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DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

1976/107

DEPTH AND THICKNESS MAPS FOR SEDIMENTARY SEQUENCES UNDER THE EXMOUTH PLATEAU

Survey 101

by

J.B. Willcox and N.F. Exon

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SUMMARY

Depth and thickness maps for sedimentary sequences under the Exmouth Plateau are presented, based on 18 000 km of seismic profiling across the area. Five seismic reflectors which are believed to range in age from Oligocene to Late Triassic have been mapped. Interval velocities used in converting seismic times to depths were derived from an analysis of refractions and high-angle reflections on sonobuoy records, and from velocity surveys in wells on the Northwest Shelf, adjacent to the plateau.

INTRODUCTION

The Exmouth Plateau (Fig. 1) lies adjacent to the Northwest Shelf petroleum province and covers an area of 150 000 km^2; continental slopes adjacent to the plateau cover a further 150 000 km^2. Water depths range from about 800 to 2000 m and the plateau forms a broad dome with a minimum water depth of 815 m at a point 250 km offshore.

This record incorporates two series of structure contour and sediment thickness maps: one for the entire Exmouth Plateau area, and the other for the central area in which water depths are relatively shallow. A BMR Bulletin dealing with the geology and petroleum potential of the area is being prepared (Exon & Willcox, in prep.) which will contain a complete suite of geophysical maps and seismic profiles.

The principal sources of data are 12 000 km of reflection seismic profiles obtained by BMR during its Continental Margin Survey 1970-73, and 6000 km obtained by petroleum exploration companies and lodged with BMR under the terms of the Petroleum (submerged Lands) Acts (1967-1974). The location of profiles is shown in Plate 1. Seismic profiles obtained aboard the M/S Gulfrex (Gulf, 1973) have enabled tentative ties to be made to wells on the Northwest Shelf. Estimates of the depths and thicknesses of the various seismic horizons and intervals have been computed using velocity data derived from wells on the shelf and sonobuoys on the plateau.

A physiographic study of the Exmouth Plateau, and the adjacent Wharton Basin and Scott Plateau, was presented by Falvey & Veevers (1974). Veevers, Falvey, Hawkins & Ludwig (1974) presented a regional study of the stratigraphy and structure of the Exmouth and Scott Plateaus and adjacent deeps, which used seismic data collected by the Lamont-Doherty Geological Observatory and the Royal Australian Navy. Seismic data from the BMR sparker survey of the shelf were also used (Whitworth, 1969; Veevers, 1973). A preliminary report on the geology of the Exmouth Plateau was prepared by Exon, Willcox & Petkovic (1975) in which 'time-depth' and 'time-thickness' maps were presented. The geology and petroleum potential of the central area has been discussed by Willcox & Exon (1976), and that of the whole area by Exon & Willcox (in prep.).

We consider the sediments beneath the Exmouth Plateu to have been deposited in part of the Carnarvon Basin (Fig. 1). The geology of the onshore Carnarvon Basin was discussed by Condon (1968) and that of the offshore portion by Thomas & Smith (1974). The geologically similar onshore and offshore Canning Basin, which is also coextensive with the Exmouth Plateau, was described by Veevers & Wells (1961) and Challinor (1970) respectively. A review of the geology of the northwest Australian continental margin was presented by Powell (1976). Geophysical data in the offshore Canning Basin and the northernmost part of the Carnarvon Basin were collected by Burmah Oil Company of Australia Ltd (BOCAL) and associated companies, and by BMR (Whitworth, 1969). In most of the Carnarvon Basin exploration has been carried out by West Australian Petroleum Pty Ltd (WAPET) and its predecessors.

Stratigraphic information on the deep ocean basins adjacent to the Exmouth Plateau has been obtained from drilling results on Leg XXVII of the Deep Sea Drilling Project (Veevers, Heirtzler et al., 1974). A bibliography of papers dealing with deep sea drilling in Australasian waters was compiled by Veevers (1975).

Manual digitization of the seismic profiles used in preparation of the accompanying maps was carried out by C. Allen. Drafting was carried out by the BMR geophysical drawing office.

DATA

Source of reflection seismic data

The seismic data used in the preparation of depth and thickness maps accompanying this Record come from five surveys:

(1) BMR Continental Margin Survey, 1970-1973 (CGG, 1975).
(2) BMR geophysical survey of the northwest continental shelf, 1968 (Whitworth, 1969).
(3) Esso Australia Ltd marine seismic survey of the Indian Ocean, offshore Western Australia, E71A, Dec. 1971-Jan. 1972 (Esso, 1972).
(4) Gulf Research and Development Co. and Australian Gulf Oil Co. regional geophysical reconnaissance off the northern coast of Western Australia, conducted with the M/S Gulfrex from 28 May-6 July 1972 (Gulf, 1973).
(5) Shell Development (Australia) Pty Ltd marine geophysical survey offshore Australia, conducted with MV Petrel from 7 June-25 Aug. 1971 (Shell, 1972).

Seismic data collected on board HMAS Diamantina, R/V Vema and R/V Conrad (see Veevers et al., 1974) have also been considered in critical areas.

The seismic energy sources used on the Esso, Gulf and Shell surveys were Maxipulse, Aquapulse, and air-guns, respectively. Twenty-four channels were recorded digitally on these surveys. On the Continental Margin Survey the seismic energy source was a single electrode sparker with a discharge energy of 120 kilojoules. Six channels were recorded in analogue form. Seismic penetration ranges from 2 to 6 s reflection time below the sea floor, and is generally greatest on the Esso and Gulf profiles.

Primary navigational control for most of these surveys was given by satellite-Doppler systems. The ships' positions between satellite fixes were computed by linear adjustment of the dead-reckoned track for the Esso, Gulf, and Shell surveys, and by VLF navigation and linear adjustment of the sonar-Doppler track for BMR's 1968 and 1970-73 surveys. The navigational accuracy in waters beyond the shelf for all the surveys is believed to be about 2 km, and this is supported by the absence of major bathymetric and seismic mistics at the intersections of seismic lines from different surveys. Post-survey processing of BMR's navigational data should lead to greater accuracy along Continental Margin Survey lines.

Seismic reflection profiles

The seismic profiles have been processed and displayed as follows -

Esso and Gulf sections: 12-fold and 24-fold Common Depth Point (CDP) stack with deconvolution and time variant filtering after stack; variable area display.

Shell sections: 2-fold CDP stack without corrections for moveout, produced on-line by an optical method: variable area display.

BMR 1968 data: Single-channel monitor sections produced on-line using EG & G electrochemical recorders.

BMR Continental Margin Survey data: Single-channel monitor sections produced on-line using EPC electrosensitive recorders. Also a 6-fold CDP stack of line 18/069, digitally processed by Geophysical Service Inc. for West Australian Petroleum Pty Ltd.

Water depth data

The water depth data presented in Plate 2 are derived from Elac fathometer records, recorded during the Continental Margin Survey and hand-digitized by Compagnie Generale de Geophysique (CGG, 1975) and from company seismic records. Recent studies have indicated that water depth measurements made using Raytheon fathometer during the Continental Margin Survey are consistently smaller than the Elac values, the difference increasing almost linearly from about 0 to 100 m for water depths from 0 to 6000 m. The studies indicate that the Raytheon measurements are generally more reliable than the Elac ones, so a correction graph for adjusting the Elac measurements was prepared (Exon et al., 1975).

Depth and thickness maps

Two sets of depth and thickness maps are presented: one at 1:2.5 million scale for the entire area (110°-118°E, 16°-22°S) (Pls.3-8), and the other at 1:1 million scale for the central area of the Exmouth Plateau (112°-115°E, 19°-21°S) (Pls.9-18). The interpreted seismic profiles were hand-scaled, and depths to the various horizons and thicknesses of sequences were calculated by computer, using velocities shown in Table 4. These maps were hand-contoured using approximately linear interpolation. The orientation of faults was determined in places where major fault-blocks could be traced from line to line and where several lines intersect, but the line-spacing is generally too great to allow small faults to be mapped. The faults shown on the maps of the whole area are essentially the major fault-zones; subsidiary cross-trending faults probably exist but were not detected. Somewhat more detail is shown on maps of the central area where there is a greater density of lines. Maps in this area were originally worked at 1:250 000 scale and then reduced.

All maps are presented on a Simple Conic Projection which has standard parallels at 18° and 36°S. This projection is generally regarded as standard for 1:2.5 million scale maps of the entire continent. Although this conic projection does not preserve angular relationships as do Mercator projections, it permits exact matching between adjacent maps of the series. The choice of 18° and 36°S as standard parallels leads to be small amount of distortion in the Exmouth Plateau area.

SEISMIC HORIZONS AND INTERVALS

Stratigraphic control in the Exmouth Plateau area is based on tentative seismic ties to the Northwest Shelf, where WAPET and BOCAL have drilled several exploration wells, and on a comparison of the structural style of the plateau with that of the northern Carnarvon Basin and southern Canning Basin.

The Late Cretaceous and older sequences of the Northwest Shelf and Exmouth Plateau appear to be similar, allowing reasonable correlations to be made, but the Cainozoic sequences differ considerably, and correlations are rather tentative.

The main characteristics of the seismic horizons and intervals, which are typical of those in most of the Exmouth Plateau area, can be seen in a profile from Esso Line 1 (Fig. 2; location shown in Pl. 1). These characteristics and the ages assigned to horizons are summarized in Table 1.

Table 1. Characteristics and proposed ages of seismic horizons

Seismic Horizon	Characteristics	Proposed Age
A1	Unconformity separating an upper zone which is acoustically semi-transparent from a lower zone of contorted reflectors or diffractions	Tertiary; probably Oligocene
A2	Unconformity marking the bed of channel-like features in some places. Where A1 and A2 are coincident the unconformity is labelled A1.	Tertiary; possibly early Eocene
B	Mild unconformity near the base of a zone of contorted reflectors or diffractions, which contains enormous lenticular bodies.	Tertiary; probably early Paleocene
C	Strong reflector at the base of a thin well-stratified zone. A mild angular unconformity under the southern Exmouth Plateau.	early Late Cretaceous
D	Reflector marking the top of a zone of northerly prograded sediment beneath the southern Exmouth plateau. Can be traced northward as a weak reflector within an acoustically semi-transparent zone. On the northeastern Exmouth Plateau Horizon D is coincident with a 'top of blocks' unconformity (E) of probable Callovian age.	Early Cretaceous; Neocomian
E	Possible mild unconformity overlying a thin sequence ponded between fault-blocks on the central Exmouth Plateau. Marks the 'top of blocks' on the northeastern Exmouth Plateau.	Late Jurassic; Callovian
F	Strong angular unconformity usually lying near the 'top of blocks' on the central Exmouth Plateau which contain parallel reflectors. Lies within the fault-blocks on the northeastern Exmouth Plateau. Underlying sequence may range from Late Triassic to Permian	Late Triassic
G	Strong reflector which in most places is parallel to Horizon F. Unconformity in some places.	possibly Permian

Basement	Envelope of diffraction patterns	Mesozoic igneous basement at margins; possibly Pilbara Block equivalent beneath Plateau

Horizon F is the most prominent unconformity in the Exmouth Plateau area. It is readily identified on the Exmouth Plateau Arch (Fig. 1) where the discordance between beds within fault-blocks below the unconformity and overlying ponded sediments is considerable (Fig. 2). The unconformity deepens and the discordance diminishes eastwards across the eastern limb of the arch into the Kangaroo Syncline. On the northeastern Exmouth Plateau horizon F appears to lie within the fault-blocks.

Tentative seismic ties to the Rankin Platform via Gulf lines AU11-24 place Horizon F near the top of the uppermost Triassic section. As the Jurassic is generally absent on the upthrown blocks on which the wells are located, the horizon can generally only be dated as in the range Late Triassic to Neocomian.

