the cotangents of the apparent dips obtained from the seismic data.

3) A line is now drawn joining points A and B.

4) Line O-X is drawn perpendicular to line A-B and passing through point O. The length of this line is equal to the cotangent of the true dip angle and its orientation is the direction of maximum dip.

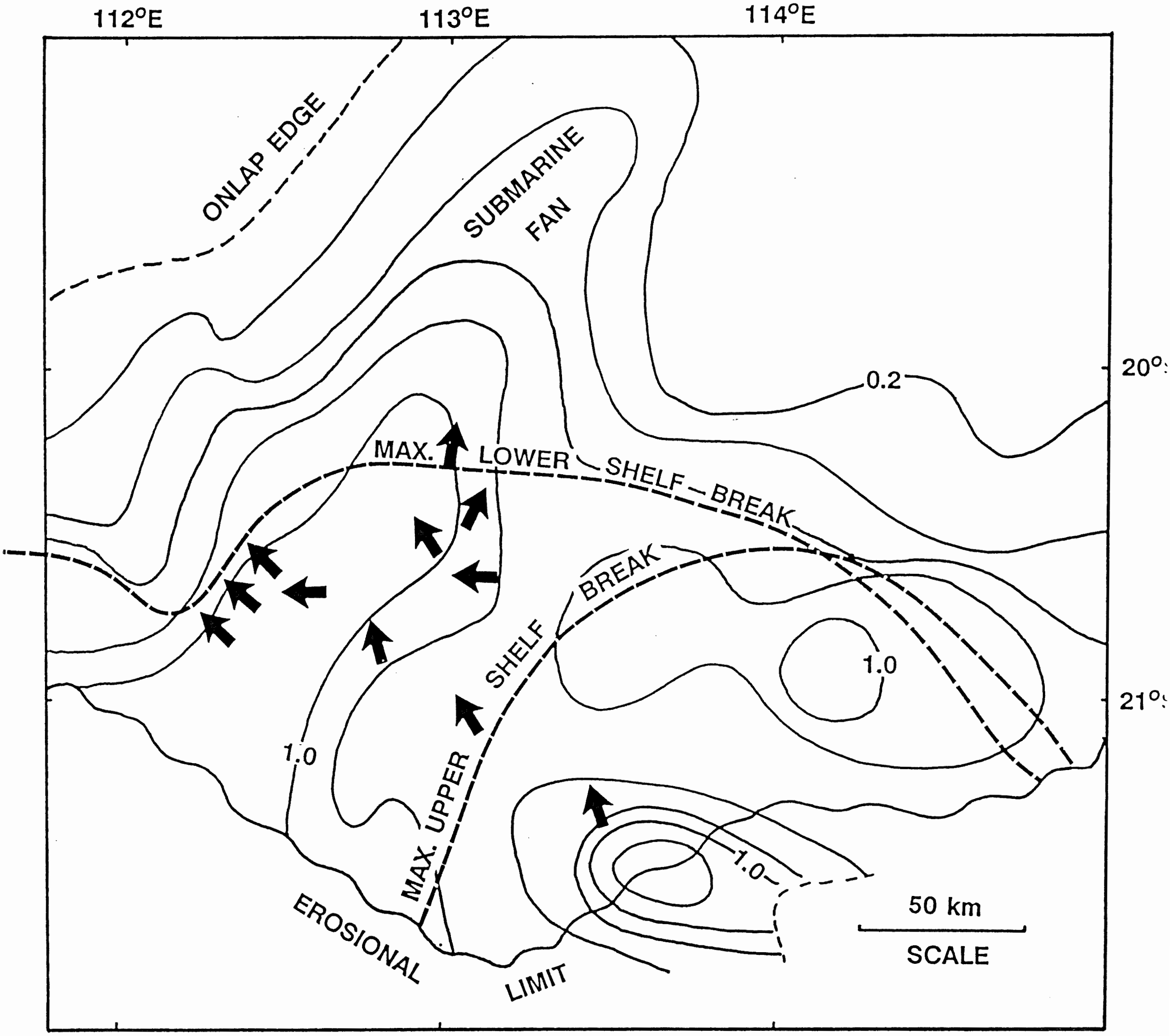
Using this information, the direction of progradation for the various depositional wedges was calculated by assuming that progradation rates were fastest in the maximum dip direction.
The results obtained by means of this procedure are recorded in table 1, these results have also been plotted on the Barrow Group isopach map, and the reduced version, figure 16.

