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**SEISMIC STRATIGRAPHY, STRUCTURAL ANALYSIS,
AND TECTONIC EVOLUTION OF THE
NORTHERN CANNING BASIN, WESTERN AUSTRALIA**

by

M.F. Middleton



**DEPARTMENT OF MINES
WESTERN AUSTRALIA**



Geological Survey of Western Australia

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and tectonic evolution of the northern
Canning Basin, Western Australia**

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Seismic stratigraphy, structural analysis, and tectonic evolution of the northern Canning Basin, Western Australia

by

M. F. Middleton

Abstract

This Record consists of three parts: seismic stratigraphy; structural analysis; and geological evolution. The seismic stratigraphy is analyzed at four key localities in the northern Canning Basin. Six unconformity-bounded sequences can be recognized from seismic stratigraphic analysis of the Late Devonian to Early Permian succession in the northern Canning Basin. These sequences are termed the Pillara, Nullara, Gumhole and Yellow Drum, Laurel, Anderson, and Grant Sequences, and can be correlated to relative changes of sea level in the basin.

The structural analysis concentrates on mapping in a number of key localities in the northern Canning Basin. Structures in the northern part of the basin are dominated by wrench tectonism superimposed on the extensional Fitzroy Trough. Wrench tectonism and intrusive activity generated the major anticlinal features in the northern part of the basin. The tectonism also caused faulting, which breached most of the structural closure of these anticlines. Intrusive activity was in the form of igneous intrusion in the Late Permian, and salt/shale flowage during wrenching in the Late Triassic or Early Jurassic.

The tectonic event that caused the formation of the Fitzroy Trough entails lateral extension of the lithosphere, and perhaps withdrawal of heat from the base of the lithosphere. Heating in the basin appears to have occurred during (i) the Late Permian in isolated localities; and (ii) the wrench event when it occurred regionally. Movement of fluids through the basin appears to have occurred in four main periods: (i) during compaction of the Fitzroy Trough sediments in the Carboniferous; (ii) during the Late Permian igneous intrusive activity; (iii) during the wrench event; and (iv) during the Miocene lamproite intrusive activity.

The tectonic model proposed for the formation of the northern Canning Basin entails: (i) intracratonic sag during the Early and Middle Devonian; (ii) graben development during the Late Devonian and Carboniferous; and (iii) the development of a classic aulacogen during the Permian. Wrench tectonism during the Late Triassic to Early Jurassic formed anticlines, which may have up to 2000 m eroded off their culminations.

In terms of petroleum exploration, the better exploration targets are the smaller structures on the Lennard Shelf and Broome Platform that have not been breached by the wrench faulting. Lead - zinc mineralization, however, may be associated with fault zones on the margins of the Fitzroy Trough.

KEYWORDS: Seismic stratigraphy, structural analysis, tectonics, structural evolution, petroleum exploration, lead - zinc mineralization, Canning Basin

Introduction

The economic importance of the northern Canning Basin has grown in the last ten years with the discovery of the Blina, Sundown, West Terrace, and Lloyd oilfields, and the Cadjebut and Blendevale lead - zinc deposits. The basin also has potential for natural industrial diamond production from lamproite intrusions in two large fields in the northern Canning Basin (Jaques et al., 1986). The Devonian carbonate rocks of the basin are host to both the oil and the base-metal mineralization; and the overlying Carboniferous and Permian sedimentary rocks contain important oil reservoirs. This study has grown out of a need to understand the subsurface facies relationships and structure in the economically important northern Canning Basin.

The area of study extends from the Lennard Shelf in the north to the Jurgurra and Barbwire Terraces in the south (Figs 1 and 14). More than 100 000 km of seismic reflection data have been acquired in the northern Canning Basin since the late 1960s. Much of the data are of very good quality, and are suitable for both detailed seismic stratigraphic and structural analysis.

Playford and Lowry (1966), Playford (1980, 1982, 1984), Benn (1984), Cooper et al. (1984), Hall (1984), Moors et al. (1984), and Kerans (1985) have described the Devonian reef complexes of the Lennard Shelf. The seismic stratigraphy of the northern Canning Basin has been studied by Rasidi (1978), and Middleton (1987a, 1987b, 1987c). Structural analysis based on seismic-reflection surveying has been carried out by Forman and Wales (1981), Middleton (1984), and various authors in Purcell (1984). A generalized seismic model of the reef complexes has been discussed by Middleton (1987a, b, c).

This report presents (1) a seismic-stratigraphic definition of the Devonian to Permian subsurface facies relationships; (2) a detailed structural analysis of some of the major structures in the northern part of the basin; and (3) a discussion of various tectonic models for the basin.

The economically important rocks in the northern Canning Basin are the reef complexes of Devonian age, and the Grant Group of Carboniferous - Permian age (Fig. 2). The reef complexes host both oil and lead - zinc mineralization, and the Grant Group contains the oil reservoirs of the Sundown and West Terrace fields.

A key to the location of the seismic lines used is given in Enclosure 1, which also shows the location of all petroleum exploration wells discussed in this report.

Part 1. Seismic stratigraphy

Introduction

The seismic stratigraphic study of the northern Canning Basin has the following aims:

- (i) to examine the seismic-stratigraphic sequences of the northern part of the basin;
- (ii) to observe the sea-level fluctuations in the basin as determined from seismic stratigraphy, and identify the components due to eustatic variation and tectonic movements; and
- (iii) to investigate the possibility of new stratigraphic plays in the basin from the seismic-stratigraphic facies examination.

Four representative sites on the southern margin of the Lennard Shelf were analysed in detail to determine seismic-stratigraphic (i.e. unconformity-bounded) sequences. These sequences were correlated between sites, and across the Lennard Shelf and Fitzroy Trough.

The four localities (Fig. 1) were selected on the basis of being representative of the stratigraphic section and having good-quality seismic data. The localities occur on the hinge line between the Lennard Shelf and the Fitzroy Trough, where the seismic character for each facies and facies change is well developed.

Sea-level fluctuations were deduced from truncation events within the seismic sequences (Vail et al., 1977). These observations were integrated with sea-level fluctuation curves deduced from outcrop geology (Playford et al., 1989).

Seismic sequences

The Devonian to Lower Permian sedimentary rocks of the northern Canning Basin (Fig. 2) are divided into six sequences, which are unconformably bounded and have distinct seismic characteristics. The sequences were examined at four localities: Meda 1 and 2, Blina Oilfield, Mimosa 1, and Mt Hardman 1, (Fig. 1). Not all the sequences occur at each locality and often a different facies of a

particular sequence occurs at any one locality. The variation within each sequence is described below.

Pillara Sequence

The Pillara Sequence is equivalent to the Pillara Cycle of Playford (1980). On the Lennard Shelf, the sequence is characterized by back-stepping carbonate platform in the Meda area (Locality 1), and shallow-marine medium- to fine-grained clastics. The seismic character of the Frasnian clastics is seen in Figure 3; the sequence character varies from horizontal, low-frequency reflections (shot points 250 - 270, Fig. 3) to erratic, discontinuous reflections (shot points 270 - 290, Fig. 4).

The erratic reflections are probably associated with a high-energy environment, possibly a turbidite flow, and the horizontal reflections probably represent low-energy, fine-clastic deposition. The seismic character of the sequence in the vicinity of the carbonate platform (Meda area) is shown in Figure 3. Horizontal reflections mark the top of the Frasnian platform (see Fig. 3), and pass basinward into low-frequency reflections dipping into the Fitzroy Trough. The low-frequency reflections indicate fine clastics, deposited in a low-energy environment, which is consistent with expected environments (Playford, 1980; 1984).

The transition of the sequence across the hinge line between the Lennard Shelf and the Fitzroy Trough in the Meda area is shown in Figure 3. The environment of deposition is different in the Mimosa area where basinal clastics dominate most of the Lennard Shelf basinward of the outcrop area (Locality 3; Fig. 5). Similar depositional environments persist along most of the hinge line (Pinnacle Fault System) in the southeast of the study area.

Structure contours on top of the Pillara sequence are shown in Figure 6.

Nullara Sequence

The Nullara Sequence is equivalent to the Nullara Cycle of Playford (1980, 1984). On the Lennard Shelf, it varies from carbonate platform facies to basinal

shale. In the Fitzroy Trough, it is comprised principally of basinal shales. In the Meda area (Locality 1), it is seen passing from platform to basinal shales over the Pinnacle Fault hinge line (Fig. 3). Deeper in the basin near the same locality (Fig. 4), onlap truncations are evident, consistent with the prograding reef front (Fig. 7). In the Blina area (Locality 2), the Nullara Sequence is similar to the Meda area, and the interfingering with basinal shales is better developed (Fig. 7, shot points 290 - 300).

In the Mimosa area (Locality 3), the sequence is essentially basinal shale, and little variation is observed across the Pinnacle Fault, which had slight growth movement during the deposition of the sequence. A similar environment occurs in the Mt Hardman area (Locality 4, Fig. 8), and in areas along the northern hinge line in the southeastern part of the study area.

Isopach contours of the Nullara Sequence are shown in Figure 9.

Gumhole and Yellow Drum Sequences

The Gumhole Sequence is equivalent to the Gumhole Formation (Druce and Radke, 1979), and drapes over the reef complex rocks. It is difficult to distinguish as a separate sequence in the Meda area (Locality 1), where it is grouped with the Yellow Drum Sequence. At this locality, a large submarine fan has shed sediment from the platform into the basinal area, shortly after the reef complexes were drowned (Fig. 10). Middleton (1987a) has briefly described the Meda fan, and has given an example of its seismic expression. The fan is well demonstrated in Figures 3 and 4. The areal extent of the fan is shown in Figure 11, which is a time-structure map of the event within the fan indicated in Figure 10. This and similar submarine fans may have introduced coarse clastics into the flanks of the Fitzroy Trough from fan deltas (siliciclastic deltas of Moors, 1986) on the northern margin of the Lennard Shelf.

The Gumhole and Yellow Drum Sequences are more easily defined in the Mt Hardman area (Locality 4). Here the Gumhole Sequence contains more shale than indicated by Druce and Radke (1979), and the Yellow Drum Sequence is essentially a limestone unit. The Gumhole Sequence and Yellow Drum Sequence are shown as units A and B, respectively, in Figure 8.

Laurel Sequence

The Laurel Sequence is equivalent to the Laurel Formation of Druce and Radke (1979). On the Lennard Shelf, in the Meda area, it has a discontinuous seismic character and is difficult to subdivide into the A and B facies of Druce and Radke (1979). In the Fitzroy Trough at Locality 4 (Fig. 8), the seismic character of the sequence can be divided into a lower low-frequency zone and an upper high-frequency zone. Both zones exhibit onlap reflections. The upper and lower zones may correspond to the A and B facies of Druce and Radke (1979).

In the Mt Hardman area (Fig. 8), three zones can be distinguished on the basis of seismic character: (i) a lower siltstone unit (C in Fig. 8 -- transparent seismic character); (ii) a siltstone, sandstone, and limestone unit (D and E in Fig. 8 -- strong, continuous reflection character); and (iii) an uppermost sandstone unit (F in Fig. 8 -- discontinuous reflection character). These three zones persist across much of the Fitzroy Trough (Fig. 12); they do not appear to fit the Druce and Radke (1979) subdivision of the Laurel Formation.

Anderson Sequence

The Anderson Sequence is equivalent to the Anderson Formation, and is essentially restricted to the Fitzroy Trough. Its seismic character is variable throughout the trough, but generally is recognized as a series of irregular reflections (Figs 4 and 12).

Grant Sequence

The Grant Sequence is equivalent to the Grant Group, and is found over most of the study area. The oil from the Sundown oilfield is produced from this sequence. The sequence was not studied in detail in this investigation. It is commonly incised by large channels that are clearly visible on the seismic reflection records (Figs 4, 5, and 12).

Sea-level fluctuations

Seismic sequence analysis (Mitchum and Vail, 1977) provides an excellent tool for examining local sea-level changes, without any assumptions of causal mechanism. Vail et al. (1977) maintain that eustatic changes exert a dominant influence on sedimentary environments, and thus the source, reservoir, and sealing rocks of hydrocarbon accumulations. Brown and Fisher (1977), however, consider that local tectonic influences play as important a role in causing changes of sea level as eustatic changes.

Playford (1980) and Playford et al. (1989) concluded, from outcrop mapping of the Devonian reef complex rocks on the Lennard Shelf (Fig. 1), that sea-level fluctuations control the reef geometry. They observed a transgressive - regressive - transgressive depositional sequence for the Late Devonian. Seismic sequence analysis of seismic data from localities 1 and 3 (Fig. 1) confirms this observation.