Equally tentative ties to Lynher No. 1 in the southern Canning Basin, using Gulf lines AU25-27, indicate that Horizon F corresponds with a 'top of blocks' unconformity separating Late Triassic from Late Permian.

In the Barrow Sub-basin, southeast of the Exmouth Plateau, a similar 'top of blocks' unconformity occurs below the uppermost Triassic. The regional dip of beds beneath the unconformity indicates that, from east to west, progressively older strata subcrop against it. In places in the region of the central Exmouth Plateau the underlying sequence may be as old as Permian.

In summary, the Horizon F unconformity on the Exmouth Plateau is probably Late Triassic but its formation was possibly not a synchronous event. Strata beneath the unconformity probably range from Permian to Late Triassic and are oldest in the west. The horizon F unconformity fits the category of a 'rift-onset' unconformity as defined by Falvey (1974).

At this stage it is pertinent to mention that in the North Rankin area of the Dampier Sub-basin a few petroleum exploration wells have penetrated Callovian and Tithonian sediments above and below a 'top of blocks' unconformity (Powell, 1973, 1976). Faulting in the North Rankin area thus terminated during the Callovian to Tithonian, and the unconformity seems to be related to formation of ocean floor beyond the northern margin of the Exmouth Plateau, as deduced from an interpretation of seafloor spreading anomalies about DSDP 261 (Larson, 1975; Veevers & Heirtzler et al., 1974). Seismic ties of the 'top of blocks' unconformity from the North Rankin area where the Late Jurassic (Callovian) to Early Cretaceous (Neocomian) is absent, to the central Exmouth Plateau where this sequence appears to be up to 2000 m thick, could lead to what we believe is an erroneous decision: that is that Horizon F is of Late Jurassic (Callovian) age.

Horizon D is another important reflector. It is easily recognized in the southern part of the plateau, where it caps a markedly prograded sequence, but it is not so easily identified in other areas. On the northeastern Exmouth Plateau it is coincident with the Callovian 'top of blocks' unconformity. Over most of the plateau it is a weak reflector, which in some places lies near the top of sediments lying between the older fault-blocks (Fig. 2). The unconformity has not been dated precisely from well data. It is visible on downthrown blocks on the Rankin Platform where few wells have been drilled, but is not present on upthrown blocks where wells are abundant. Its dating as mid-Neocomian depends on ties to the Barrow Sub-basin and on whether the identification of the underlying sequence as the Barrow Formation is correct. The deltaic character and thickness of the sequence, are similar to those of the Barrow Formation.

The younger horizons under the plateau were dated by studying their continuity with, or similarity to, known horizons under the Northwest Shelf. Horizon C, a strong reflector at the base of a well-stratified zone, can be traced onto the Rankin Platform along a number of profiles, and its identification as the base of the Late Cretaceous carbonate sequence is quite positive.

Prominent unconformities have been identified within the Late Cretaceous to Recent section, and others may be present but obscured by the complex of channel-like structures, slumps, and synsedimentary faults on the plateau. Across the southern part of the Exmouth Plateau Arch two unconformities are apparent: the lower one, Horizon B, lies within a zone of contorted beds and in places near the base of that zone, and is conformable with the gross structure of the arch; the upper one, Horizon A1, separates the contorted beds from the flat-bedded section above. In a few places an intermediate unconformity, Horizon A2, is apparent at the base of channel-like features; in these places A1 lies on top of the channel fill. Across the northern part of the arch both Horizons A1 and A2 are present.

The ages assigned to the unconformities defined by Horizons A1, A2, and B are speculative. No wells have been drilled in the area, and the thickness of sedimentary section increases abruptly across the upper continental slope to the nearest wells on the continental shelf. However, in the Tryal Rocks area on the southern extension of the Rankin Platform (Quilty, 1974) there are three unconformities, of Oligocene, early Eocene, and Paleocene ages, which we correlate with Horizons A1, A2, and B on the Exmouth Plateau.

Table 2 is a summary of the Exmouth Plateau stratigraphy for the Permian to Recent sequence, as proposed by Exon & Willcox (in prep.).

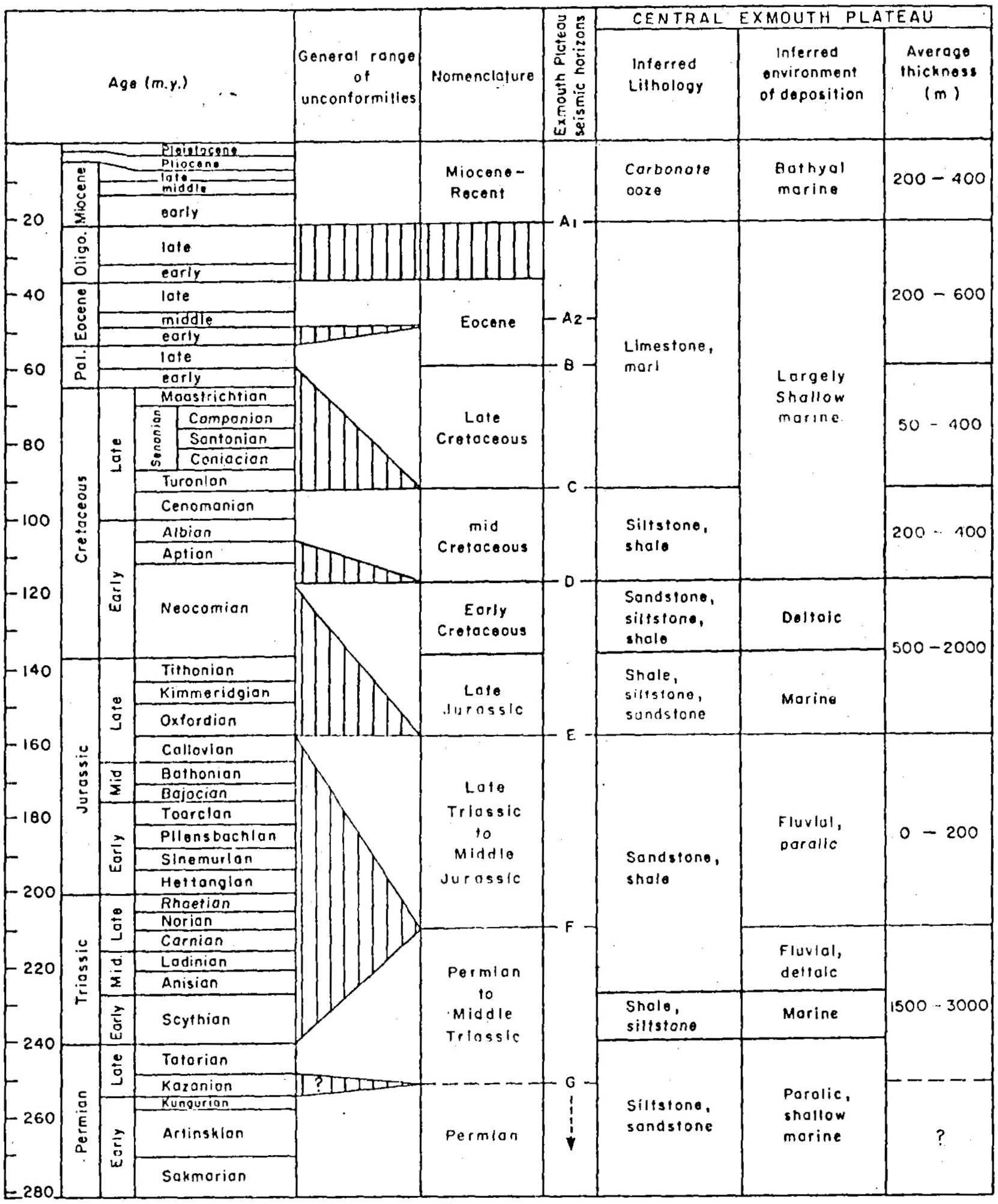
SEISMIC INTERVAL VELOCITIES FOR TIME-TO-DEPTH CONVERSION

Velocities and depths of refracting horizons were determined from an analysis of refraction events on nine BMR sonobuoy records from the Exmouth Plateau area (Table 3 & 4). It was found that refractors lying within any particular seismic reflection interval had similar velocities, so it was possible to assign a meaningful average refraction velocity to each interval. As a first approximation, the average refraction velocities were regarded as interval velocities for the purpose of time to depth conversion.

The average velocities obtained are in reasonable agreement with those derived from sonobuoy records by Veevers et al. (1974), who calculated velocities from the refractions, and from high-angle reflections using a technique described by Le Pichon et al. (1968). From the Late

Jurassic upwards (above seismic horizon F) the velocities derived from sonobuoy data on the Exmouth Plateau are considerably less than those derived from velocity determinations in wells along the edge of the continental shelf. This is probably because pelagic sediments, which have low velocities owing to their high porosity, are in greater abundance on the plateau than on the shelf. Table 4 shows the relation between seismic reflectors and interval velocities derived from well velocity surveys and sonobuoy records, together with the velocities chosen for converting times to depths. The use of a constant velocity for each interval accounts for some substantial misties between the computed depths and depths derived from well data, but the gross structures and thicknesses indicated in the maps are believed to be reliable over most of the Exmouth Plateau area.

TABLE 2



EXMOUTH PLATEAU STRATIGRAPHY:
PERMIAN TO RECENT SEQUENCE

Table 3. Location of BMR Sonobuoys

No.	Line	Time (DD.HHMM)	Approx. location	
			Lat.	Long.
1	17/074	56.0143-56.0250	18°25'S	115°50'E
2	17/093	82.0510-82.0640	17°35'S	117°15'E
3	17/084	75.1403-75.1530	15°50'S	119°25'E
4	17/090	80.2337-81.0051	15°20'S	119°55'E
5	17/089	80.1240-80.1400	14°25'S	121°10'E
6	17/076	59.2244-60.0013	17°25'S	116°25'E
7	17/079	65.2235-66.0103	16°55'S	116°25'E
8	17/072	54.0217-54.0314	18°55'S	144°10'E
9	18/007	07.0547-07.0615	17°55'S	113°30'E

Table 4. Seismic velocities from well velocity surveys and sonobuoys

Seismic horizons	Wells: Seismic velocities from well velocity surveys	Sonobuoys: Plateau & edge zone (Veevers et al., 1974)	Sonobuoys: Plateau & Continental Slope (BMR Continental Margin Survey)	Seismic velocities chosen for time to depth conversion
Seabed				
	2733 average from Malus, N. Tryal Rocks & W. Tryal Rocks	2200 range 2000-2500; average of 6 interval velocities	2350 range 2020-2570; average of 6 refraction velocities	2300
C				
	2866 average from Malus, N. Tryal Rocks & W. Tryal Rocks	2500	2525 range 2480-2570; average of 2 refraction velocities	2500
D				
	3920 average from Malus, Egret, Angel, Dampier & Legendre	range 2400-2700; average of 3 refraction & 3 interval velocities	3033 range 2840-3220; average of 3 refraction velocities	3500
F				
		3150*	3025**	3500
	4000 average from Rankin & Goodwyn	3700 - 4800 refraction velocities	3880 range 3460-4330; average of 3 refraction velocities	4000

* Range 2800-4000; average of 8 refraction and 3 interval velocities

** Range 2900-3460; average of 4 refraction velocities. Value 3850 determined from sonobuoy 6 has been excluded as it probably relates to older? Triassic section.

\+ All figures give velocities in m/s.