Figure 14 Calculation of Progradational Vectors



length of OX = cotangent of true dip

Figure 16 Barrow Group Isopach and Facies Map



Discussion

The Barrow Group isopach map illustrates the final morphology of the entire Barrow Group after several cycles of progradation, each cycle` being separated by a time of nondeposition. The continental margin complex outlined in red is actually a composite of two progradational systems, one on top of the other. These two sedimentary sequences were deposited during Portlandian-Neocomian and Berriasian-Valanginean times respectively and the two of them display similar overall depositional trends, hence their being grouped together, The orange complex represents a later phase of deposition which took place during Mid Valanginian to Hauterivian times and is similar to the red complex in its composition, though it is thinner and not as extensive.

The red and orange lines which illustrate the lateral extent of the continental margin complexes are in fact the northern limits of shelf break progradation. The shelf breaks were picked from the seismic data using the criteria illustrated in figure 12. The dipping clinoforms seen within the Barrow Group in this figure represent successive locations of the continental margin as it advanced northward across the plateau. Measurements of these clinoforms indicate that the continental margin complex had, on average, a vertical relief of 350 metres and dipped northwards with a slope of about 4.

Figure 16 illustrates the aerial distribution of the facies found within the Barrow Group. The large sedimentary wedges bounded by the shelf break lines are continental margin complexes which have a morphology similar to that seen in deltaic sequences. In some instances, the tops of these units appear to have been reworked by later alluvial systems which supplied sediment to the advancing continental margin. This channeling and reworking can be seen in figure 12.

A second noteworthy feature which can be seen in this figure is the vertical aggradation at the top of the Barrow Group. This feature is created by a rise in sealevel which keeps pace with sedimentation such that the sediment wedge builds upward but not forward. This is evidenced at the top of the Barrow unit where successive shelf break sequences are located progressively higher in the section, whereas lower down in the section, shelf breaks advance horizontally. The rising water level probably reflects the subsidence of the Exmouth Plateau and the end of Barrow deposition.

To the north of the continental margin complexes, deep basin conditions prevail. Seismic horizons in this region are horizontal and display a mottled appearance characteristic of shale sequences.

One noteworthy feature of Barrow sedimentation in this area is the thick section of Barrow sediment which is most pronounced in the southwestern corner of the study area and extends as a large ridge to the northeast. The vertical thickness of this unit bears little or no relation to the location of the shelf break for the package as a whole as one would expect it to, that being the northerly limit of continental progradation. The northeasterly extent of this sediment beyond the shelf break in this region is generally accepted as having been caused by a series of turbidites which followed channels northward off of the shelf complex and onto the basin floor. This interpretation is supported by the existence of turbidite sand deposits at the Investigator and Scarborough wellsites.

Seismic lines in this area which provide geologic profiles of this ridge do not indicate the existence of any pre-existing structural features such as subsided fault blocks which may have caused the deposition of these sediments in a northeasterly trending ridge. In fact, examination of this area reveals that the turbidite sediments were deposited on top of a region of uplift adjacent to the subsided Kangaroo Trough to the east, (see figures 10a and 10b).

The direction of continental progradation is indicated by the vectors plotted on the Barrow Group Isopach Map. These vectors indicate that the continental margin advanced to the north west, with sediment being supplied from a southerly source. This finding is significant in terms of the tectonic implications associated with it. According to the theory of Veevers and Powell (1979), sediment was supplied from a southwesterly source and the Barrow Group advanced to the northeast. Clearly, this postulate is not supported by seismic evidence which supports instead the theory of Boote and Kirk (1988) who proposed a southerly sediment source from the continental mainland of Australia.