The results of the sea-level analysis carried out for the present study are summarized in Figure 13. Locality 1 (Fig. 1) has the best seismic sequence expression of the localities analysed. The interpretation of a portion of seismic line 1979-10 (Fig. 4) demonstrates:

- (a) two periods of onlap (transgression) during the Frasnian Pillara Cycle of deposition;
- (b) toplap during the regressive Famennian Nullara Cycle of deposition;
- (c) onlap during the transgressive Gumhole Formation deposition;
- (d) excellent examples of toplap and downlap, classic indicators of regression and low sea level, for Yellow Drum Formation deposition;
- (e) a number of periods of onlap during Laurel Formation deposition (see also Fig. 8).

The sea-level analysis is consistent with the observation of Playford (1984) and Playford et al. (1989) that at least two phases of abrupt backstepping (abrupt transgression) of the carbonate platforms occurred during the Pillara Cycle of deposition.

The Canning Basin sea-level curve differs slightly from the Euramerican eustatic curve (Playford et al., 1989), suggesting that tectonic events have been important.

Application

Four stratigraphic play types have been recognized in the Canning Basin (Purcell, 1984): (i) marginal-platform reef plays; (ii) pinnacle reefs; (iii) sand-filled channels of possibly glacial origin in the Grant Group; and (iv) submarine fans possibly containing clastic material.

The Nullara cycle reef expression on seismic data is a trough-on-peak wavelet response with occasional steeply dipping reflections (on migrated data) immediately beneath the trough-on-peak response. The trough-on-peak and dipping reflections are easily detected on good quality seismic data. Also, on good quality seismic data, pinnacle and patch reefs are readily detected (Middleton, 1987c).

Sand-filled channels, as in the Grant Group in the Sundown oilfield, or in the Anderson Formation in the Lloyd oilfield, can be detected by detailed seismic modelling. The channels of the Grant Group are well defined on seismic data (Figs 4, 5, and 12), and detailed modelling may not be necessary to outline the channel banks. However, modelling is suggested to define adequately facies changes within the fluvial environment (Middleton, 1987a).

Submarine fans or turbidite mounds on the platform margin have not been pursued to date as viable hydrocarbon plays (Middleton, 1987a). These are often large features that can be easily mapped seismically (Fig. 11). Coarse clastic input into the basin through these fans is possible as a result of fan deltas, described on the northern margin of the Lennard Shelf (Moors, 1986). Such clastics in a basinal environment can provide an excellent hydrocarbon reservoir.

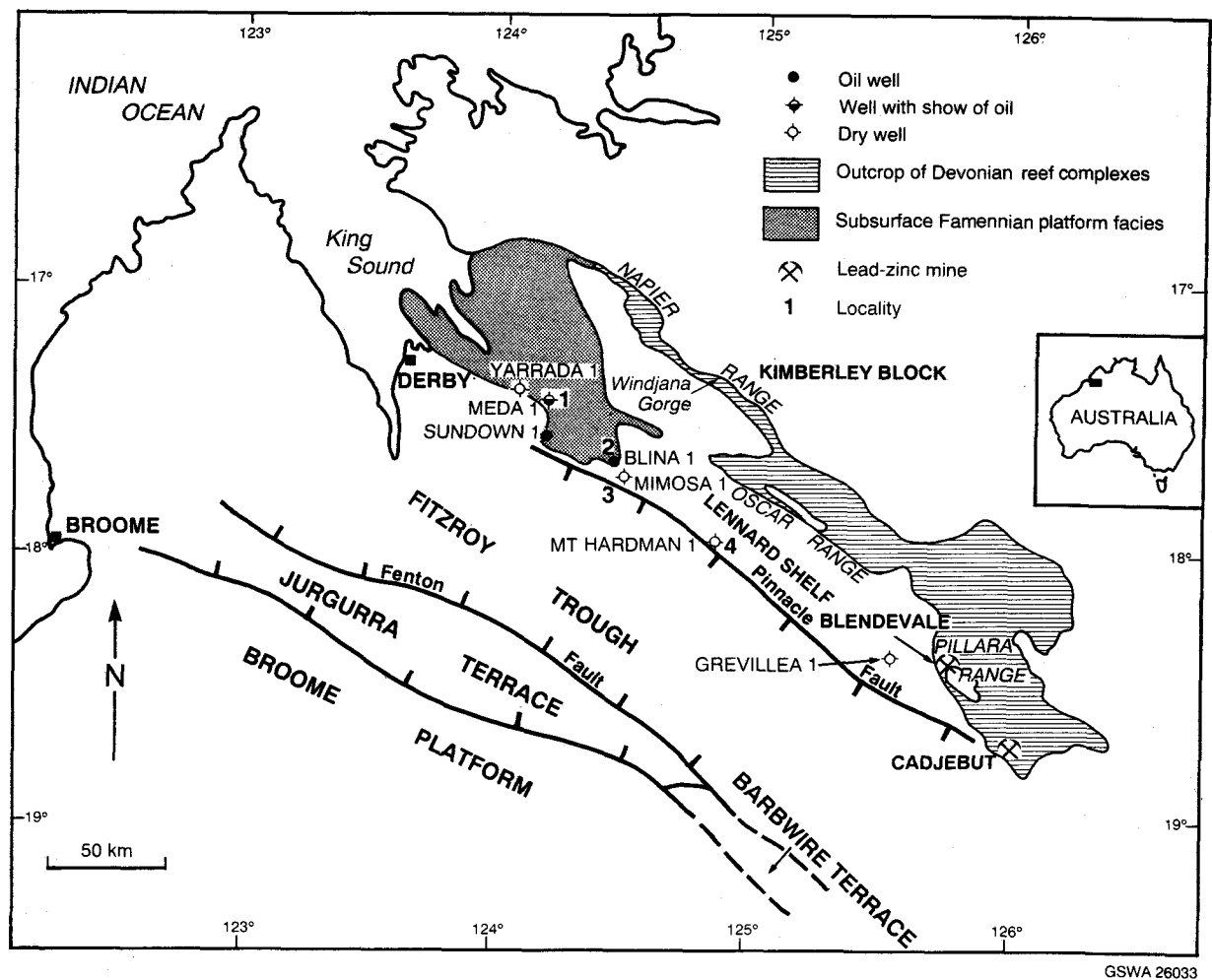
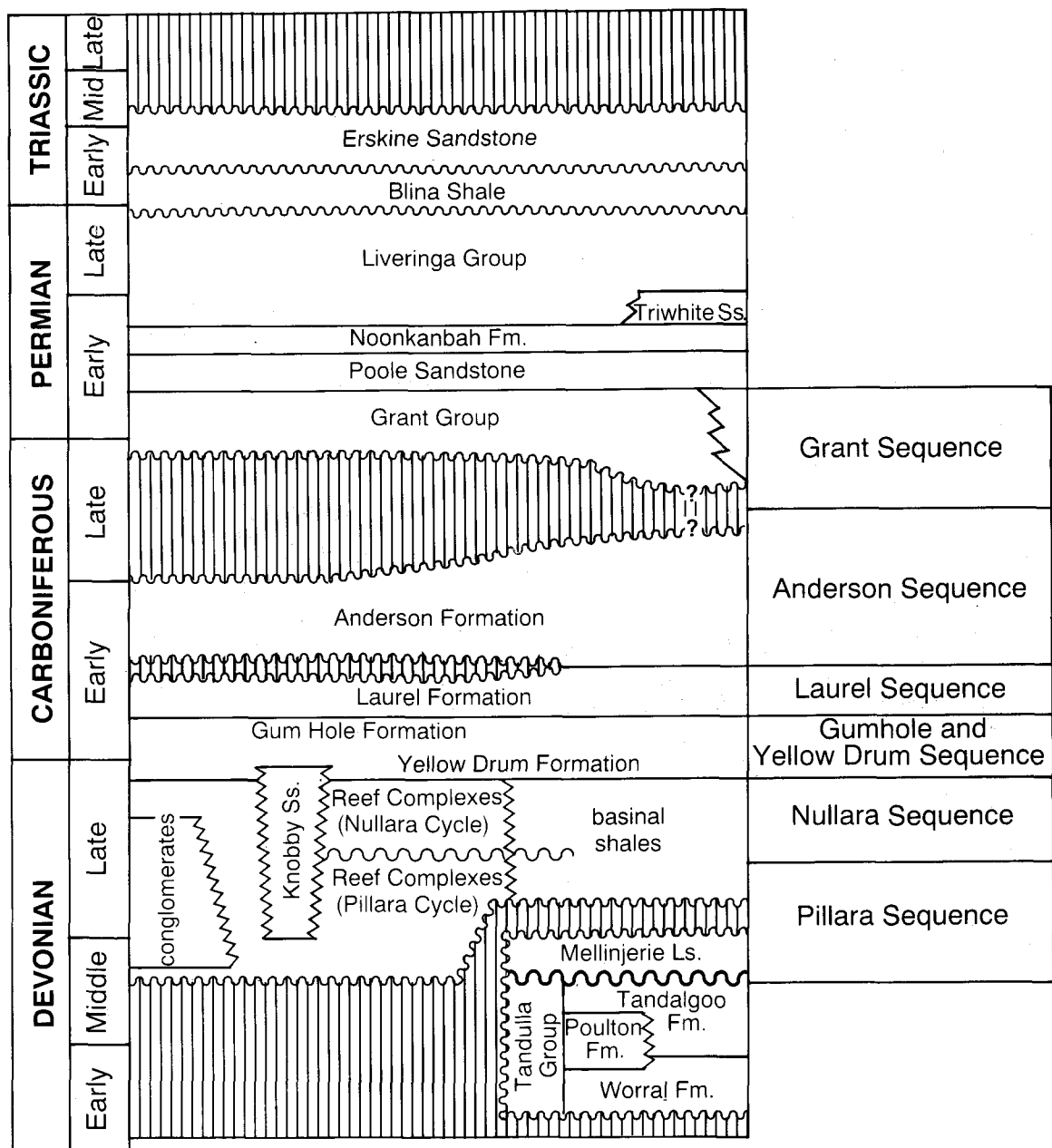


Figure 1. Location diagram showing the northern Canning Basin and localities selected for seismic stratigraphic analysis. Legend for oil wells is the same for all figures.



GSWA 26034

Figure 2. Stratigraphy of the northern Canning Basin.

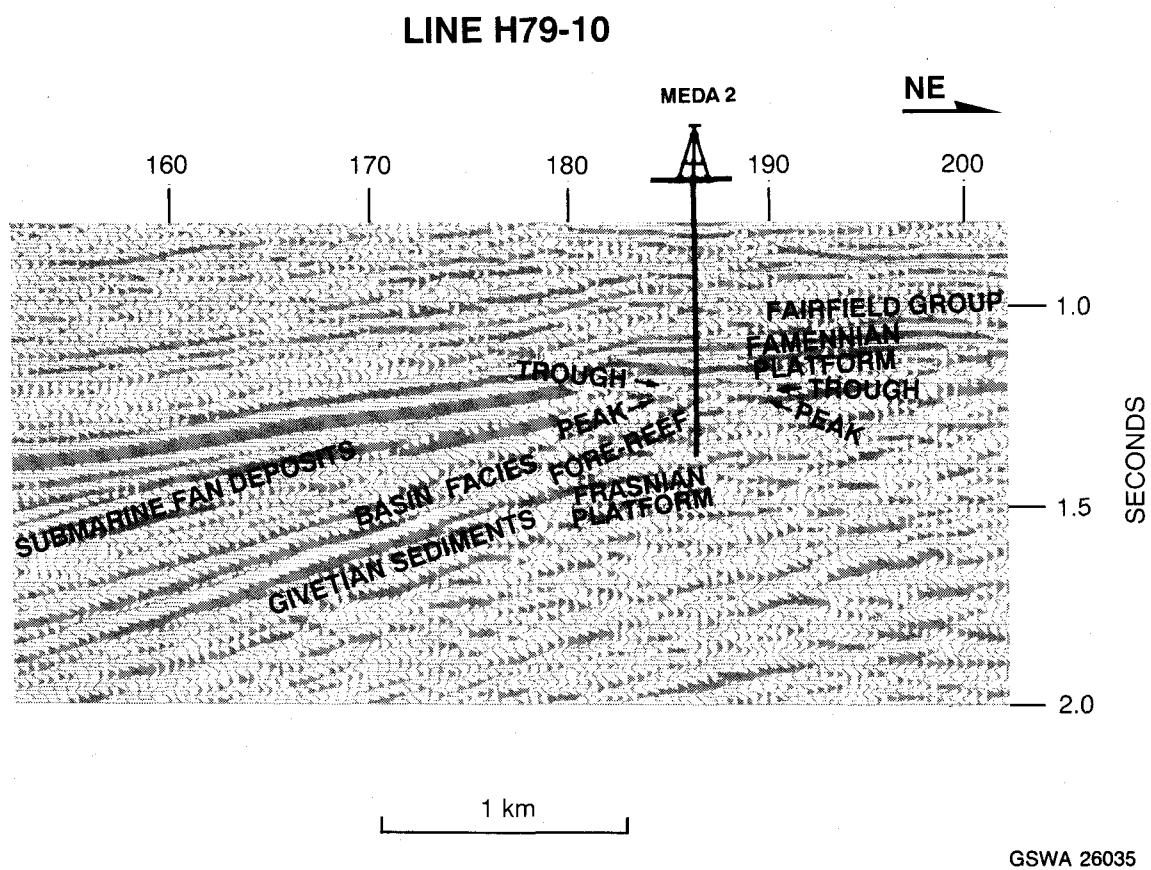


Figure 3. Locality 1, Meda Reef seismic section.