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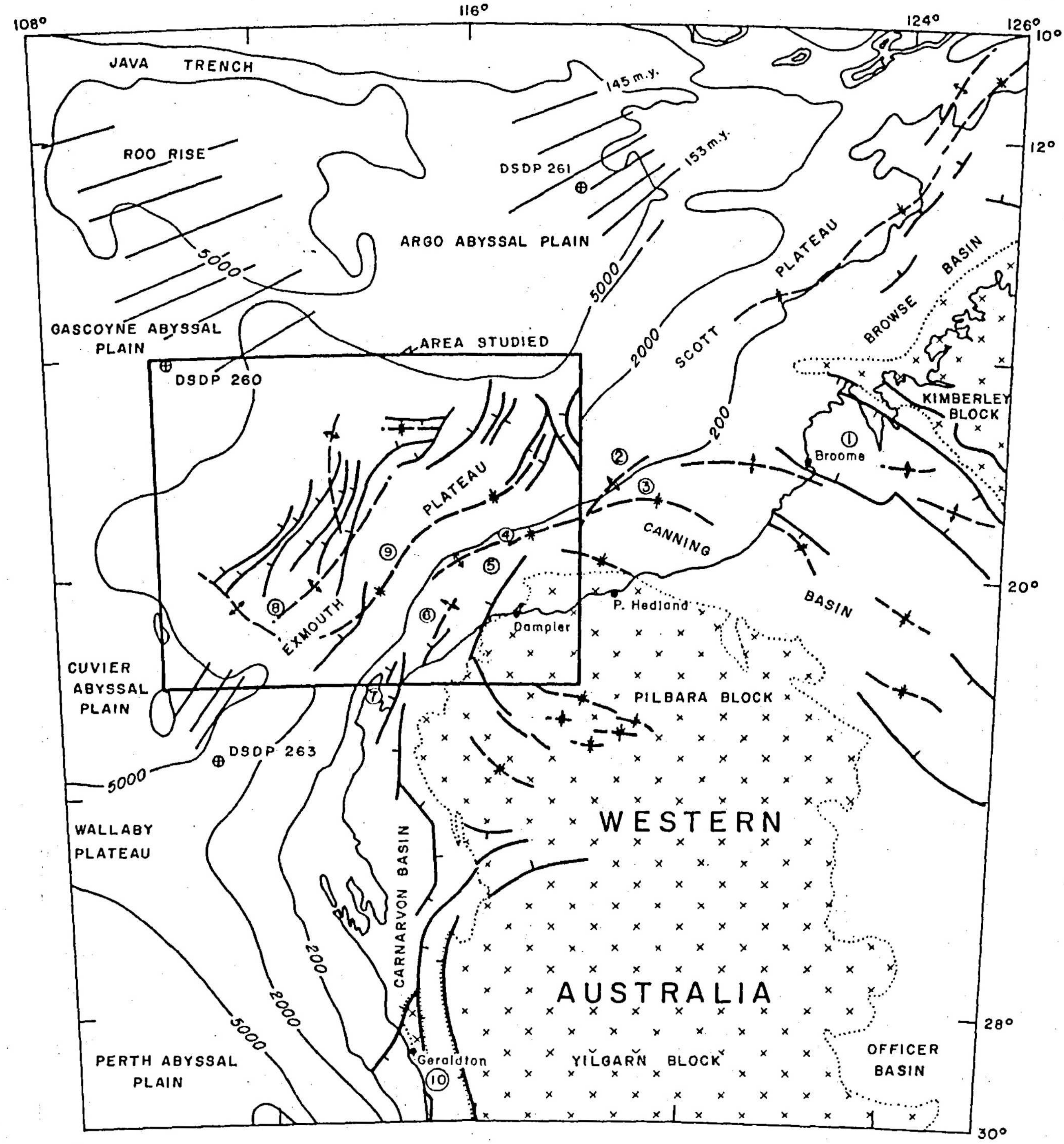
FIG. 1



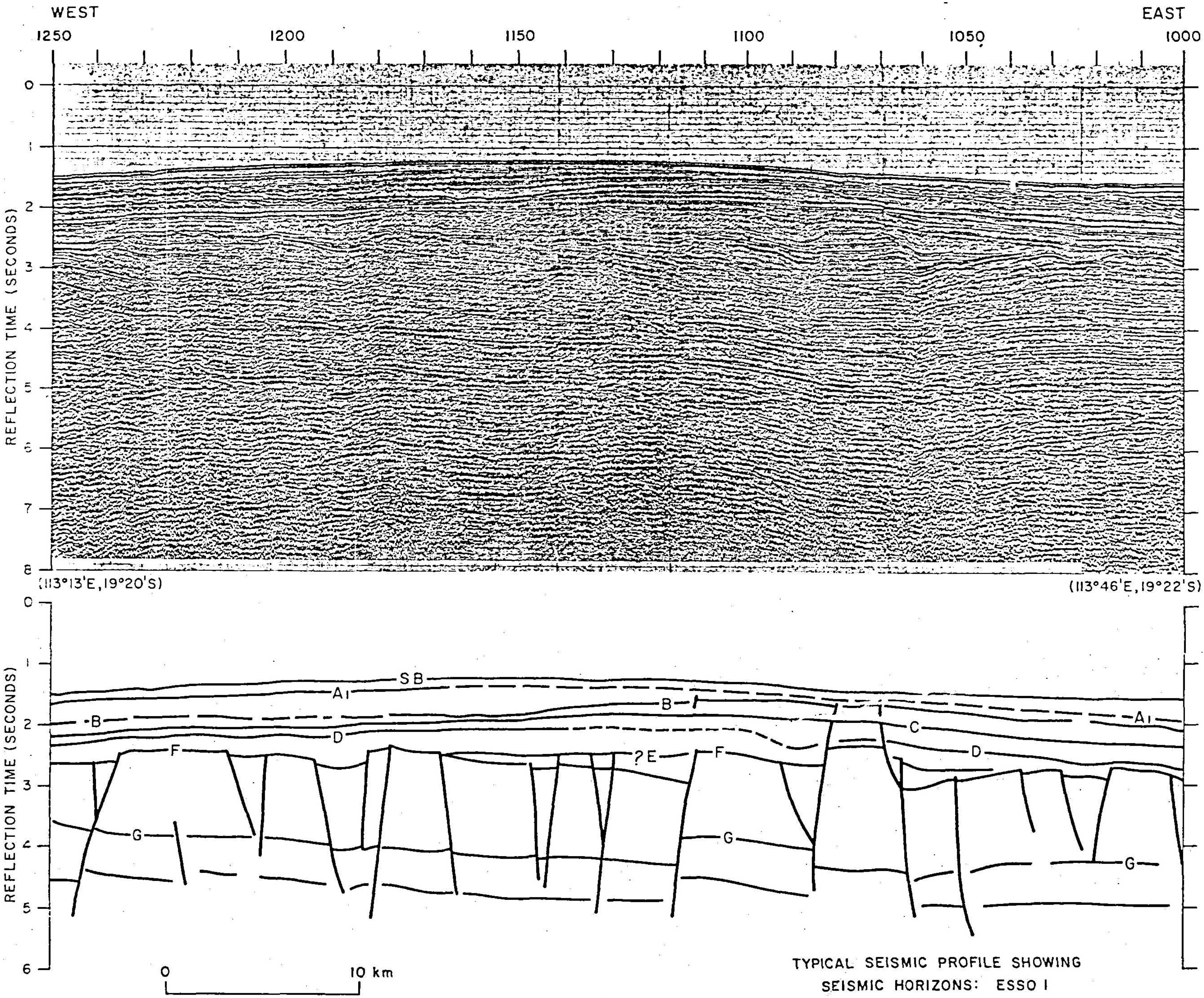
(1) Fitzroy Trough
(2) North Turtle Arch
(3) Bedout Sub-basin
(4) Rankin Platform
(5) Dampier Sub-basin
(6) Barrow Sub-basin
(7) Exmouth Sub-basin
(8) Exmouth Plateau Arch
(9) Kangaroo Syncline
(10) Perth Basin

-200- Generalized isobath (metres)
Fault, with displacement
Fault, displacement unknown
Anticline
Syncline
Phanerozoic basin
Magnetic lineation (Falvey, 1972; dated by Larson, 1974)

REGIONAL SETTING

SCALE AT 24°S
200 0 200 400 600 kilometres

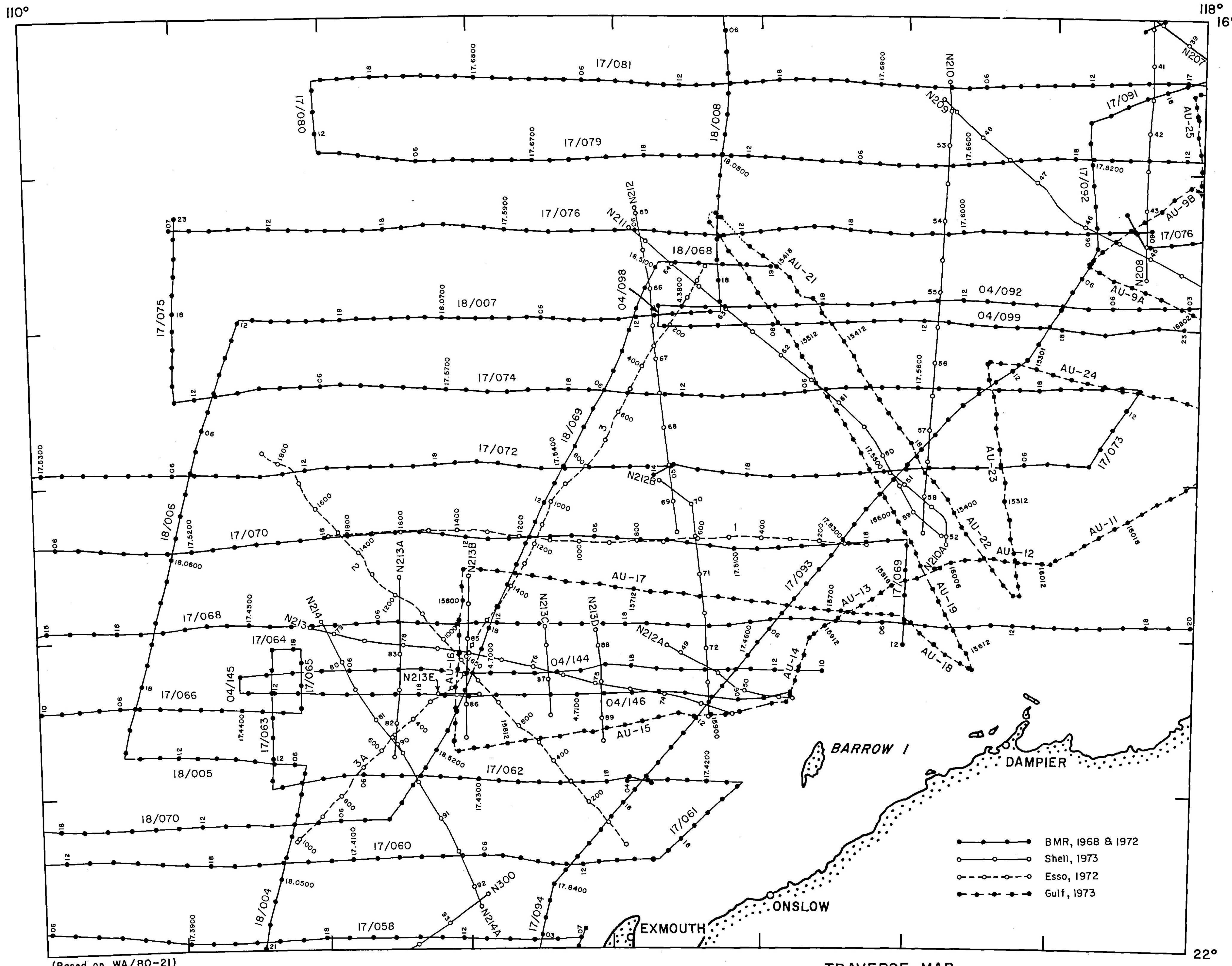
From Tectonic Map of Australia (1971), Veevers and Johnstone (1974) and by authors