Conclusions

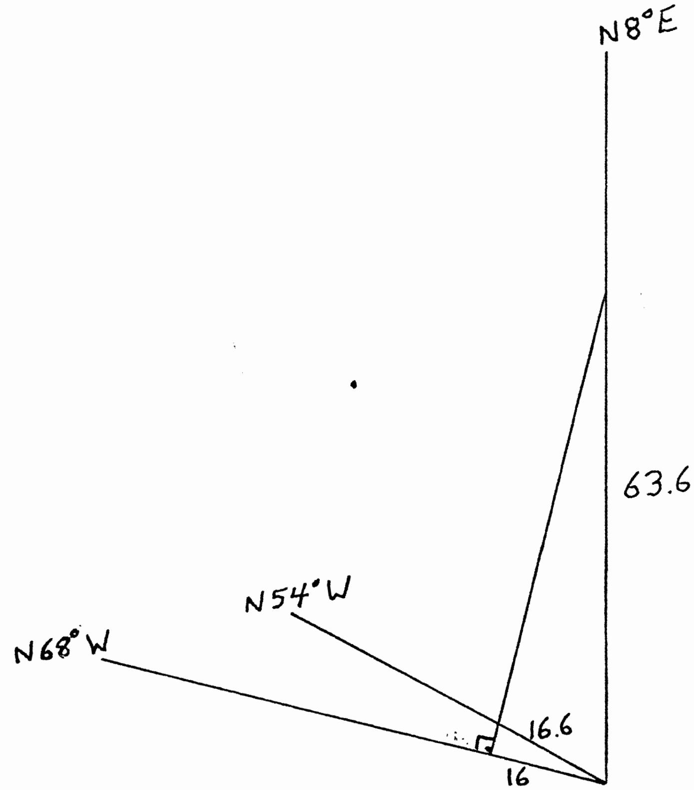
The results obtained from this seismic investigation provide some new insights into the history of Barrow Group deposition. The Barrow group represents the progradation of an entire continental margin system across a block of subsiding continental crust, within the Barrow unit, depositional environments range from deep marine to continental rise to alluvial plain. Because the Exmouth Plateau is composed of continental crust, it lies at a higher elevation than would a corresponding piece of oceanic crust. This being the case, the difference in elevation between the sea floor and the shoreline is less than it normally would be and the continental margin is reduced in thickness from the usual four kilometres to approximately 400 metres. The development of an entire continental margin on such a small scale is quite unusual and is not seen on any other similar plateaus world wide. ie the Blake Plateau on the Atlantic coast of the United States hosts carbonate reefs with some deltaic sedimentation. The conditions which allowed for the deposition of the Barrow Group must have arisen because of a unique relationship between sediment influx, subsidence rates, and water energy.

The Barrow Group sediment was supplied from a southerly source, presumably the Australian continent, which had been uplifted as a result of the tectonic activity in the area. The existence of southerly sediment source for the Barrow unit contradicts the ideas put forth by Veevers and Powell (1979), who suggest that sedimentation was from the southwest, associated with the formation of a rim basin.

Progradational vectors indicate that Barrow sediments were carried to the northwest and fanned out as they were carried farther away from the source area. Several vectors indicate progradation in directions other than to the north west, but this is understandable since the lobate nature of the deposit would require it to build in several directions simultaneously as it advanced.

The Barrow deposits do not appear to have been strongly influenced by basement topography in that the major thicks and thins do not correspond to elements of relief in the underlying triassic strata. This indicates that currents and other marine influences must have played an active role in shaping the Barrow deposit, possibly creating features such as the linear sediment ridge in the west of the study area.

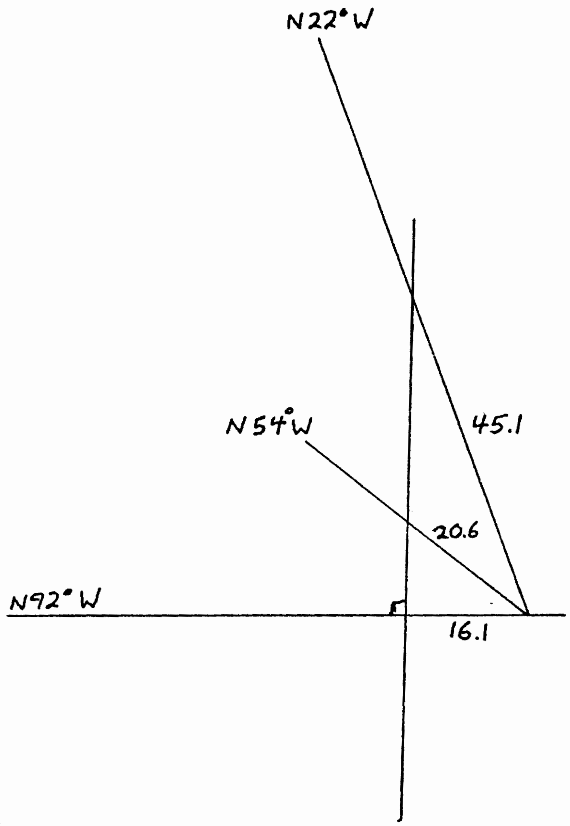
APPENDIX



Dip Direction= N68°W
True Dip = 3.5°

(2)