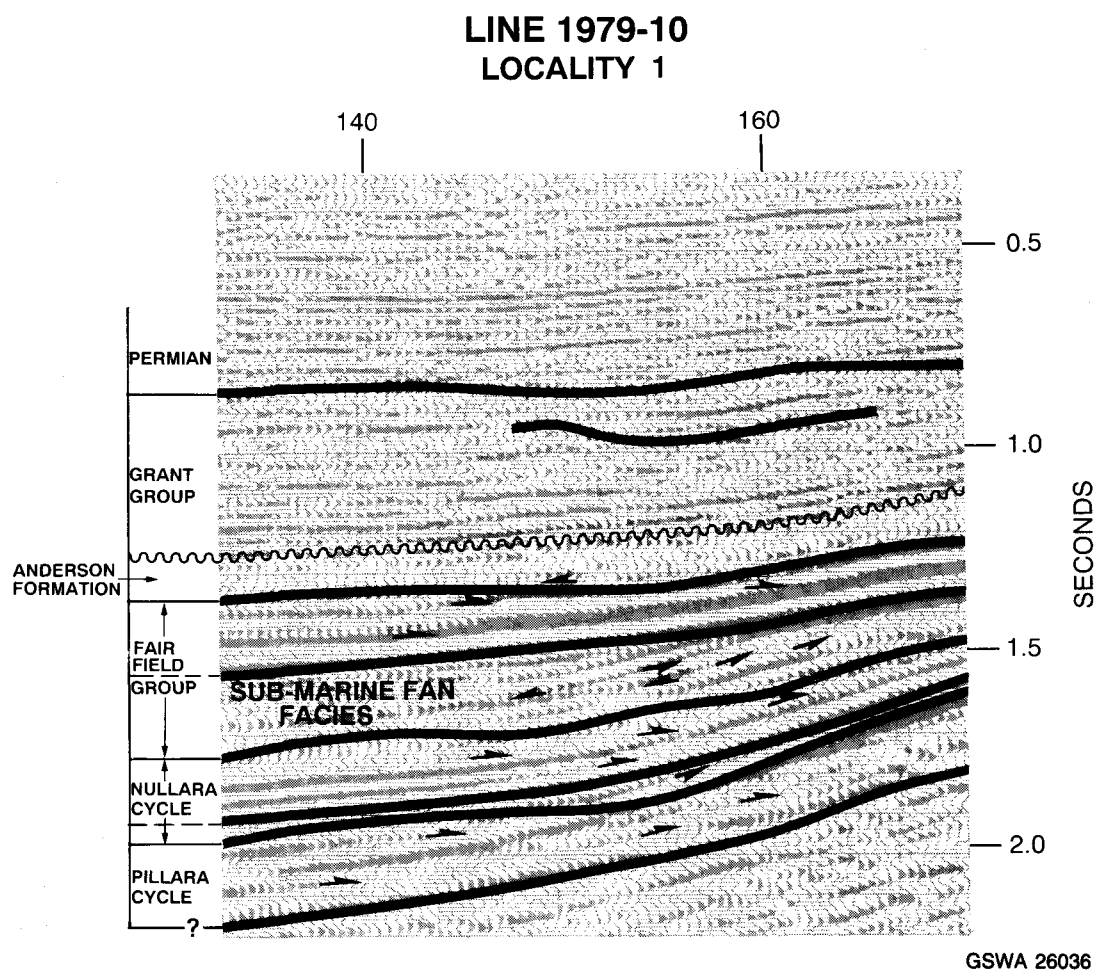


Figure 4. Seismic sequences at Locality 1.

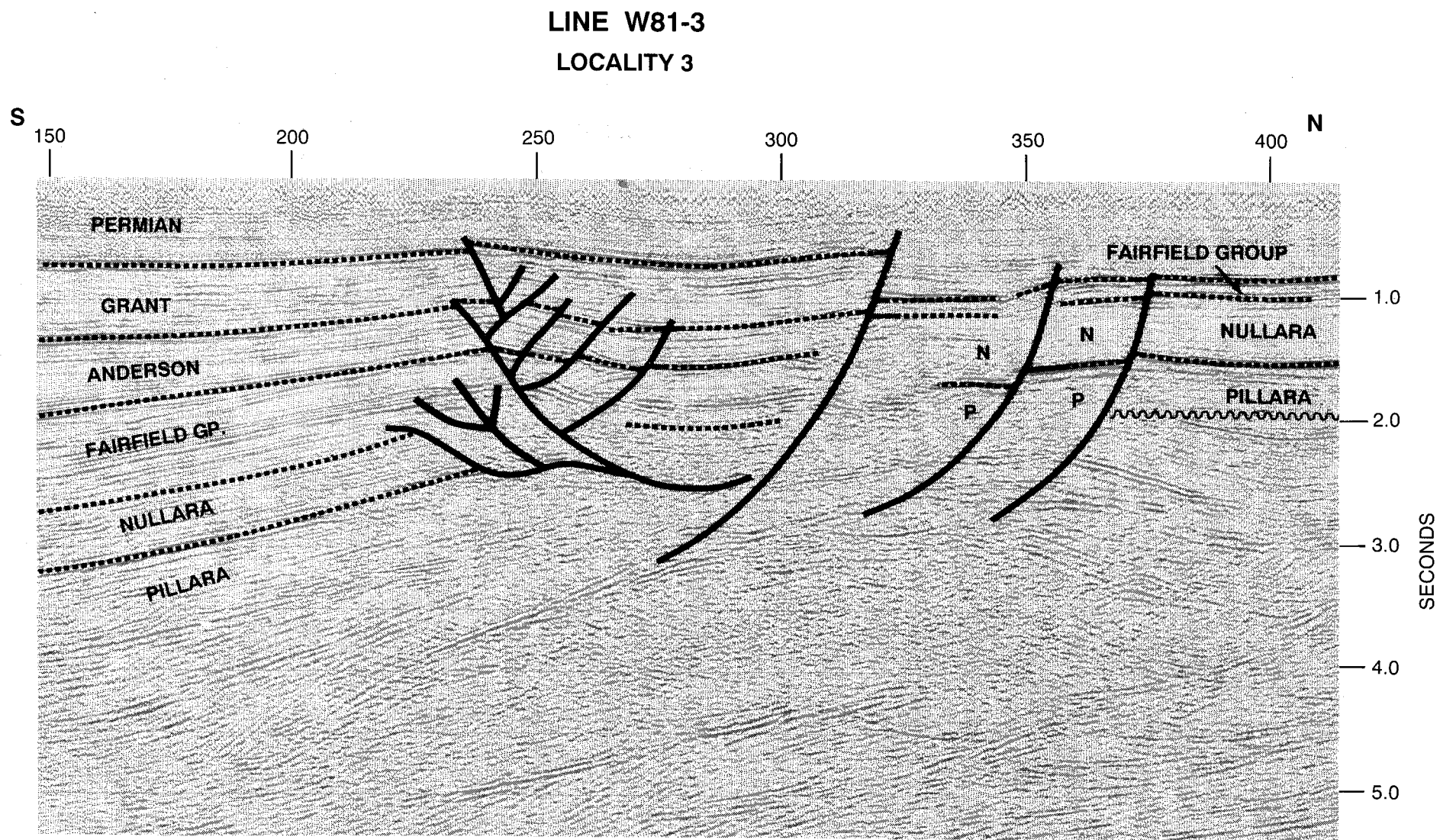


Figure 5. Locality 3, Mimosa area.

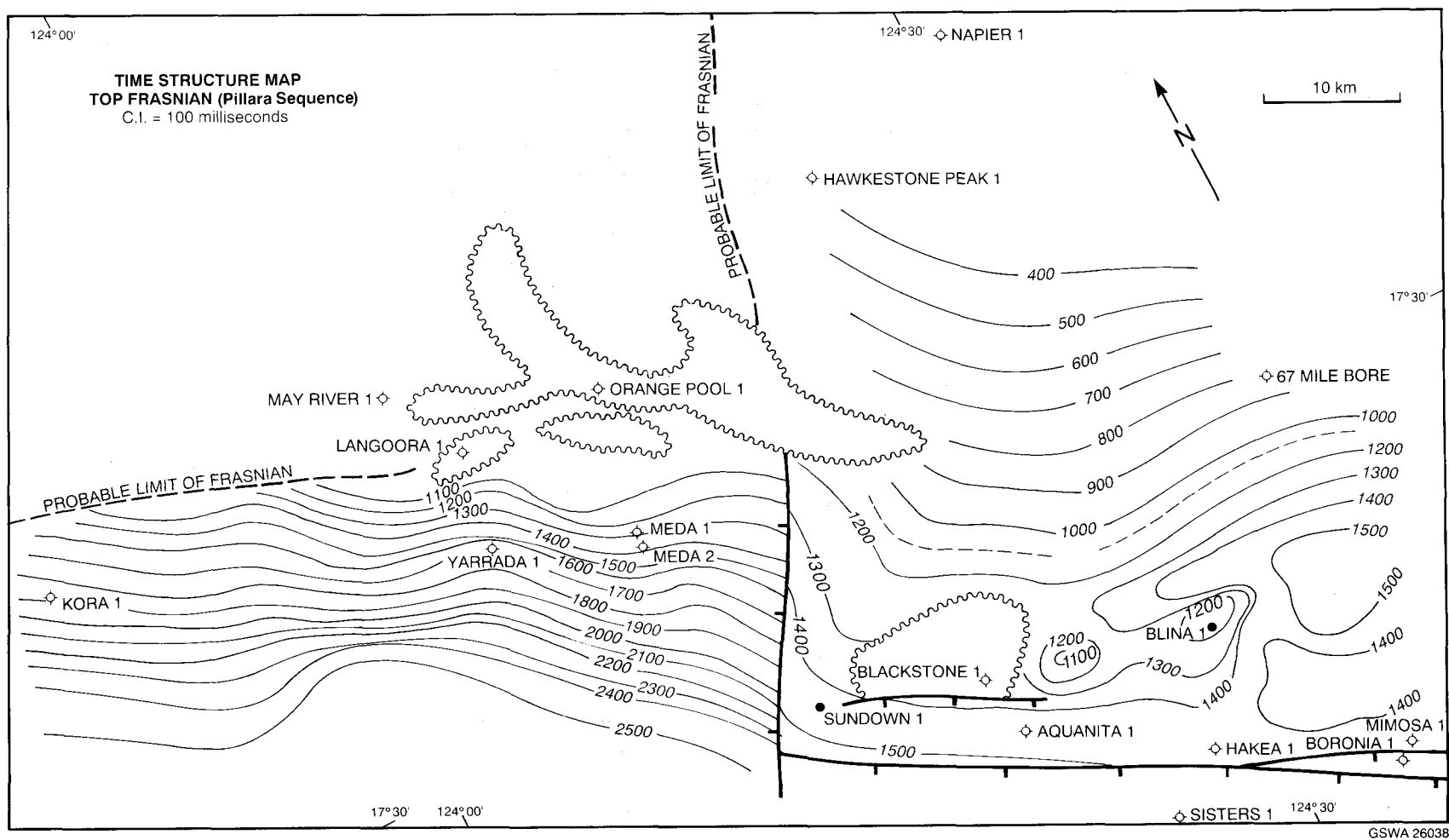
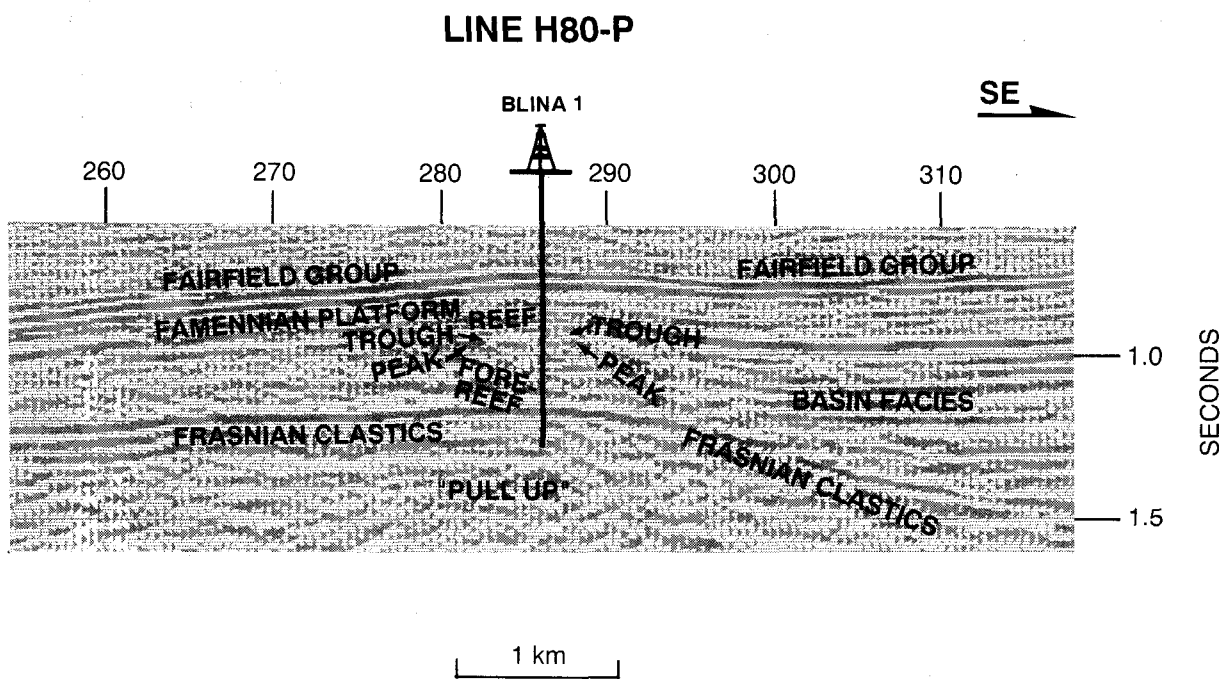
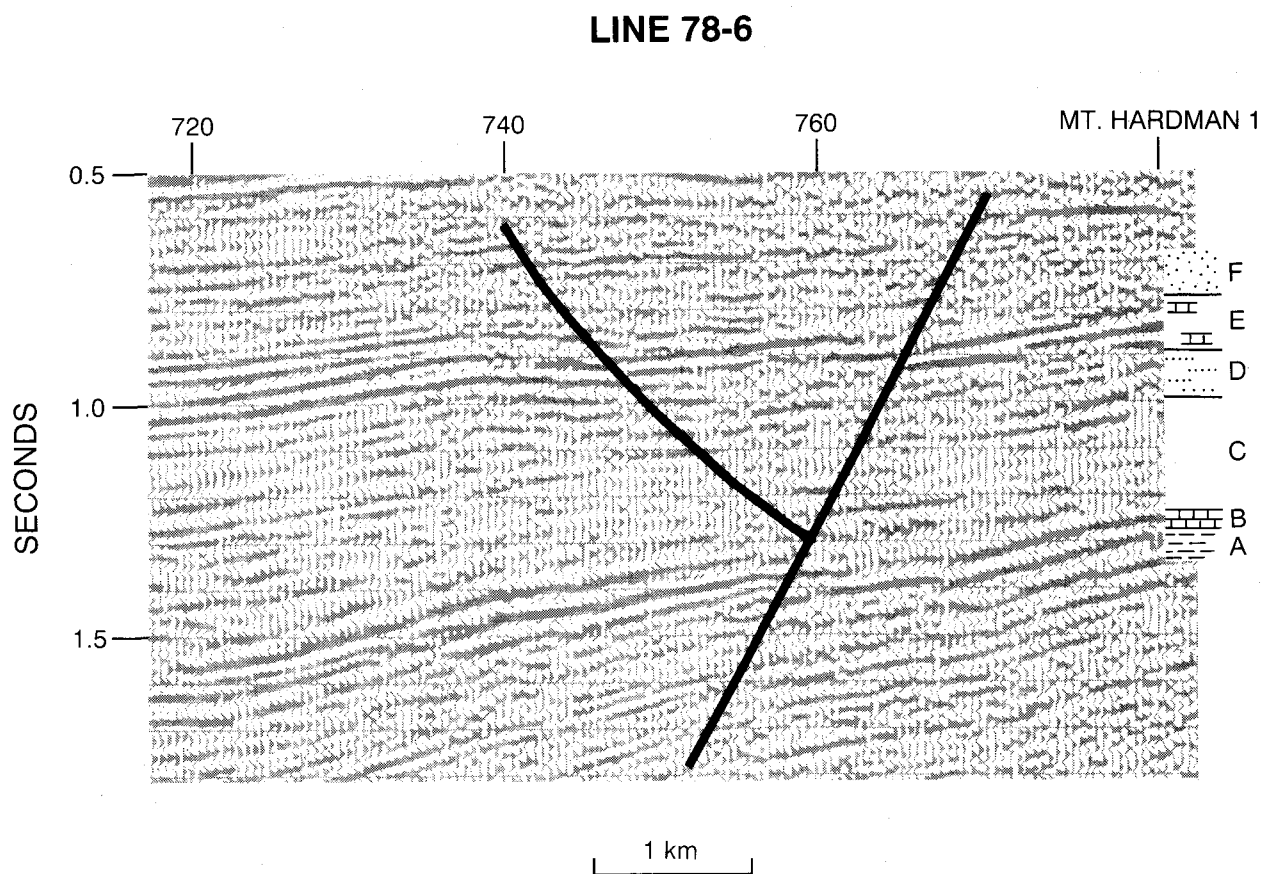