TYPICAL SEISMIC PROFILE SHOWING
SEISMIC HORIZONS: ESSO 1

FIG. 2

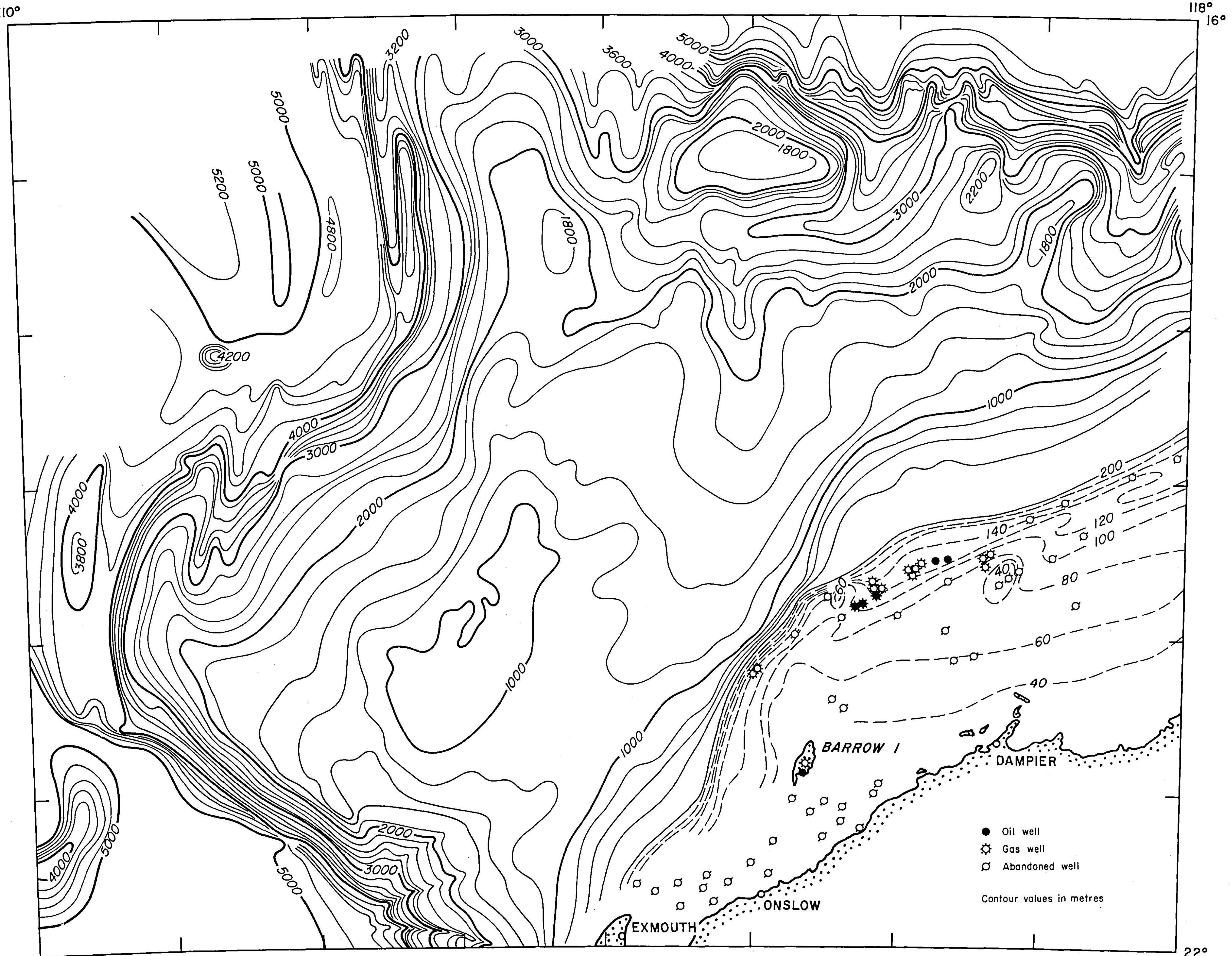
PLATE I



(Based on WA/BO-21)

TRAVERSE MAP

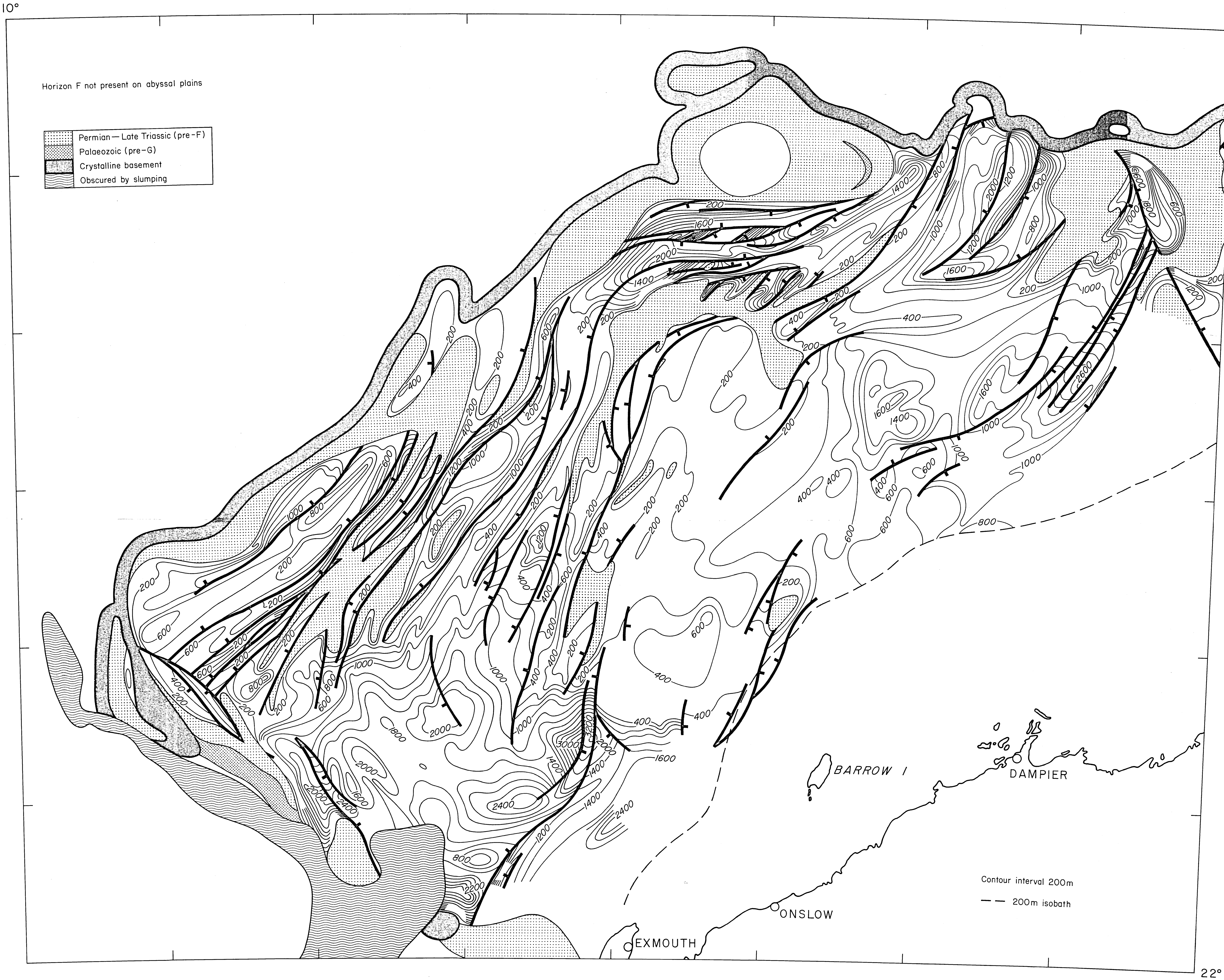
BMR AND EXPLORATION COMPANY LINES



(Based on WA/BO-21)

BATHYMETRY

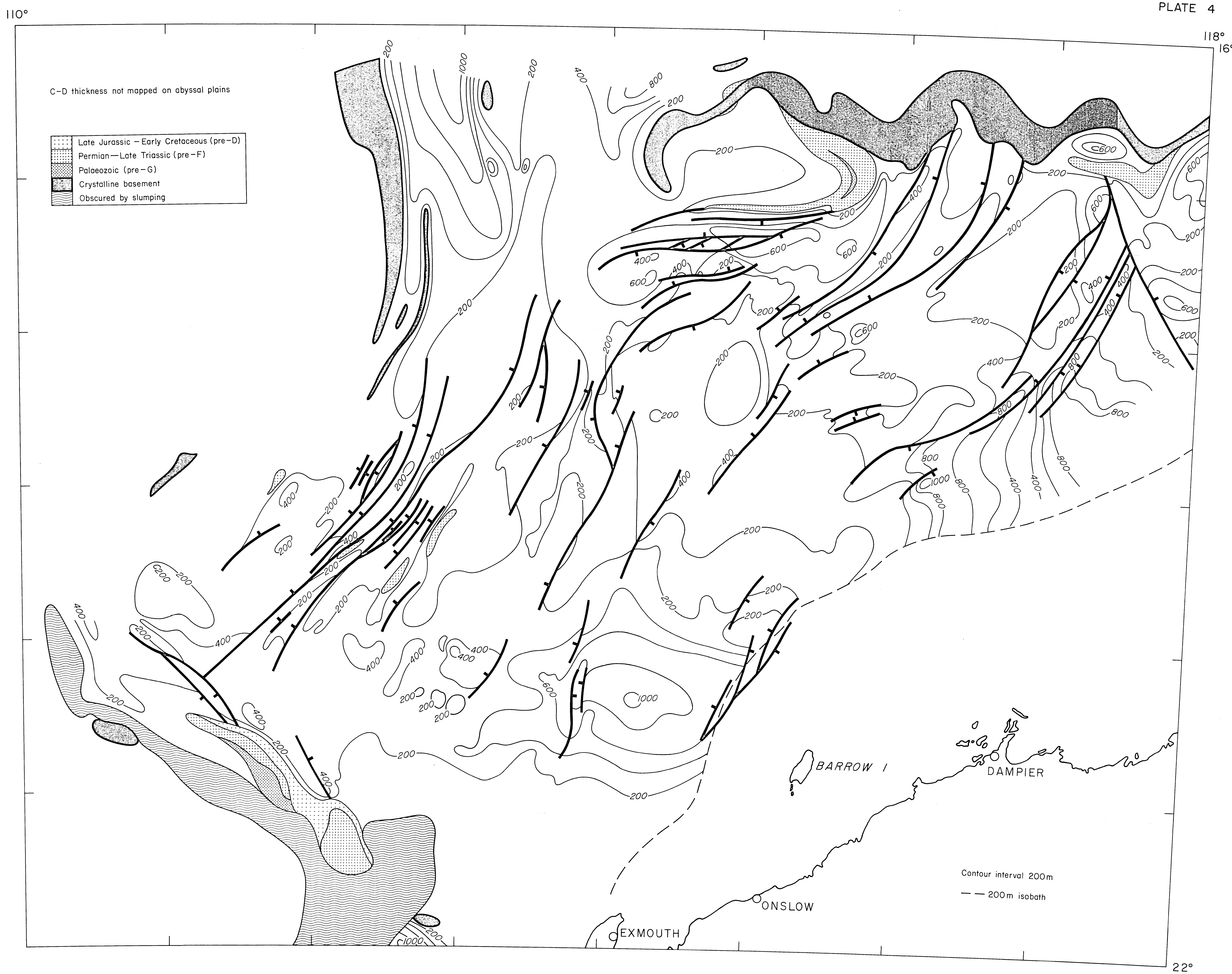
WA/B8-117-1



ISOPACHS,
LATE TRIASSIC TO EARLY CRETACEOUS
(F–D)