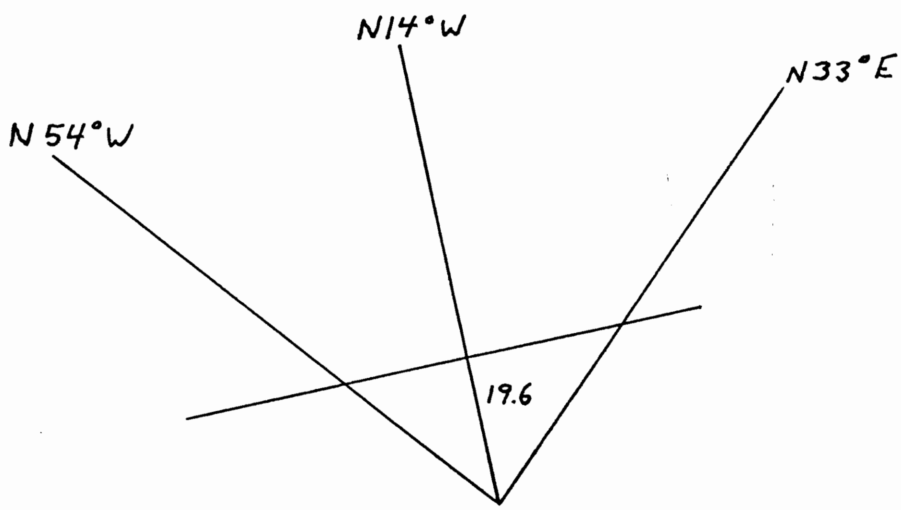
109 — 76-2



True Dip = 3.55°
Dip Direction = N92° W

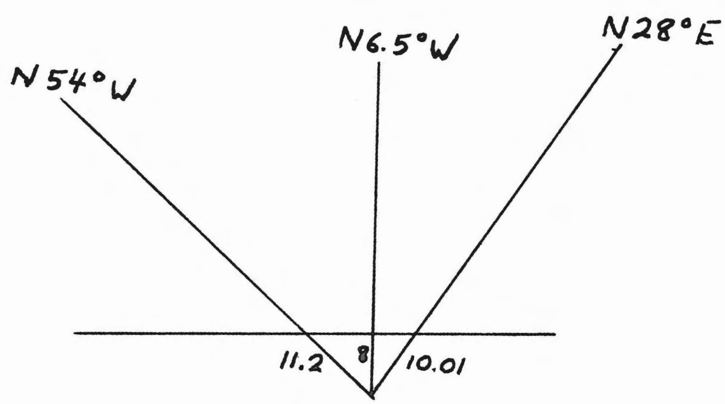
(3)