Figure 6. Structure-contour map (time structure) of the Pillara Sequence on the Lennard Shelf.



GSWA 26039

Figure 7. Locality 2, Blina reef.



GSWA 26040

Figure 8. Locality 4, Mt Hardman area.

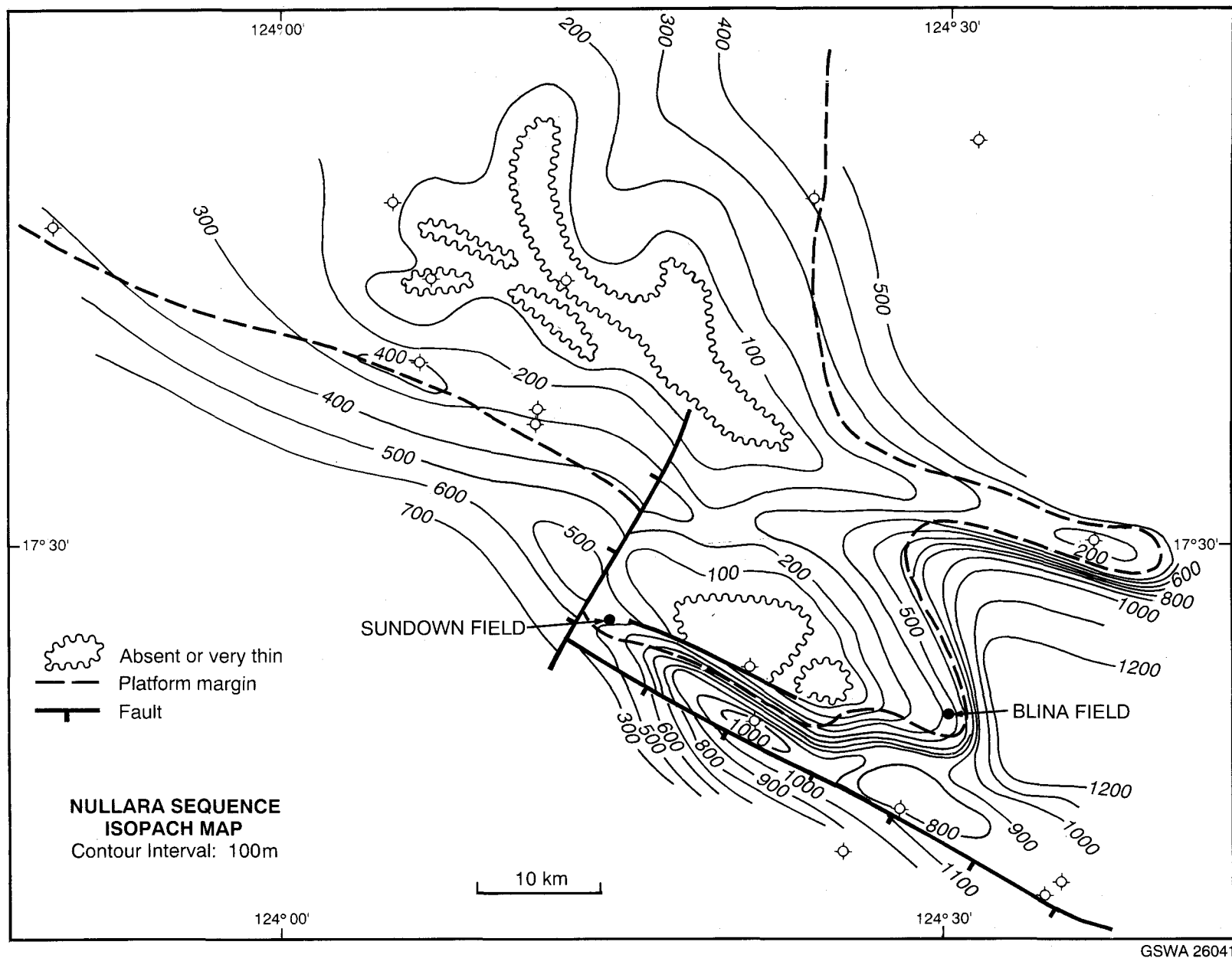


Figure 9. Isopach contour map of the Nullara Sequence on the Lennard Shelf.

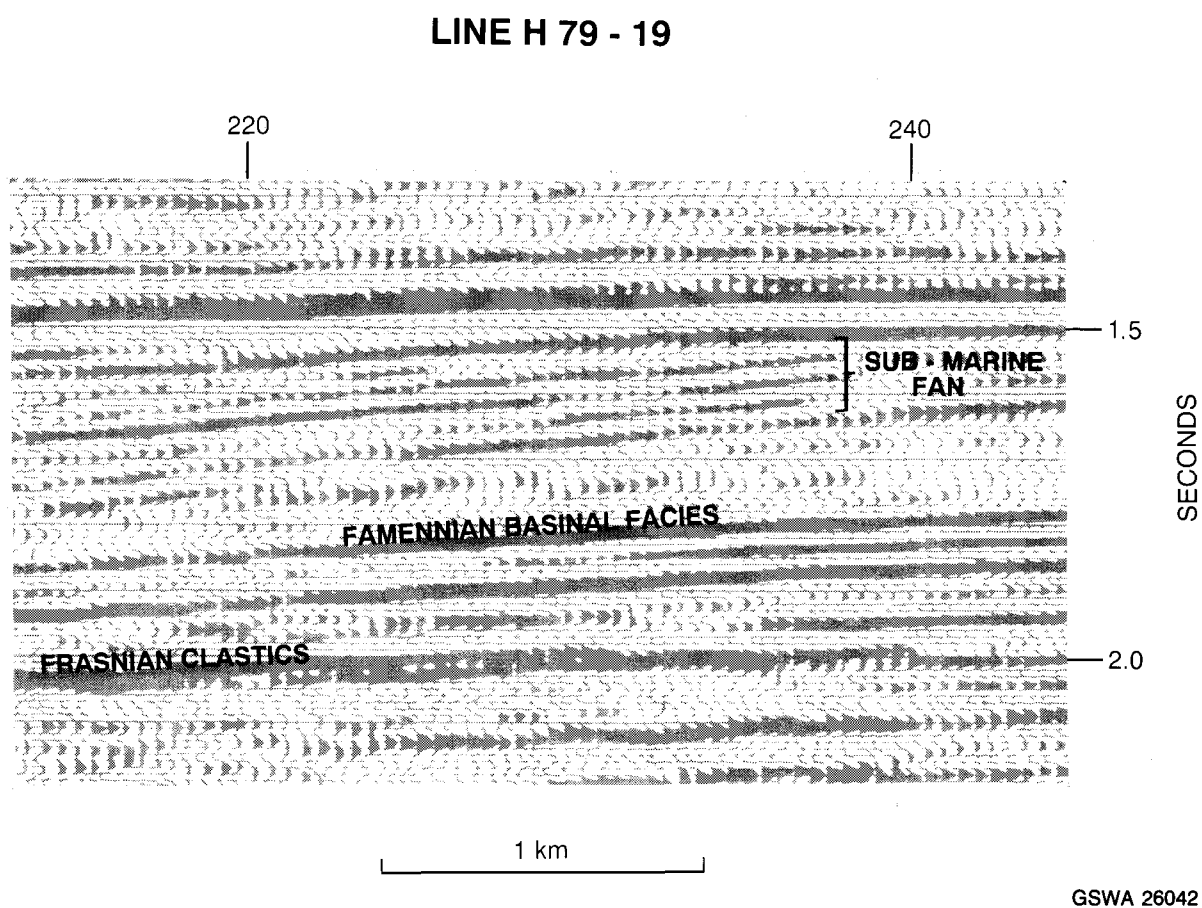


Figure 10. Seismic Line H79-19, Meda submarine fan.