Record No. 1976/107

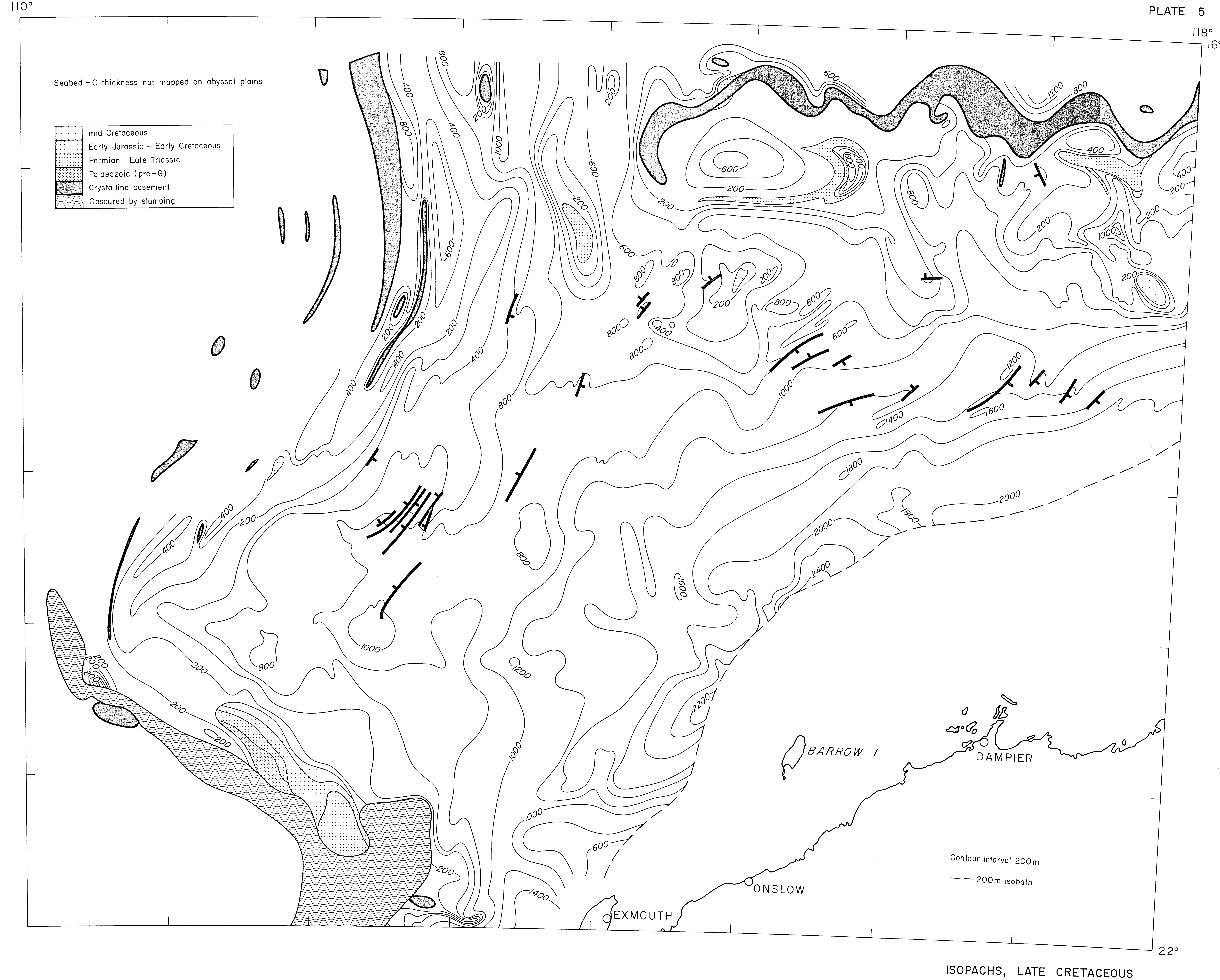
WA/B8-181



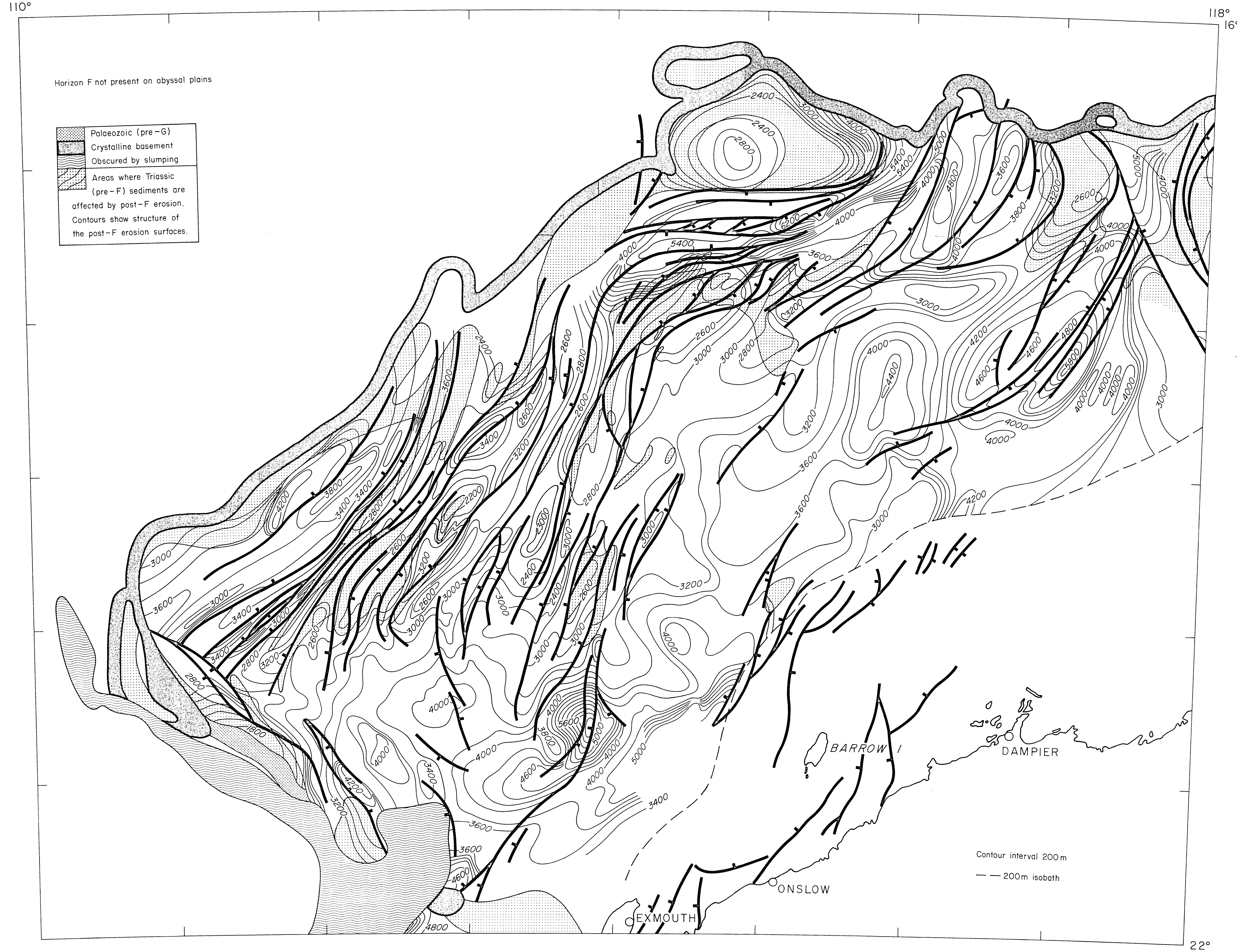
ISOPACHS,
MID CRETACEOUS (D-C)