76-2 — 76-18



True Dip = 2.92°
Dip Direction = N14°W

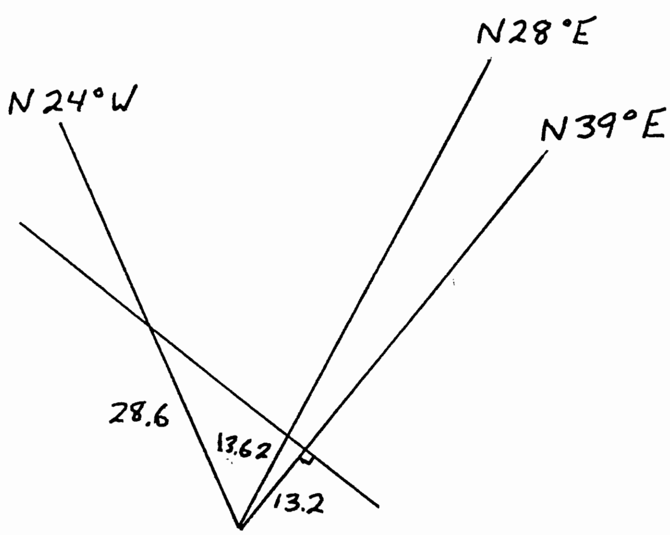
76-4 — 76-20



True Dip 7.13°
Dip Direction N6.5°W

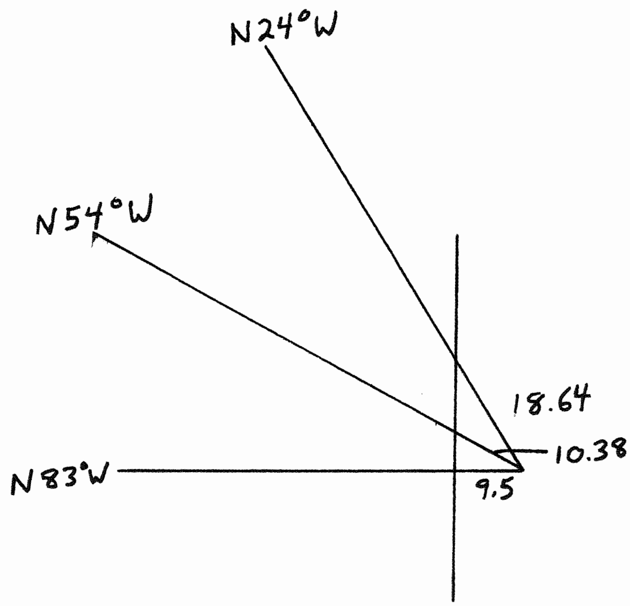
(5)

A-51 — 76-20



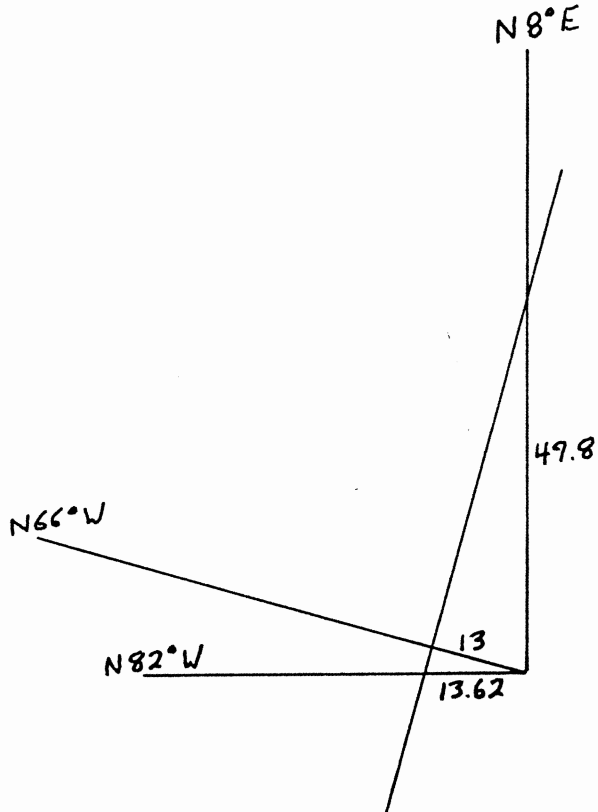
True Dip = 7°
Dip Direction = N39°E

A-51 — 76-4



True Dip = 6°
Dip Direction = N83°W

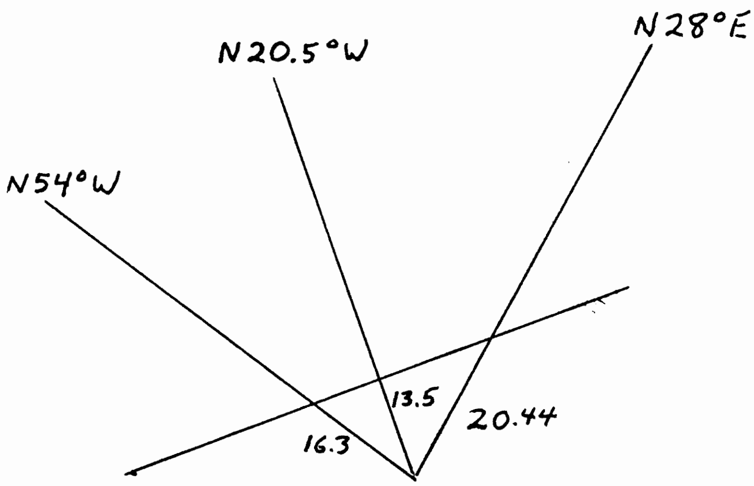
205 — 272



True Dip = 4.4°
Dip Direction = N66°W

(8)