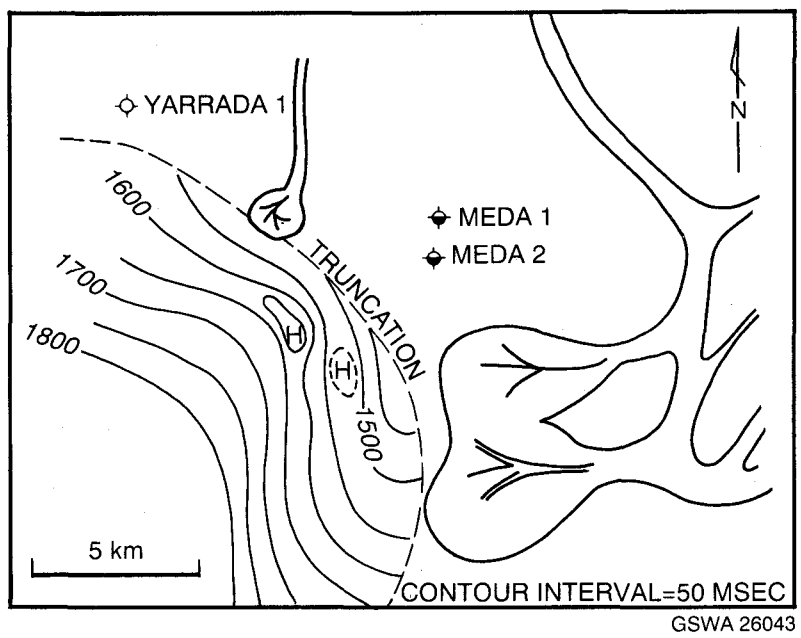
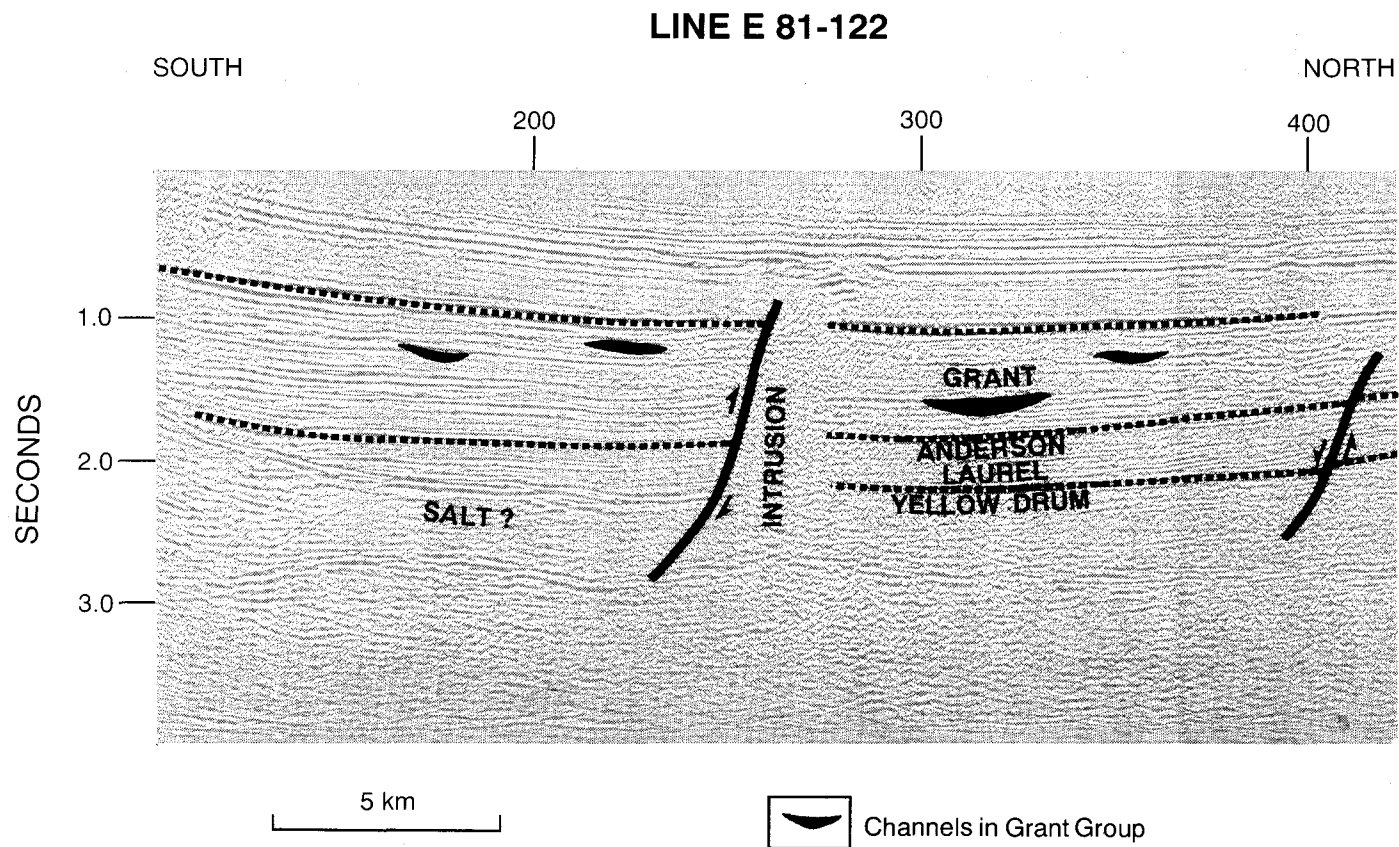


Figure 11. Time-structure map, Meda submarine fan.



GSWA 26044

Figure 12. Example of the reflection character of the Fitzroy Trough seismic sequence, and also intrusive and flowage features.

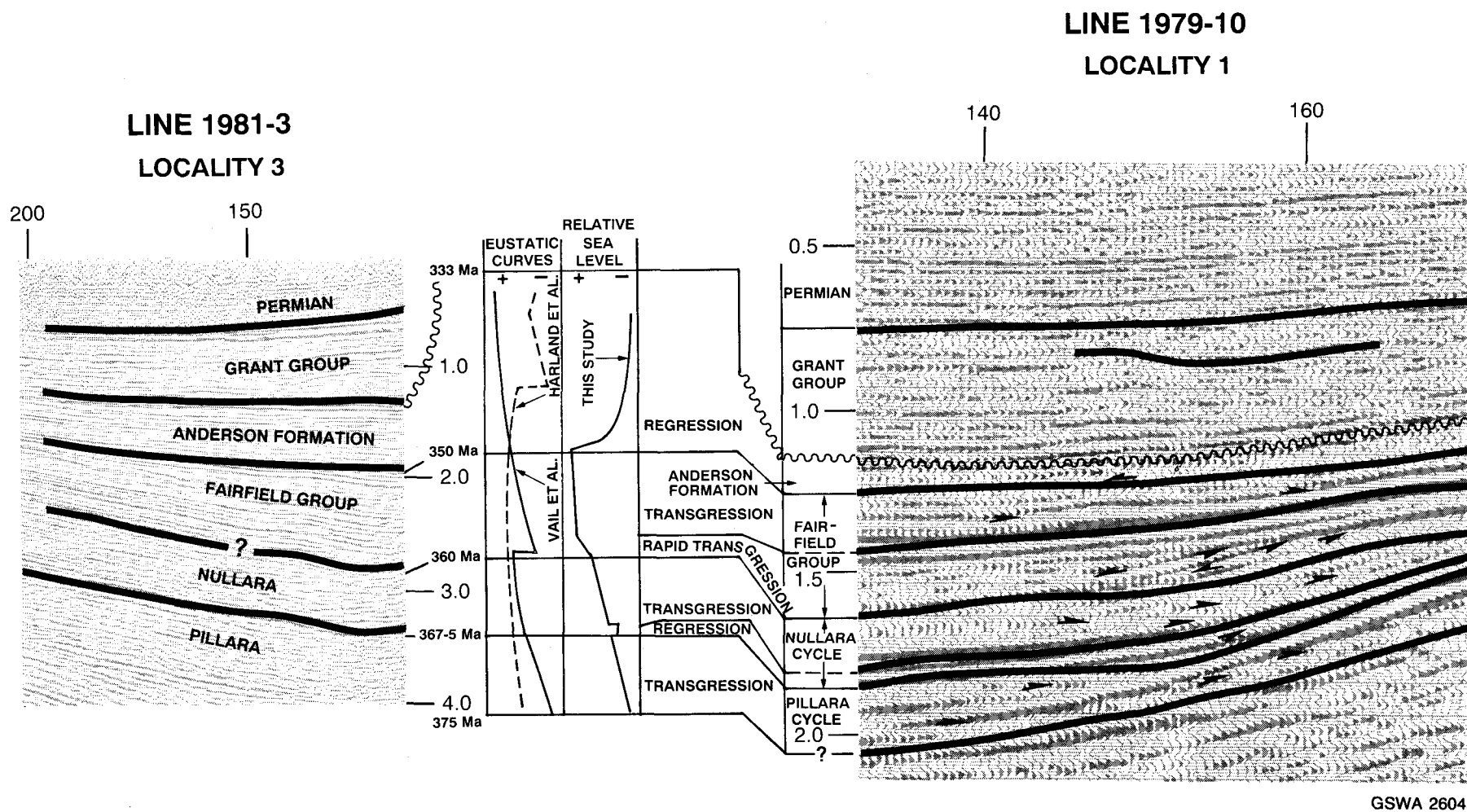


Figure 13. Summary of the sea-level fluctuations, and data from seismic lines 1979-10 and 1981-3.

Part 2. Structural analysis

Introduction

The structural analysis was designed to:

- (i) define the Triassic/Jurassic wrench event in detail;
- (ii) investigate the graben subsidence of the Fitzroy Trough; and
- (iii) obtain sufficient structural detail of the major northern Canning Basin anticlines to determine why they lack oil.

In Part 3, various tectonic models are proposed to explain the geological and thermal histories and economic status of the basin.

A number of specific areas, selected to highlight particular features in the northern Canning Basin, were studied in detail. They fall into three groups (shown on Enclosure 1 and Fig. 1):

- A. Fitzroy Trough margins -
 - (i) Pinnacle Fault, Mimosa area.
 - (ii) Fenton Fault, Grant Range area.
- B. Wrench and intrusive structures -
 - (i) Mt Wynne structure
 - (ii) Grant Range structure
 - (iii) Fraser River structure
 - (iv) Wrench faulting -- central Fitzroy Trough (Yeeda area)
 - (v) Jones Range structure
- C. Structures on the Lennard Shelf -
 - (i) Blina structure
 - (ii) Frasnian structures

Fitzroy Trough margins

Pinnacle Fault System

The Pinnacle Fault System occurs along the northeastern margin of the Fitzroy Trough (Figs 1 and 14), and marks the hinge line between the Lennard Shelf and the trough. The fault system varies from a flexured hinge line with little throw in the northwest to a complex set of faults with throw up to a kilometre or more in the southeast of the study area (Fig. 15). The Triassic - Jurassic Fitzroy movement (Forman and Wales, 1981), a left-lateral wrench event (Rattigan, 1967; Smith, 1968; Rixon, 1978), pushed sediments back up onto the Lennard Shelf - Fitzroy Trough hinge line. Two seismic profiles (Figs 16a and 16b), which cross the hinge line to the northwest of Mimosa 1, show the variable nature of the hinge zone. The main fault in the eastern profile has significantly less throw than that in the western profile.

Maps of time structure on the near-top Grant Group (Fig. 17) and near-top Yellow Drum Formation (Fig. 18) confirm the complex structure of the fault system. Petroleum exploration wells drilled close to the fault system have had little success, with only some shows of oil staining and fluorescence. It is highly probable that any oil generated within the basin sediments leaked along conduits in this complex fault system.

The Pinnacle Fault System does not appear to be a system of major movement in the northwest during the evolution of the Fitzroy Trough in the Late Devonian and Early Carboniferous. This conclusion is supported by the isochron map of the top Yellow Drum Formation to top Frasnian (Fig. 19). The map shows minor fault development, but regionally a gradual increase in thickness across the hinge line.

Fenton Fault System

The Fenton Fault System on the southern side of the Fitzroy Trough is the location of main movement during the formation of the trough (Late Devonian - Early Carboniferous). A seismic profile across the southern margin of the Fitzroy Trough near the Myroodah area (Fig. 20) implies that the Fitzroy Trough formed essentially as a half graben. This will be discussed further in Part 3. The

throw of the Fenton Fault may be 6 km or more in the northwest. In the southeast the geometry of the fault system approaches that of a hybrid flexured-faulted margin. This effect is probably due to considerable fault reversal, and salt/shale flowage up the fault at Frome Rocks 1 and other localities, resulting from the Triassic - Jurassic wrench movement. The actual throw on the fault is difficult to determine, because correlation of seismic horizons is difficult in the structurally complex region; only the near-top Frasnian horizon can be mapped with any reliability in the Jones Range area. It is important to note that in the southeastern part of the study area, there are strong growth faults both on the north and south sides of the Fitzroy Trough.

Maps of the structure of the fault system are given in Figures 21 and 22, which show the near-top Grant Group and near-top Yellow Drum Formation, respectively. Most of the complex structure on these maps is due to the wrench event, which produced the Myroodah Anticline and salt mobilization in the Frome Rocks area. Little good-quality seismic data could be obtained in the vicinity of the Grant Range Anticline, presumably due to structural complexity caused by the wrench event.