Record No. 1976/107

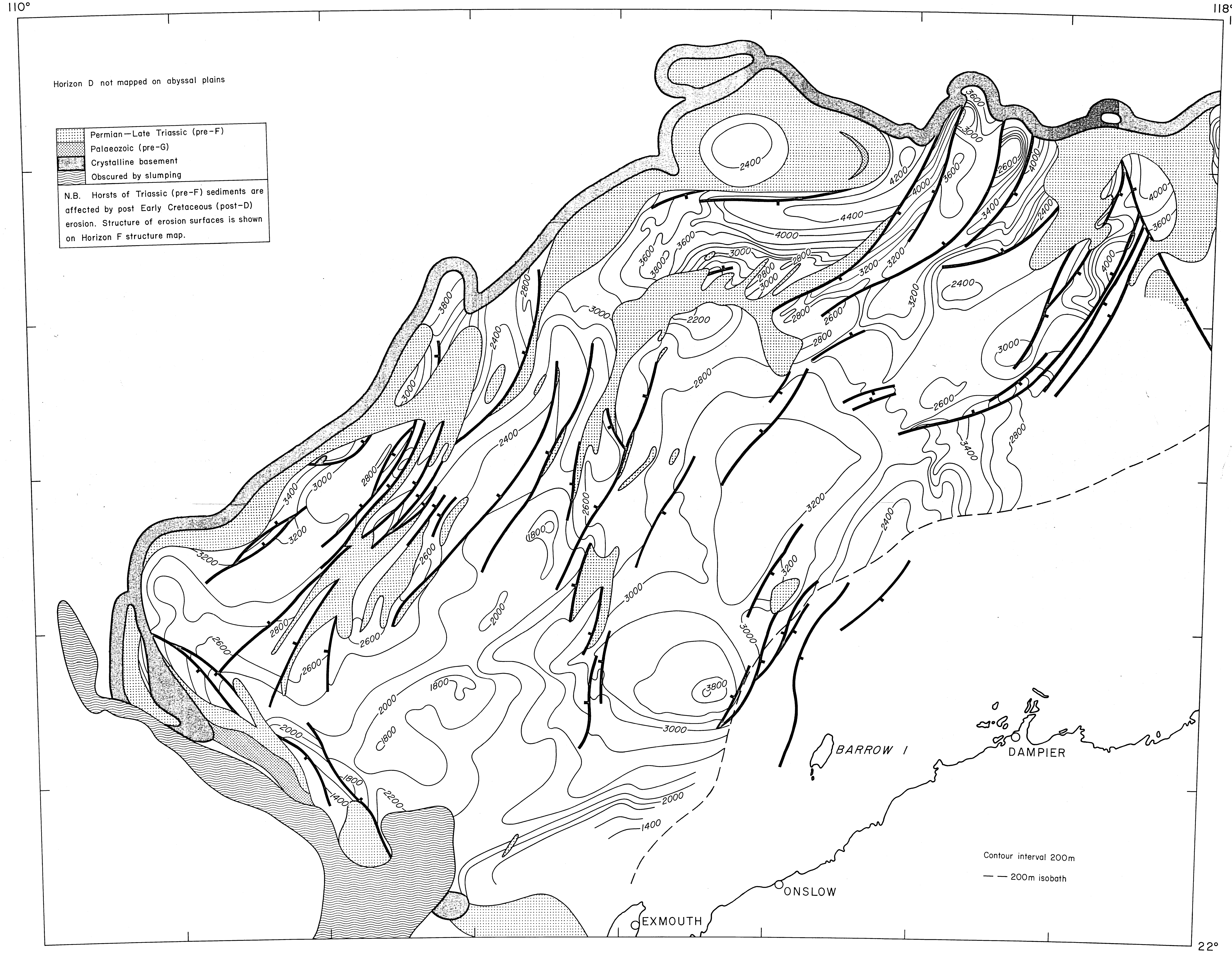
WA/B8-182



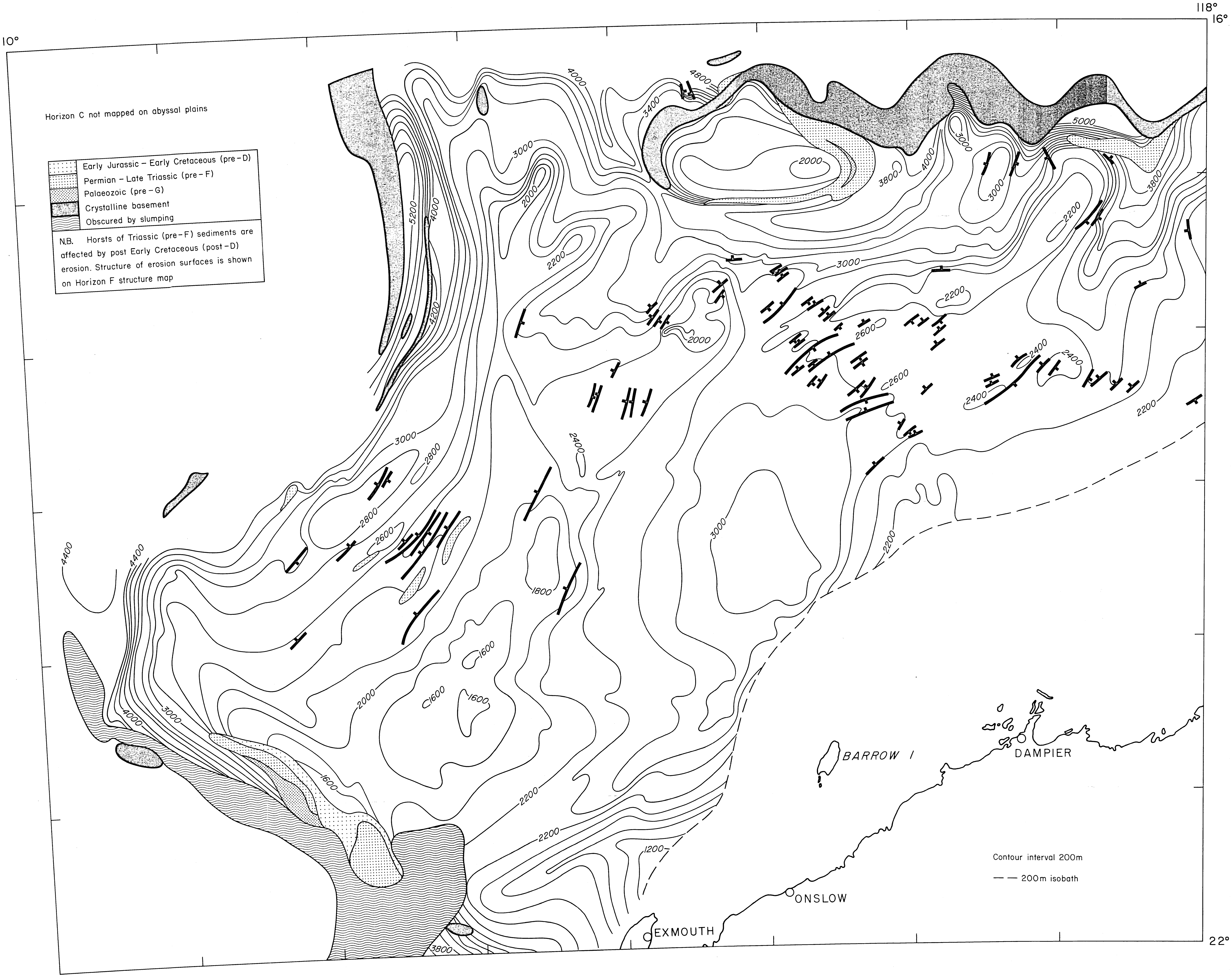
ISOPACHS, LATE CRETACEOUS
TO RECENT (C– SEABED)



STRUCTURE CONTOURS,
LATE TRIASSIC UNCONFORMITY (F)



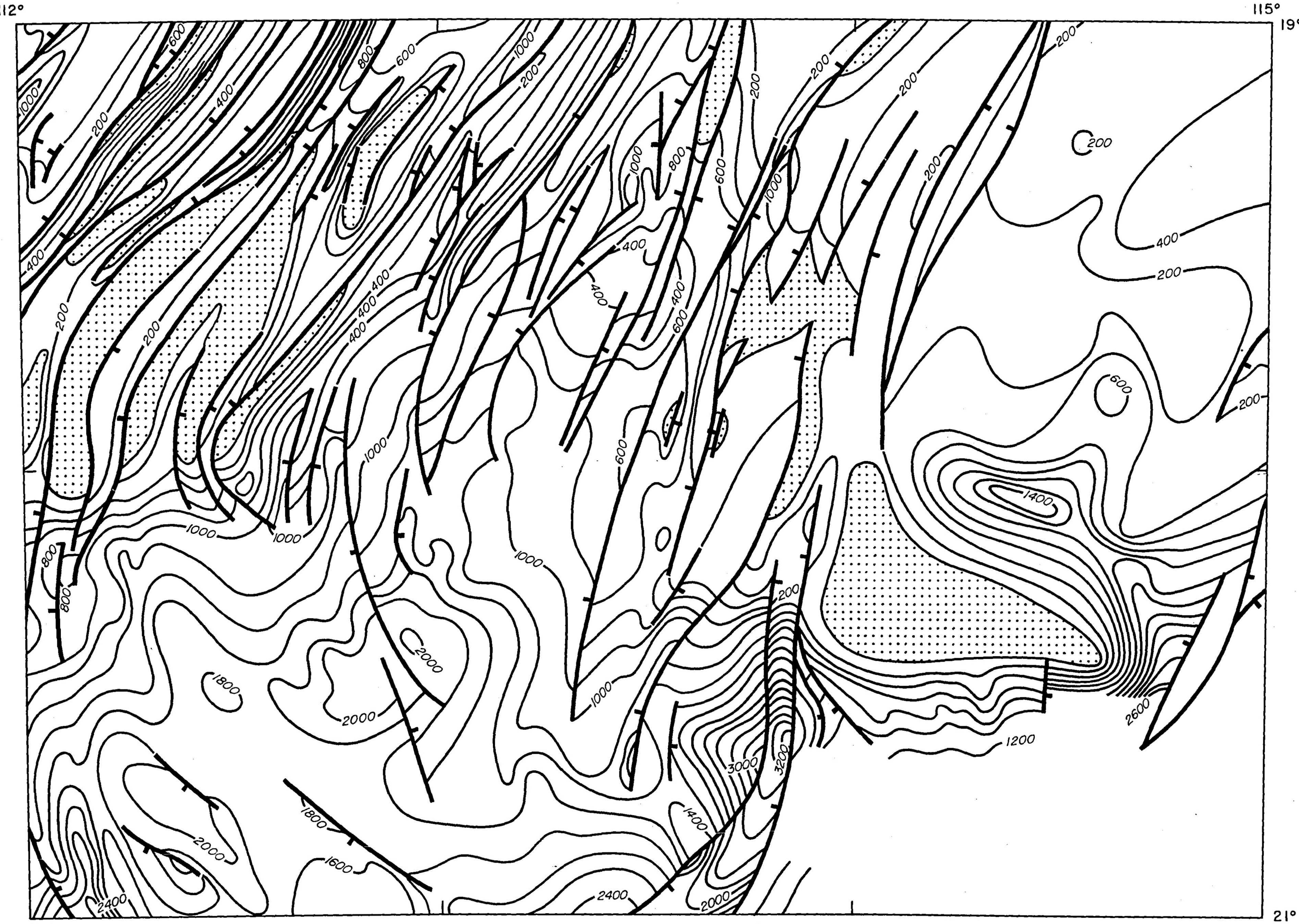
STRUCTURE CONTOURS,
EARLY CRETACEOUS HORIZON (D)



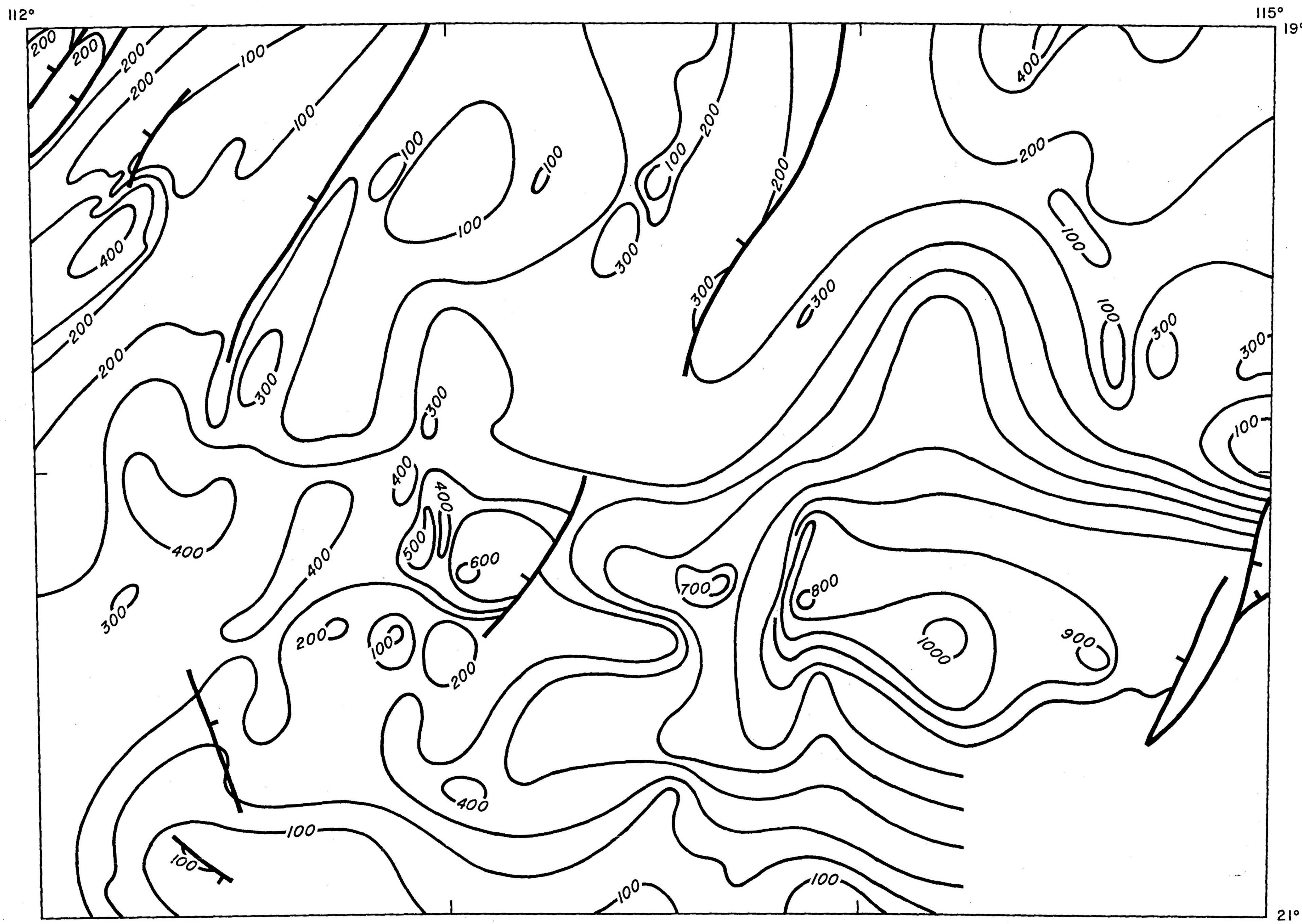
STRUCTURE CONTOURS,
LATE CRETACEOUS HORIZON (C)