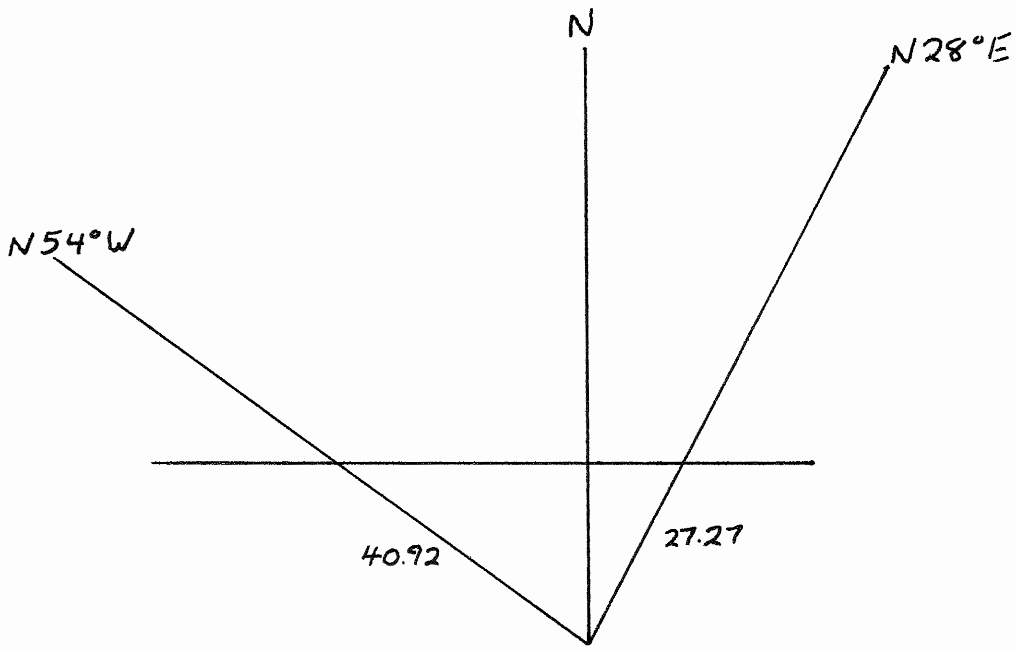
76-20 — 76-2



True Dip = 2.2°
Dip Direction = N20.5°W

(9)

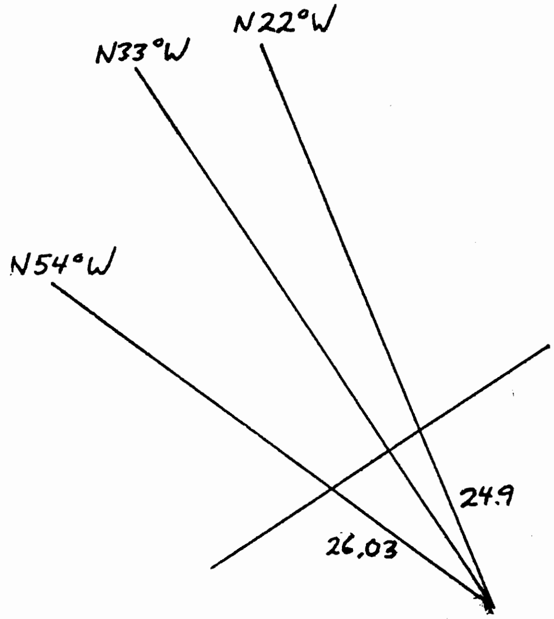
76-20 — 76-2



True Dip = 2.4°
Dip Direction = 0°N

(10)

A-71 — 76-2

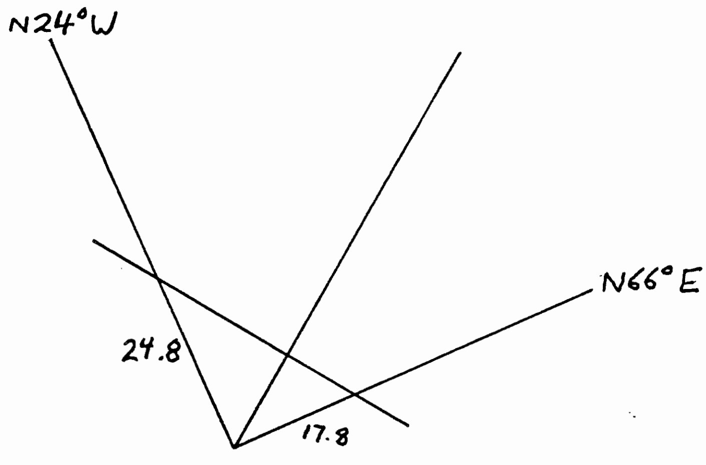


Dip Direction = N33°W
True Dip = 2.3°

(11)

A28 — A51

True Dip = 4.1°
Dip Direction = N29°E



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