Wrench and intrusive structures

Mt Wynne structure

The Mt Wynne structure is in the centre of the Fitzroy Trough (Encl. 1), and was drilled by Freney Oil Co. in the early 1920s; asphalt and bitumen were reported in cores, but no commercial oil was found. The structure has two approximately circular culminations in outcrop, where the Grant Group is exposed in the core of the culminations. It is an excellent example of a wrench-induced anticline, with the structure itself appearing to be caused by salt and/or shale mobilization rather than lateral displacement.

Time-structure maps of the near-top Grant Group and near-top Yellow Drum Formation are shown in Figures 23 and 24, respectively. It is virtually impossible to map the Yellow Drum Formation over the culmination of the structure due to the loss of observable reflections. Some data are mappable over the culmination for the near-top Grant Group horizon. However, the mapping

shows the structure is elongate in a northwesterly direction rather than simply circular as suggested in outcrop.

The nature of the Mt Wynne intrusion can be determined from magnetic and gravity data. The structure has no magnetic signature, and it must be concluded that it is caused by salt or shale diapirism. An associated gravity - seismic feature, which does not appear to have a magnetic signature, occurs on Wapet seismic line 1972-35 (Fig. 25).

Gravity modelling of both the Mt Wynne structure and the associated feature on line 1972-35 is shown in Figure 26. The modelling shows convincingly that Mt Wynne is cored by a narrow salt diapir. The associated feature appears to be caused by an igneous intrusive body. There are insufficient magnetic data to adequately define the intrusive body, although the magnetic low in Figure 25 is probably related to it.

Grant Range structure

The Grant Range structure is a large east-trending anticline in the centre of the Fitzroy Trough. It is one of a group of anticlinal structures with this trend caused by the wrench movement. The Grant Range and St Georges Range anticlines are the two most spectacular of these structures; both have strongly faulted Grant Group exposed in their cores. Intrusive activity was a minor feature of these two anticlines, and they therefore differ from the Mt Wynne structure.

Seismic coverage over the culmination of the anticline is poor. Contours on the flanks of the structure to the south are shown in Figures 21 and 22, and to the north in Figures 27 to 29. The anticline is structurally simpler on the northern flank than on the southern flank. The many faults with small throw, seen in outcrop, cannot be mapped on seismic because of the lack of resolution of faults with less than about 20 m throw.

Fraser River structure

The Fraser River structure (Encl. 1) was formed by the intrusion of basic igneous rocks of Permian age.

The structure may have been accentuated during the Triassic - Jurassic wrenching of the Fitzroy Trough. Reeckmann and Mebberson (1984) have discussed the igneous activity, and presented thermal data from Fraser River 1, which is modelled below.

Vitrinite reflectance - palaeogeothermal models can be used to determine physical characteristics of the Fraser River intrusion. In the case of heating by intrusion, a relationship between vitrinite reflectance and the temperature to which a rock near the intrusion was exposed, has been demonstrated by Middleton (1982). An equation relating maximum temperature T_m at a distance x from the edge of an intrusion with initial temperature T_i and thickness of the intrusion W , is given by Goguel (1976):

$$T_m = T_0 + (T_i - T_0) \left[\frac{\operatorname{erf}\left\{\frac{(z+e)^2}{2}\right\} \ln\left[\frac{(z+e)}{(z-e)}\right]}{2ez} - \frac{\operatorname{erf}\left\{\frac{(z-e)^2}{2}\right\} \ln\left[\frac{(z+e)}{(z-e)}\right]}{2ez} \right]$$

where T_0 is ambient temperature, $e = W/2$, $z = x + W/2$ and erf is the error function.

Figure 30 shows the vitrinite reflectance profile at Fraser River 1 (Reeckmann and Mebberson, 1984) and the corresponding maximum temperatures from the relationship of Middleton (1982). Assuming an ambient temperature T_0 of 110°C and observing that the maximum temperature at the contact is 480°C (Fig. 30), the above equation gives the intrusion temperature to be 850°C. Observing also that the aureole affected by heating from the intrusion is approximately 300 m wide, the above equation gives an intrusion thickness W of 3 km.

This estimate is supported by gravity modelling of the structure (Fig. 31) which suggests that a 2.5 km-thick near-circular body of density about 2.9 g/cm³ is buried at a depth of 5 km, and has a radius of approximately 20 km. The

calculated width of the intrusive body of 20 km is consistent with the dimensions of the Fraser River anticline as observed on company seismic data.

Wrench faulting -- central Fitzroy Trough

Northeast-trending faults with throws varying from 0.1 seconds (200 m) to 0.3 seconds (600 m) are commonly observed on seismic reflection data in the Fitzroy Trough away from the major strongly deformed anticlinal features. Figures 27 - 29 show maps of the near-top Grant Group, near-top Anderson Formation, and near-top Yellow Drum Formation in a region of the Fitzroy Trough south of King Sound (Yeeda area).

The near-top Yellow Drum Formation time-structure map (Fig. 29) shows regions of submarine fan development from the northern margin of the Fitzroy Trough, and a large zone of deformation probably due to salt or shale flowage (Fig. 12). The zone of salt/shale flowage is also visible on the Anderson Formation horizon (Fig. 28) but is restricted to two small zones associated with fault planes.

The western part of the mapped area in Figures 27 - 29 is severely deformed and events could not be reliably mapped. The deformation is probably due to massive salt or shale flowage activated by the wrench event.

Jones Range structure

The Jones Range structure (Fig. 32) is a large anticline abutting the Fenton Fault in the southeast of the study area. The structure is similar to the Myroodah structure and is caused by the Triassic - Jurassic wrench movement. The most recent seismic reflection data over the structural culmination were acquired in 1973, and the quality is sufficiently poor in places to make correlation from the Jones Range 1 well almost impossible over the whole structure. A map has been made of a near-top Frasnian horizon (Fig. 32), which is not fully reliable on the western side of the apparent reverse fault in the trough. The Fenton Fault is a dominant feature and the throw at the Frasnian level is about 2 seconds (about 4000 m) away from the culmination of the anticline. Also, the horizons equivalent to the top Yellow Drum Formation, top

Famennian, and top Carribuddy Group can be clearly identified on seismic sections over most of the Barbwire Terrace to the south of the Fenton Fault.

The Jones Range structure is coincident with a major gravity high and magnetic feature. Figure 33 shows the Jones Range gravity anomaly and interpretative model. The structure appears to have a high density core (approximately 3.0 g/cm^3) which is probably igneous in nature. Vitrinite reflectance data from Jones Range 1 suggest that the igneous rocks form basement rather than being intrusive. Using the method described by Middleton (1982), the average palaeogeothermal gradient is approximately 35°C/km , effectively the world continental average gradient. It is probable that Jones Range has not received abnormally high heat flow since the Carboniferous.

Structures on the Lennard Shelf

Blina structure

A seismic section (Fig. 7) across the Blina oilfield shows the nature of the structure. The field is small, with total recoverable oil in the order of 100 000 kL (90% probability). The reservoirs are in the Yellow Drum Formation and Nullara Limestone. Moors et al. (1984) show that there appears to be no time-structural closure on the Yellow Drum Formation horizon (Fig. 18), but good closure on the top Nullara Limestone horizon (Fig. 9). A time closure of the Yellow Drum horizon may appear after detailed velocity analysis, or the seal may be stratigraphic to the east.

The Nullara Limestone reservoir is in a zone of limestone with secondary porosity, and the trap is partly stratigraphic.

Frasnian structures

Based on studies of the outcropping Devonian rocks on the northern margin of the Lennard Shelf, Playford (1980) observed that a brief period of emergence of the platform carbonates occurred at the end of the Frasnian. Evidence of Frasnian tectonism can be found at a number of localities in the subsurface. The tectonism is confined to a narrow zone of uplift about 30 km wide, surrounded

on either side by Famennian reef development, and dies out towards the northern margin of the Lennard Shelf, where there is a relatively minor unconformity on the Frasnian - Famennian boundary.

The seismic line through Yarrada 1 (illustrated in Middleton, 1987b) depicts the unconformity between the Famennian and Frasnian. The Famennian reefal buildup can be seen accumulating on steeply dipping Frasnian beds. A further example of the late Frasnian tectonism is seen on seismic line 82-177 (Fig. 34), where faulted Ordovician to Frasnian sediments are overlain by horizontal Famennian strata. Similar structural deformation can be interpreted from seismic data from Puratte 1, northwest of King Sound, and can be seen as far east as Grevillea 1 (Fig. 1).

This Frasnian tectonism is probably related to the central Australian Alice Springs Orogeny. Drummond et al. (1988) and Begg (1987) have suggested that such tectonism is related to extension of the lithosphere (after McKenzie, 1978). While extension of the lithosphere is a possible mechanism, the classic case of numerous tilted fault blocks dipping into the basin is not clearly observed. Furthermore, the extensive transfer fault-systems proposed by Begg (1987), do not extend into the outcrop regions. An alternative tectonic model, to explain the tectonism in the narrow band along the northern margin of the Fitzroy Trough and possibly along the Broome Platform, is proposed in Part 3.

It is important to note that these structures are not directly related to the major bounding faults of the Fitzroy Trough. Figures 16 and 34 illustrate the relationship between the Frasnian faulting and the Pinnacle Fault.

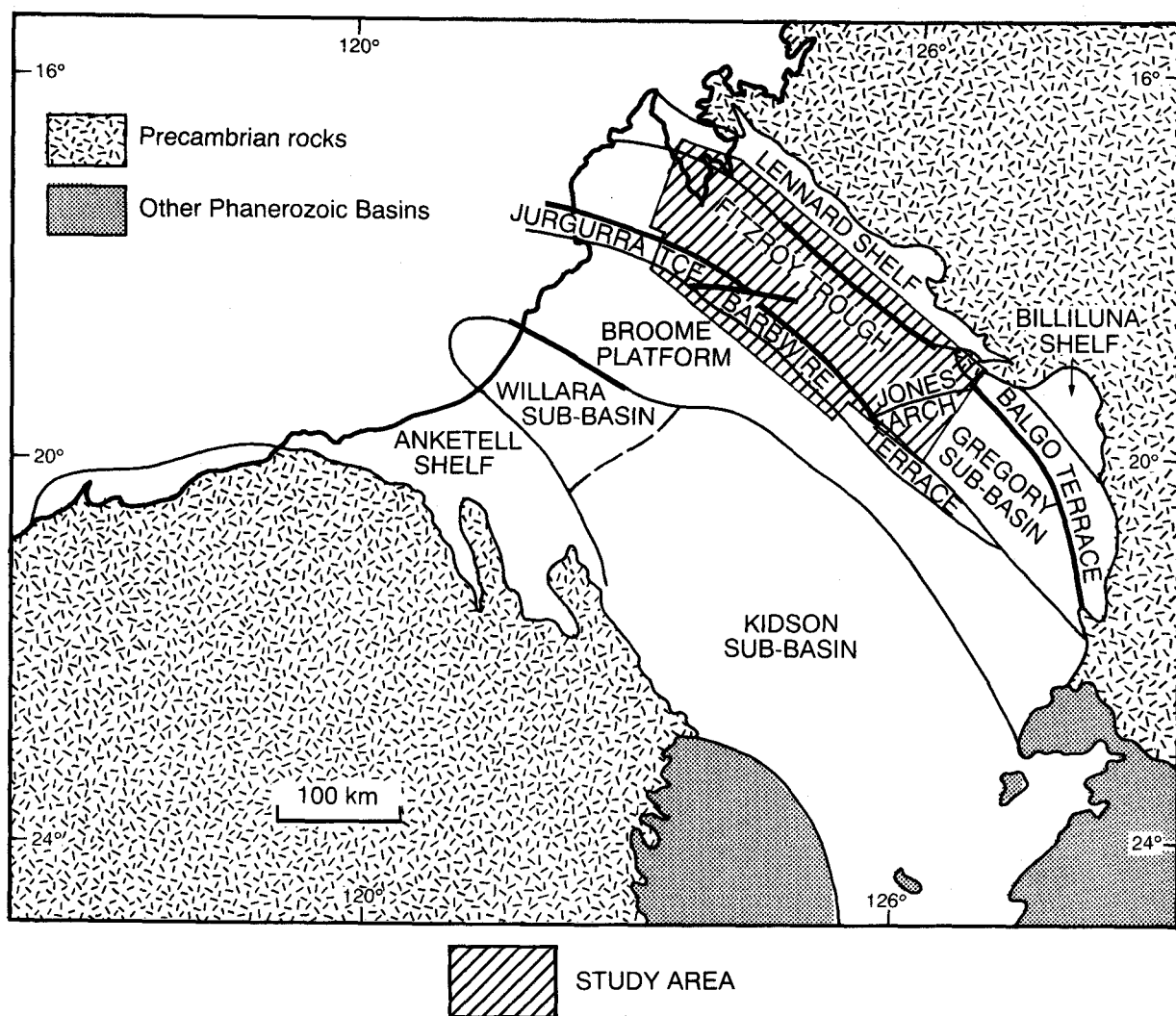
Mineralization and fault zones

Recent base-metal exploration on the Lennard Shelf has led to the discovery of significant lead - zinc deposits associated with the Upper Devonian reef complexes (Murphy et al., 1986; Isles et al., 1987). Mineralized zones appear to be associated with brecciated fault systems. This offers the potential to locate possible mineralized zones using the seismic reflection technique.