WA/B8-186

Record No. 1976/107

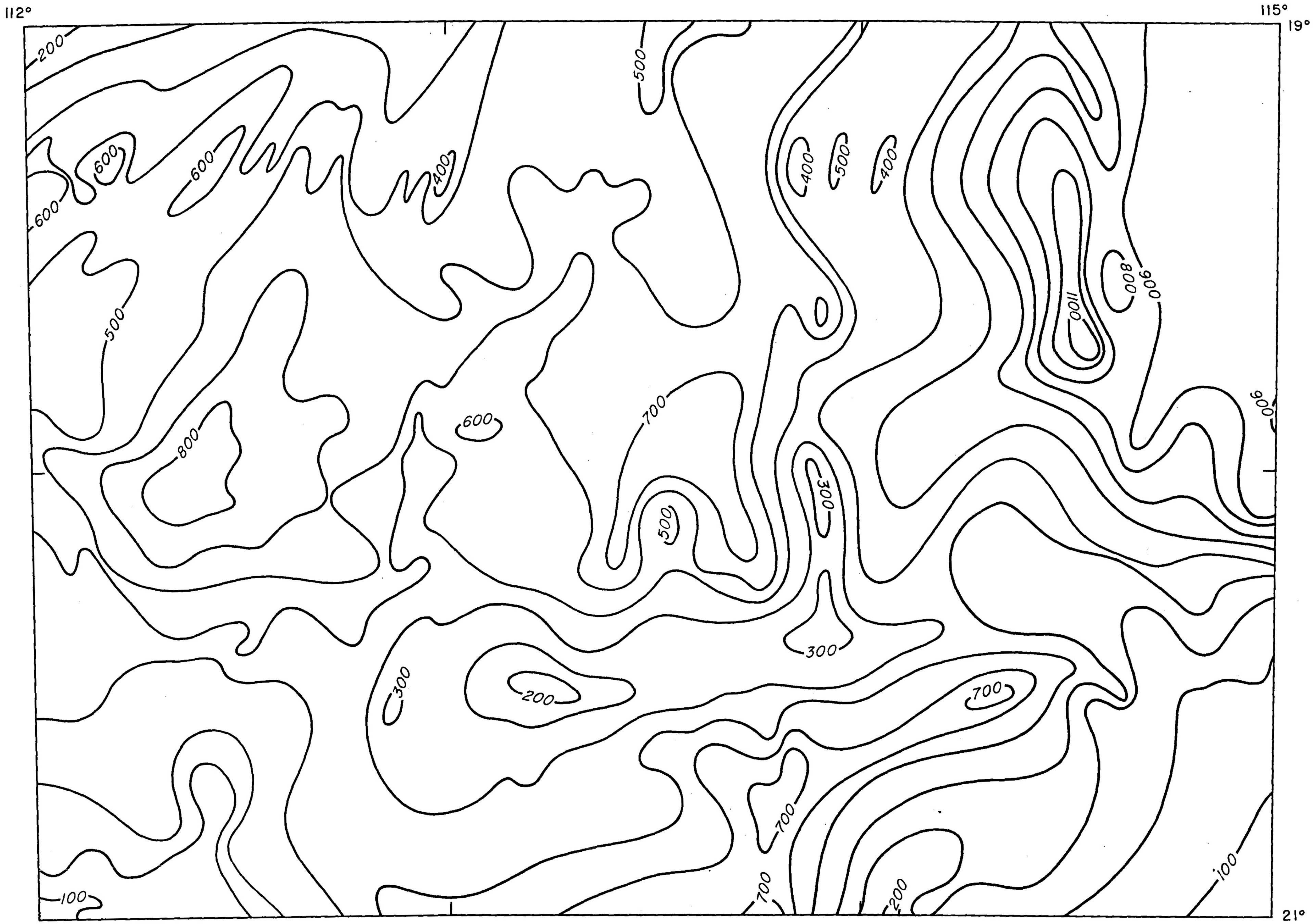


ISOPACHS OF CENTRAL AREA
LATE TRIASSIC TO EARLY CRETACEOUS (F-D)

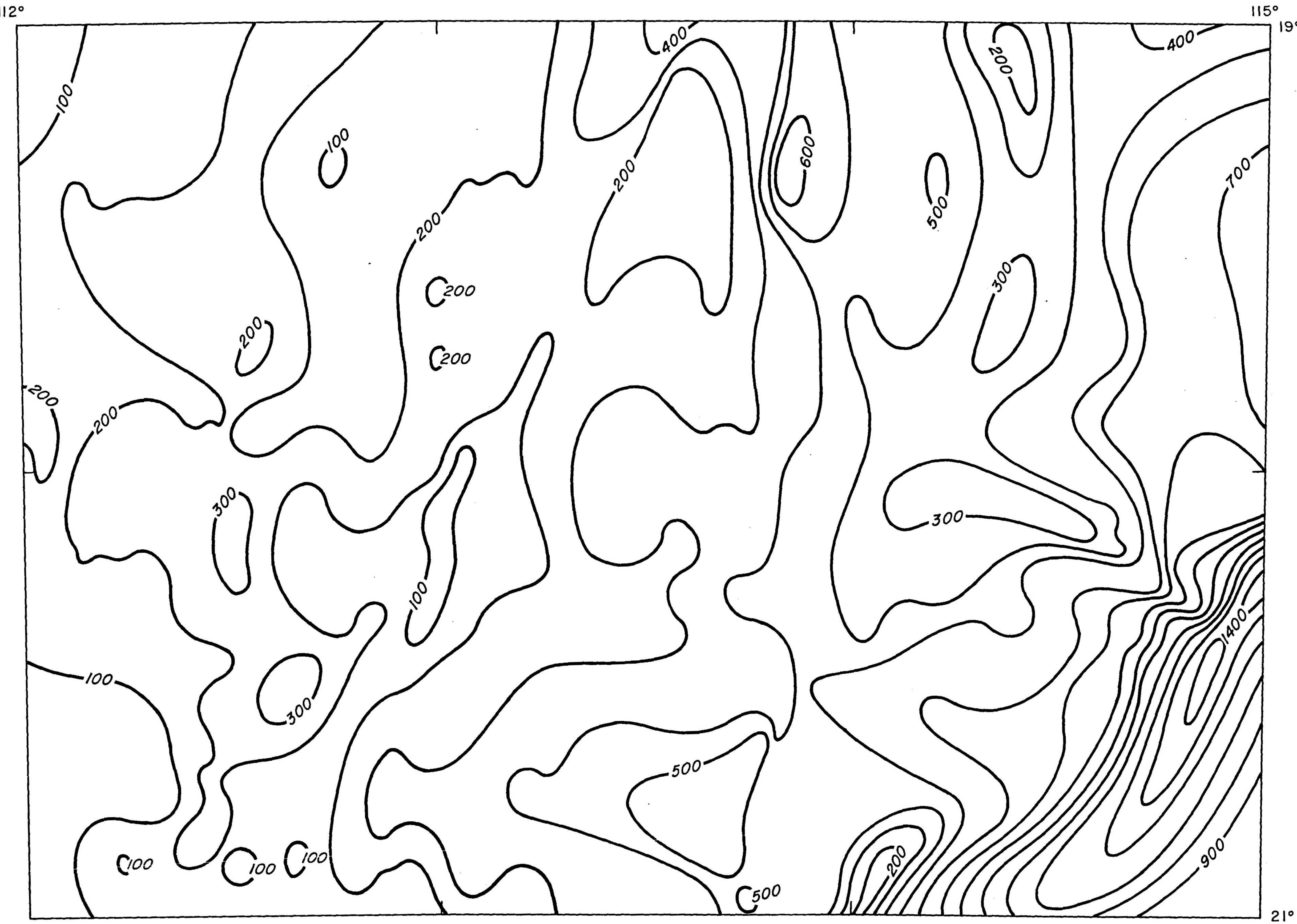


ISOPACHS OF CENTRAL AREA
MID-CRETACEOUS (D-C)

ISOPACHS OF CENTRAL AREA
LATE CRETACEOUS (C-B)

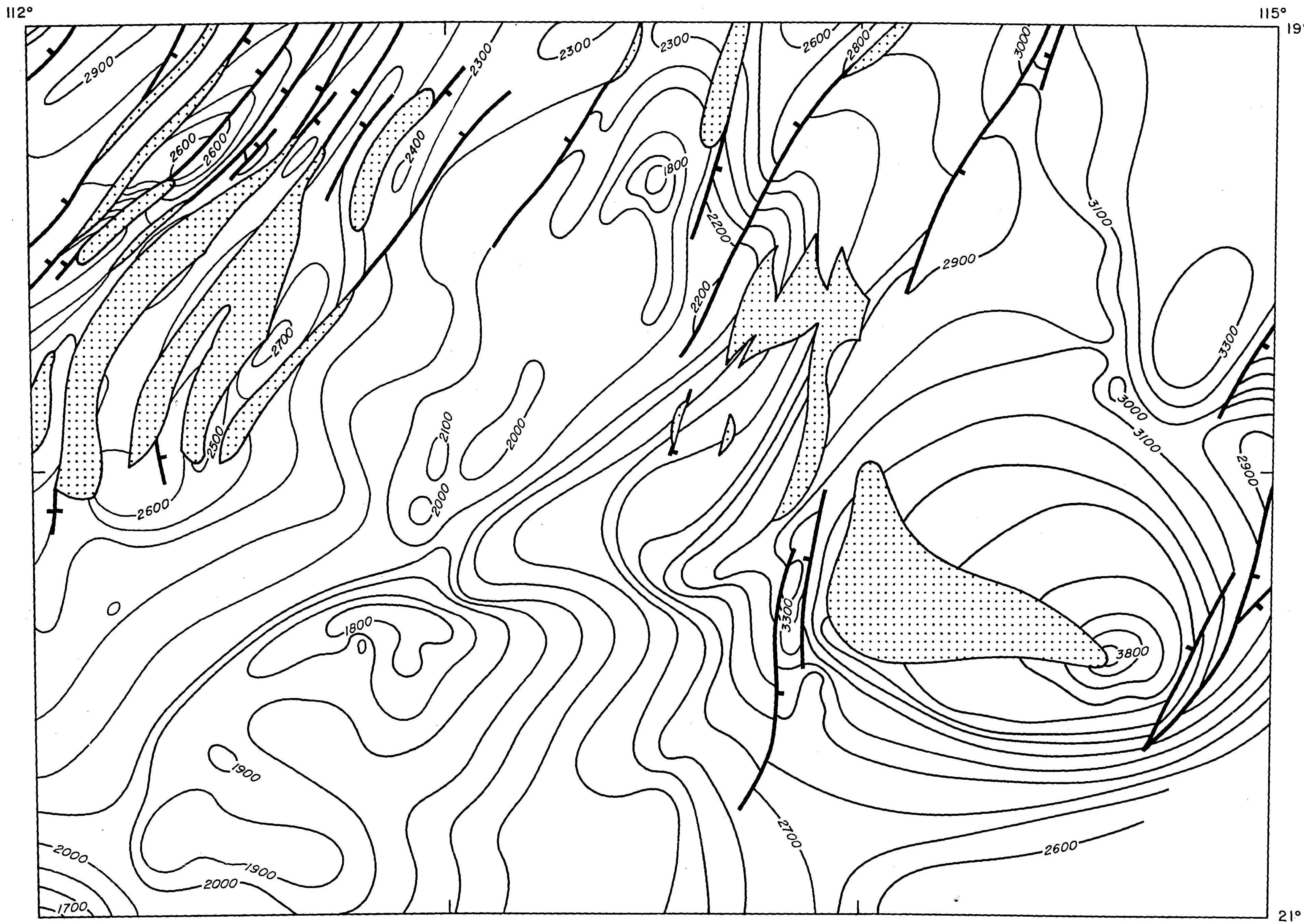


ISOPACHS OF CENTRAL AREA
EOCENE (B–A_1)