Brecciated fault zones are known to have an observable seismic response under certain conditions (Anstey, 1986). These conditions are essentially that (i)

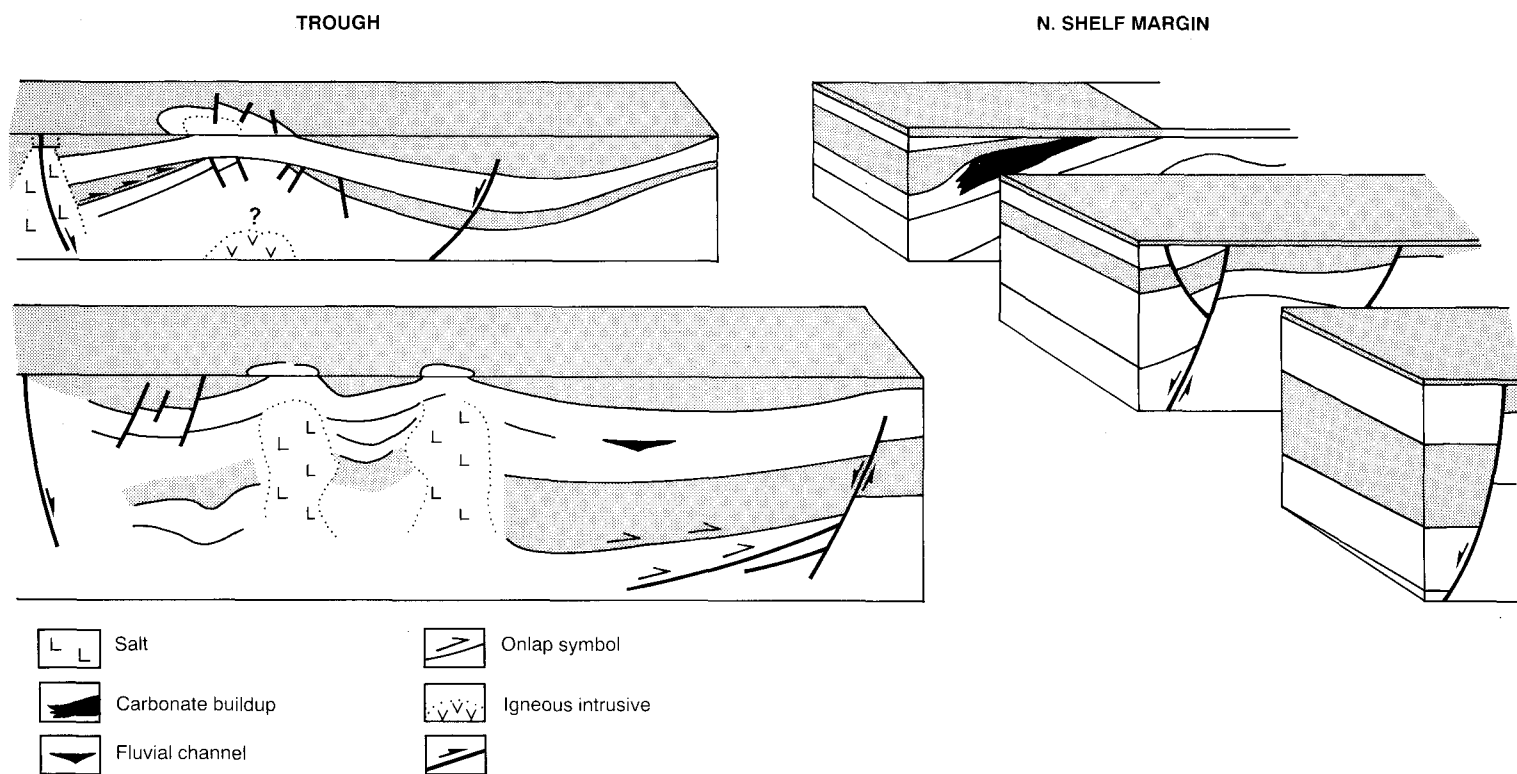
the rocks involved have an observable acoustic impedance; (ii) the brecciated zone is within the resolution bandwidth of the survey; and (iii) the seismic field parameters are set appropriately. Item (iii) is beyond the scope of this discussion, but essentially implies that the spread, length, and direction of shooting are appropriate.

Figure 35 shows a model of a fault zone that has no mineralized zone, and a model of a fault zone with a mineralized brecciated zone. The mineralized segment stands out distinctly, shown as high-amplitude reflection events along the fault plane. For comparison with these models, seismic profiles of fault zones on the Lennard Shelf are given by Purcell and Poll (1984), and fault zones on the southern margin of the Fitzroy Trough are shown by Middleton (1990). Isles et al. (1987) showed seismic data over the Blendevale mine which support the modelling results that 'bright spots' can occur because of lead - zinc mineralization. Clearly, the modelling shows that mineralized zones can be detected by seismic reflection, and data presently available show possible mineralization at depth on some fault zones.



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Figure 14. Main structural features in the study area of the northern Canning Basin.



GSWA 26047

Figure 15. Schematic block diagram of gross structural features in the northern part of the study area.

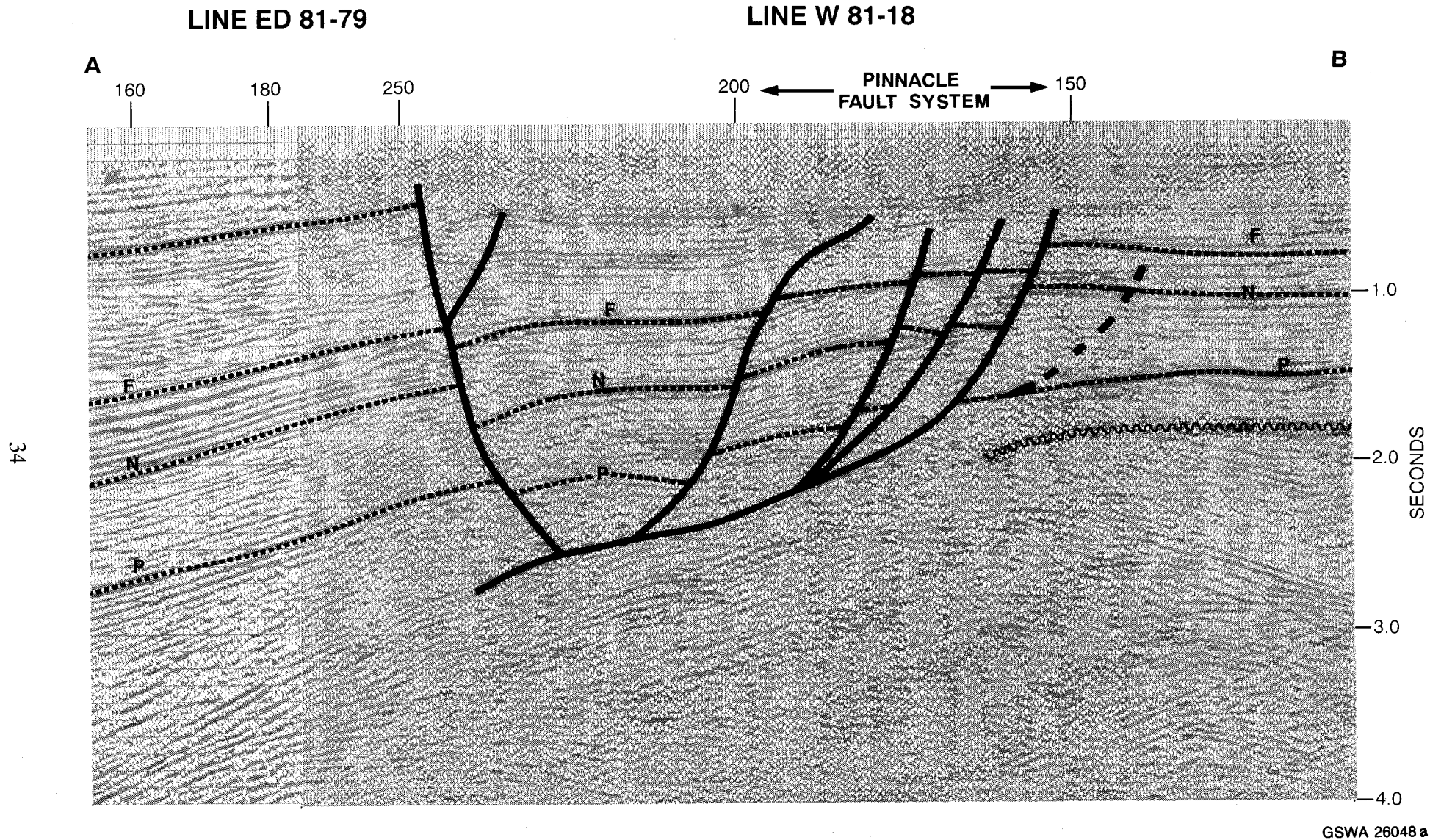
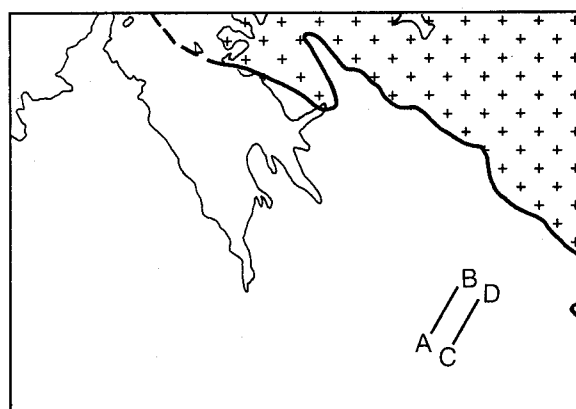


Figure 16(a). Seismic profiles over the Pinnacle Fault System in the Mimosa area. Cross-section A - B. See Figure 16(c) for location and legend.