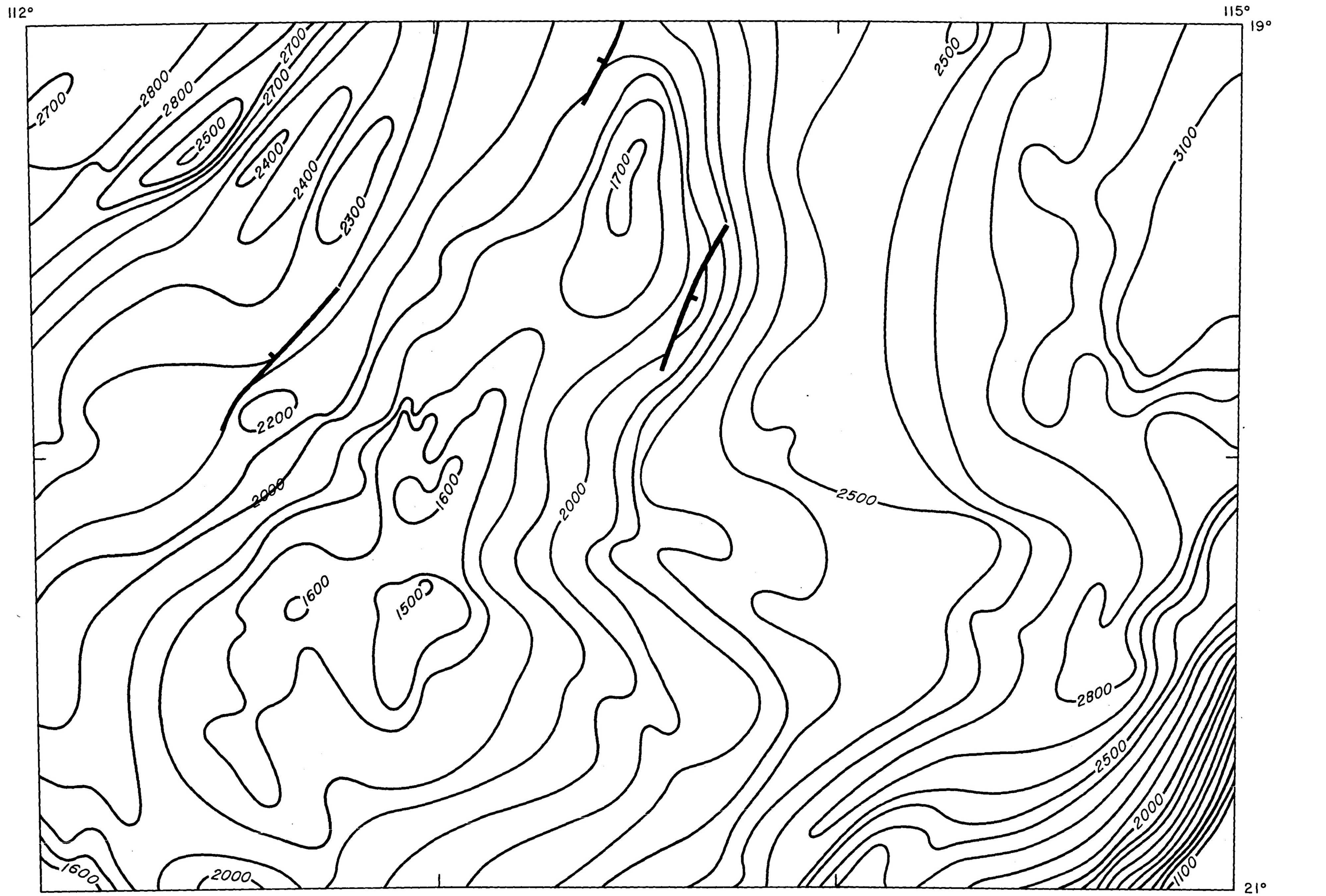


ISOPACHS OF CENTRAL AREA
MIOCENE TO RECENT (A_1-SEABED)

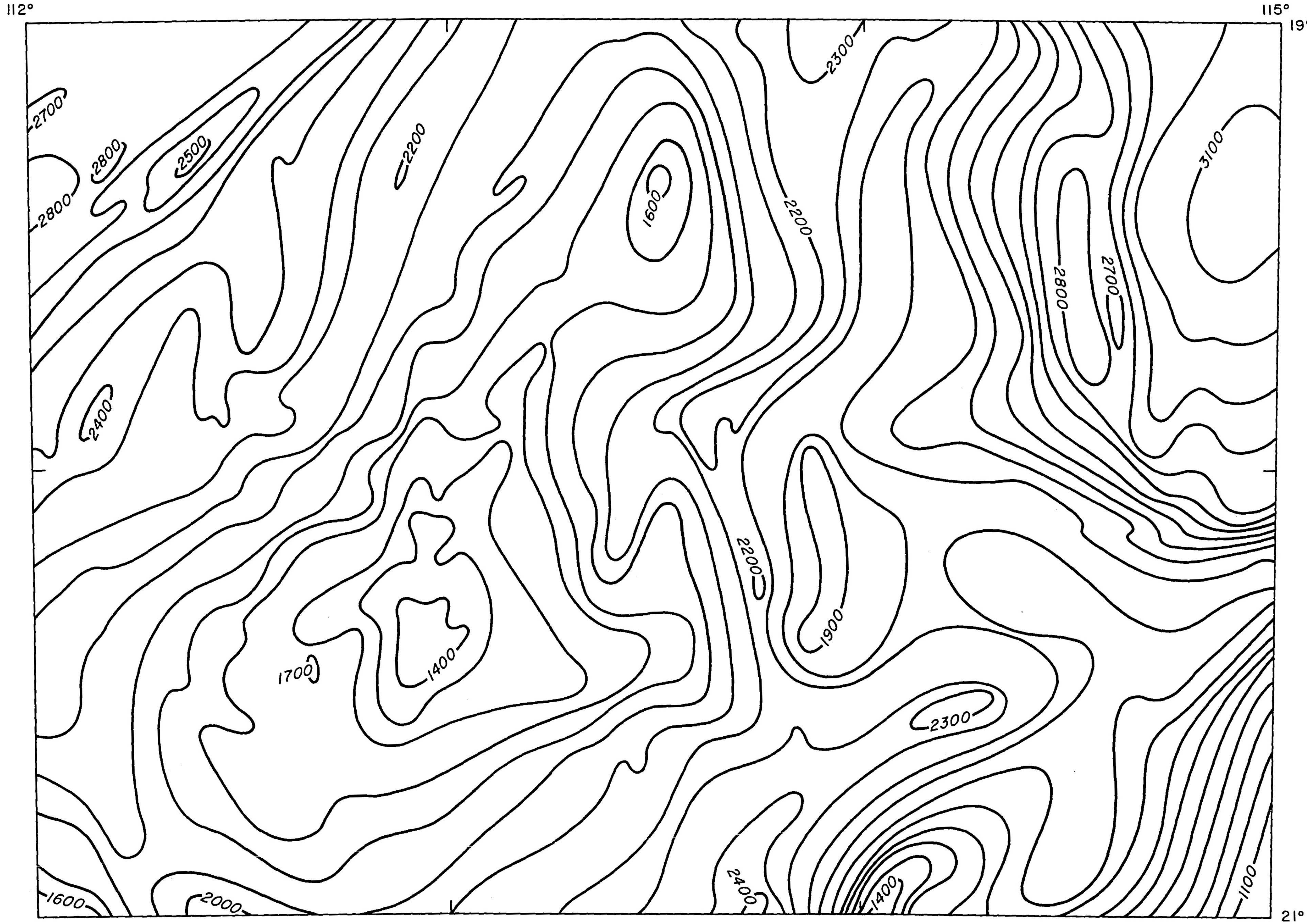
STRUCTURE CONTOURS OF CENTRAL AREA
LATE TRIASSIC UNCONFORMITY (F)



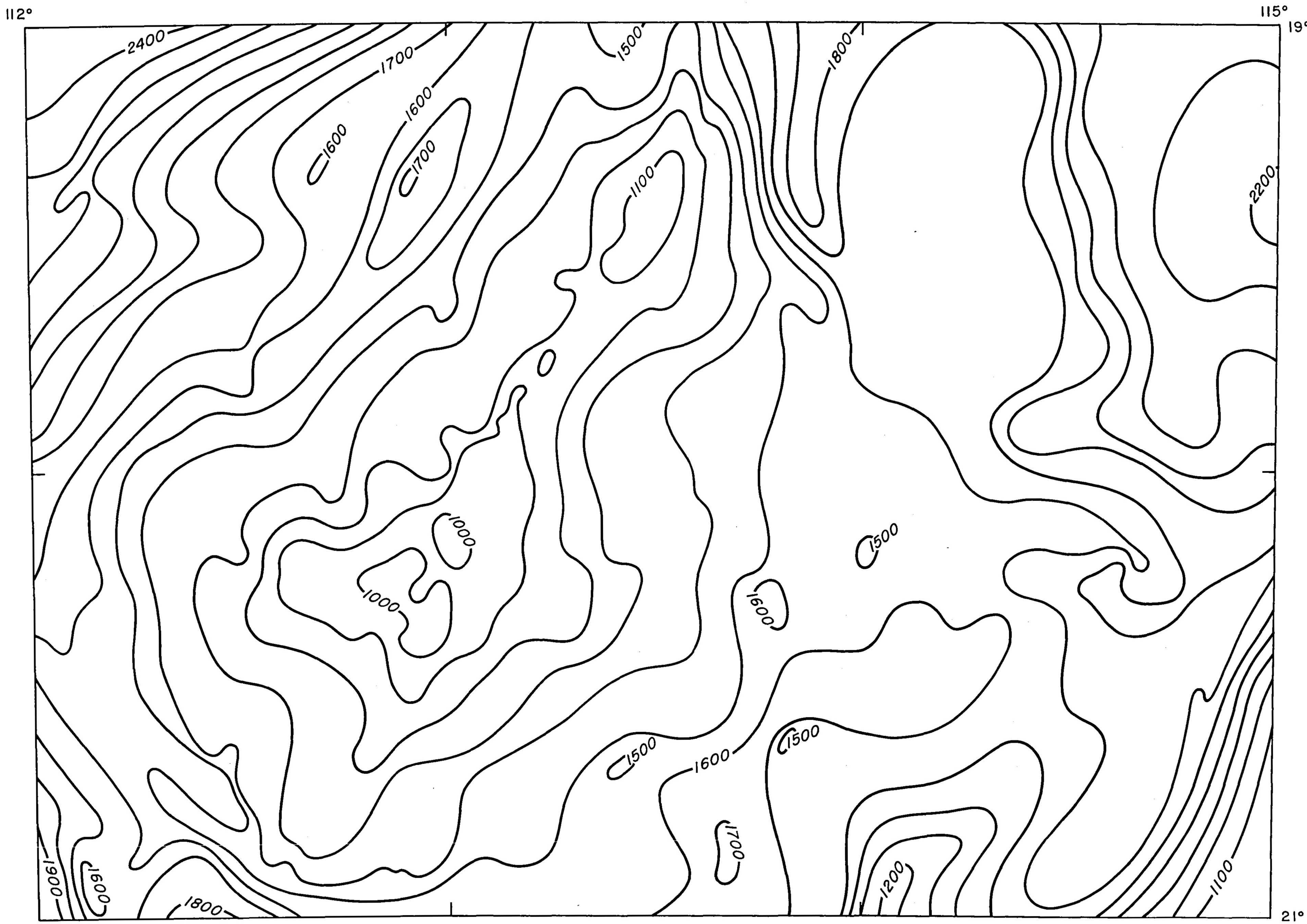
STRUCTURE CONTOURS OF CENTRAL AREA
EARLY CRETACEOUS HORIZON (D)



STRUCTURE CONTOURS OF CENTRAL AREA
LATE CRETACEOUS HORIZON (C)



STRUCTURE CONTOURS OF CENTRAL AREA
PALEOCENE HORIZON (B)



STRUCTURE CONTOURS OF CENTRAL AREA
OLIGOCENE HORIZON (A_1)