LOCALITY MAP

CORRELATION

F : TOP FAIRFIELD GROUP

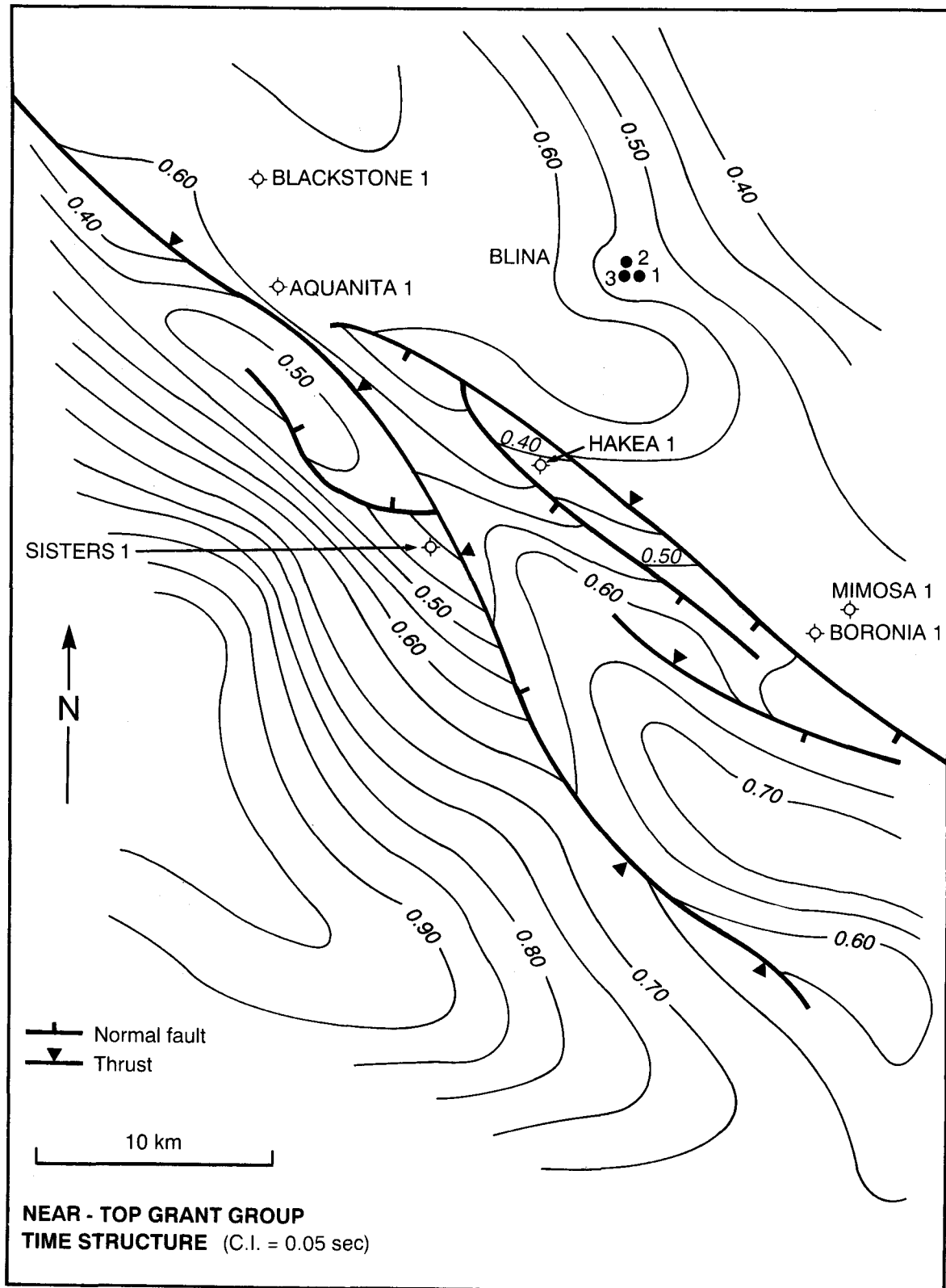
N : TOP NULLARA SEQUENCE

P : TOP PILLARA SEQUENCE

~~~~~ : MID - FRASNIAN UNCONFORMITY

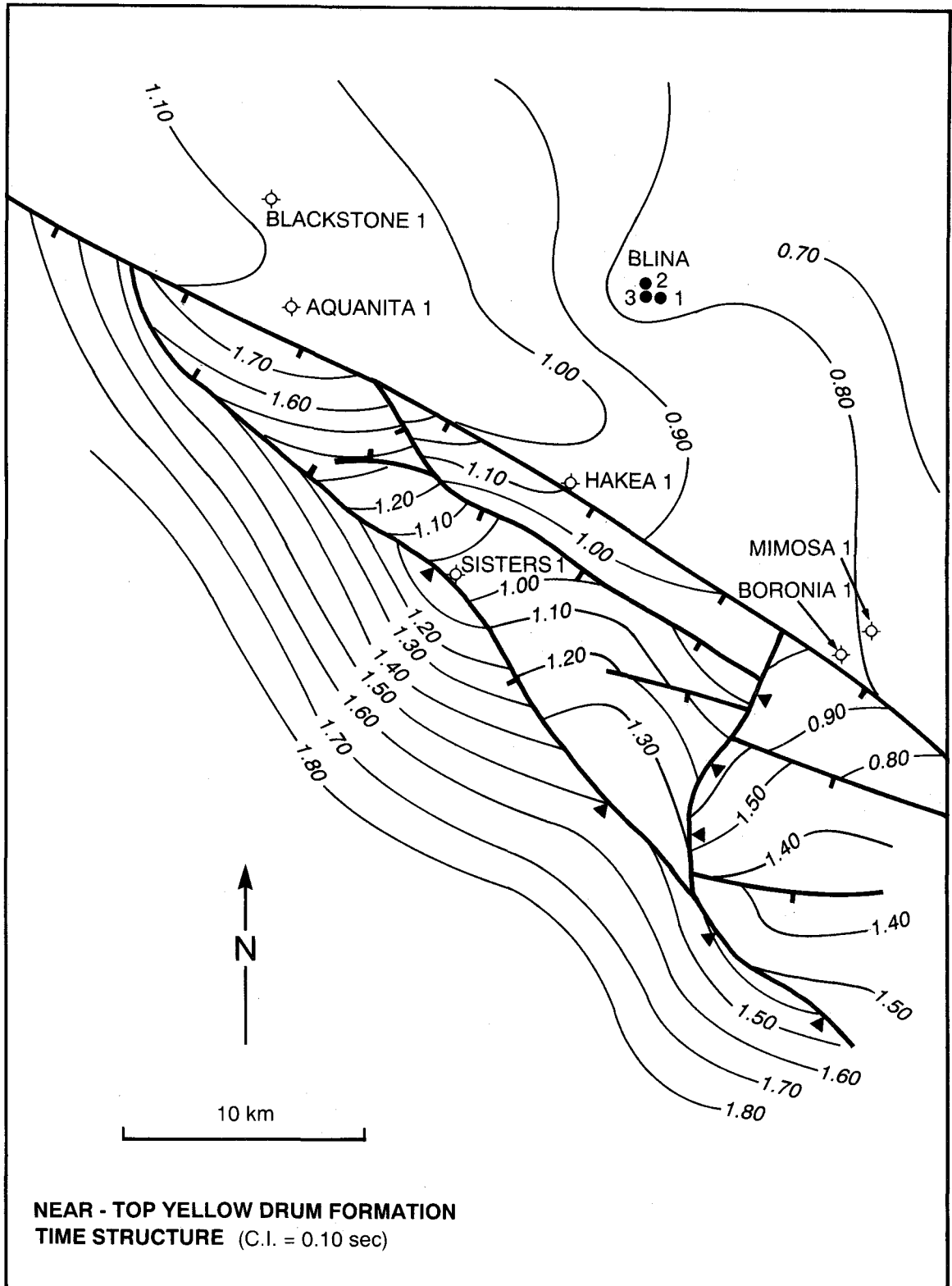
100 km

Figure 16(c). Locality map and legend for cross-sections A - B and C - D, shown on Figures 16(a) and 16(b).



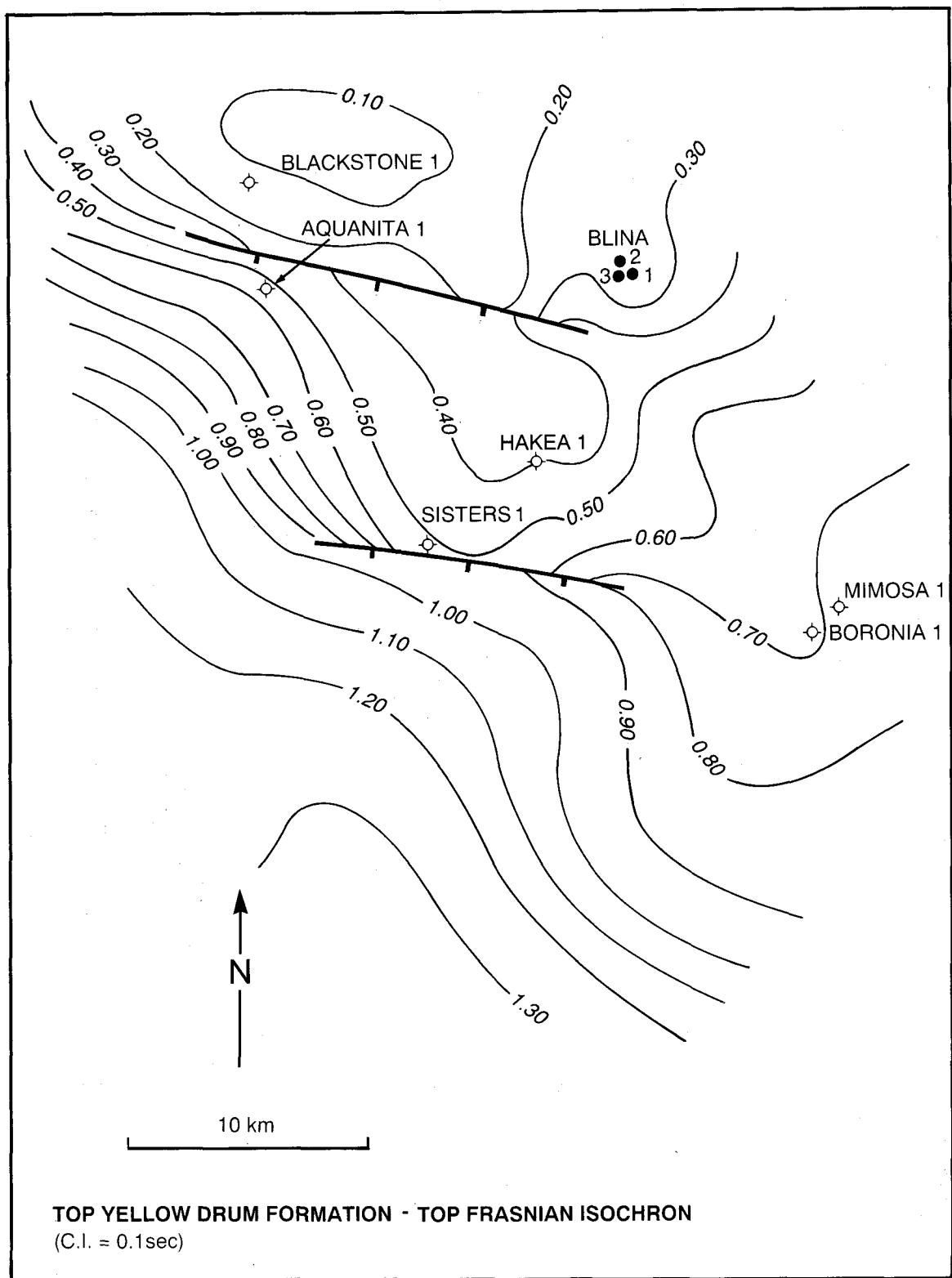
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Figure 17. Time structure: near-top Grant Group, Mimosa area.



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Figure 18. Time structure: near-top Yellow Drum Formation, Mimosa area.



GSWA 26051

Figure 19. Isochron map: top Yellow Drum Formation to top Frasnian, Mimosa area.



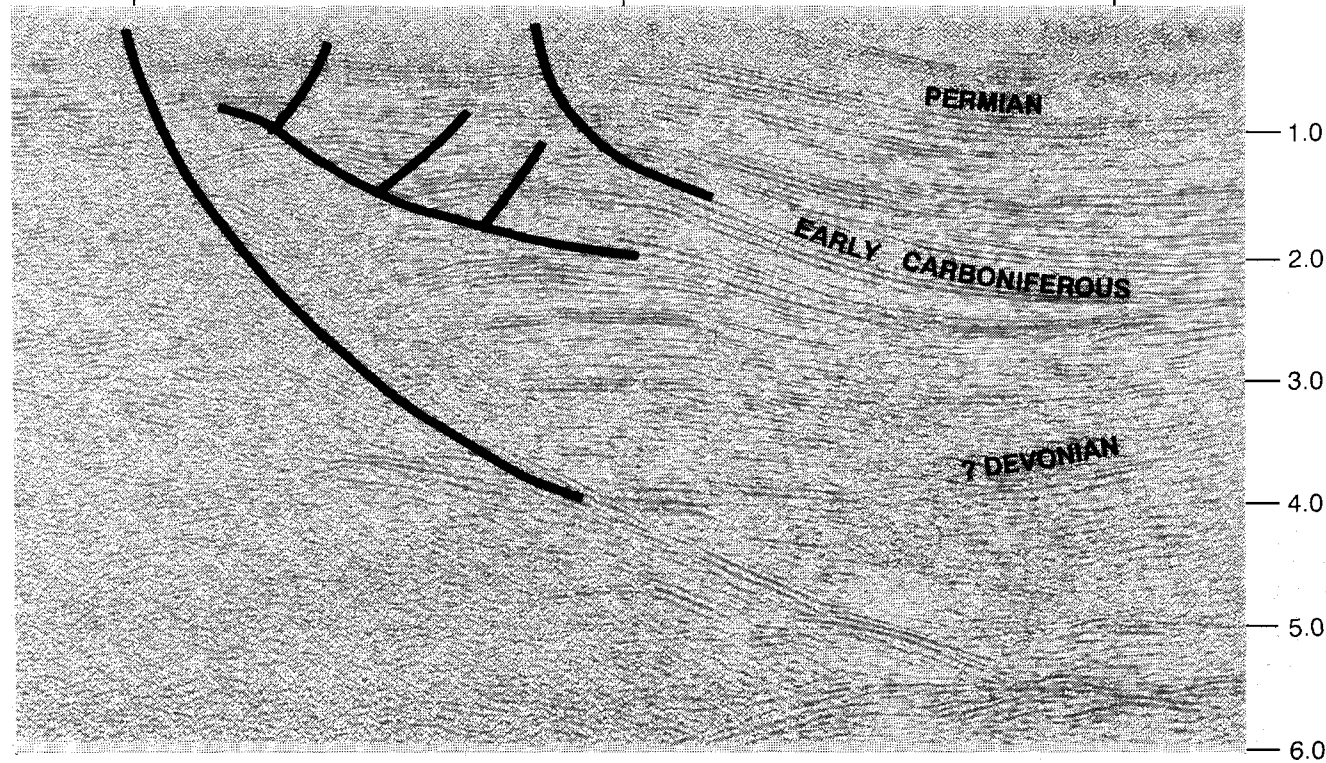
LINE W 81-15

FENTON  
FAULT

400

300

200

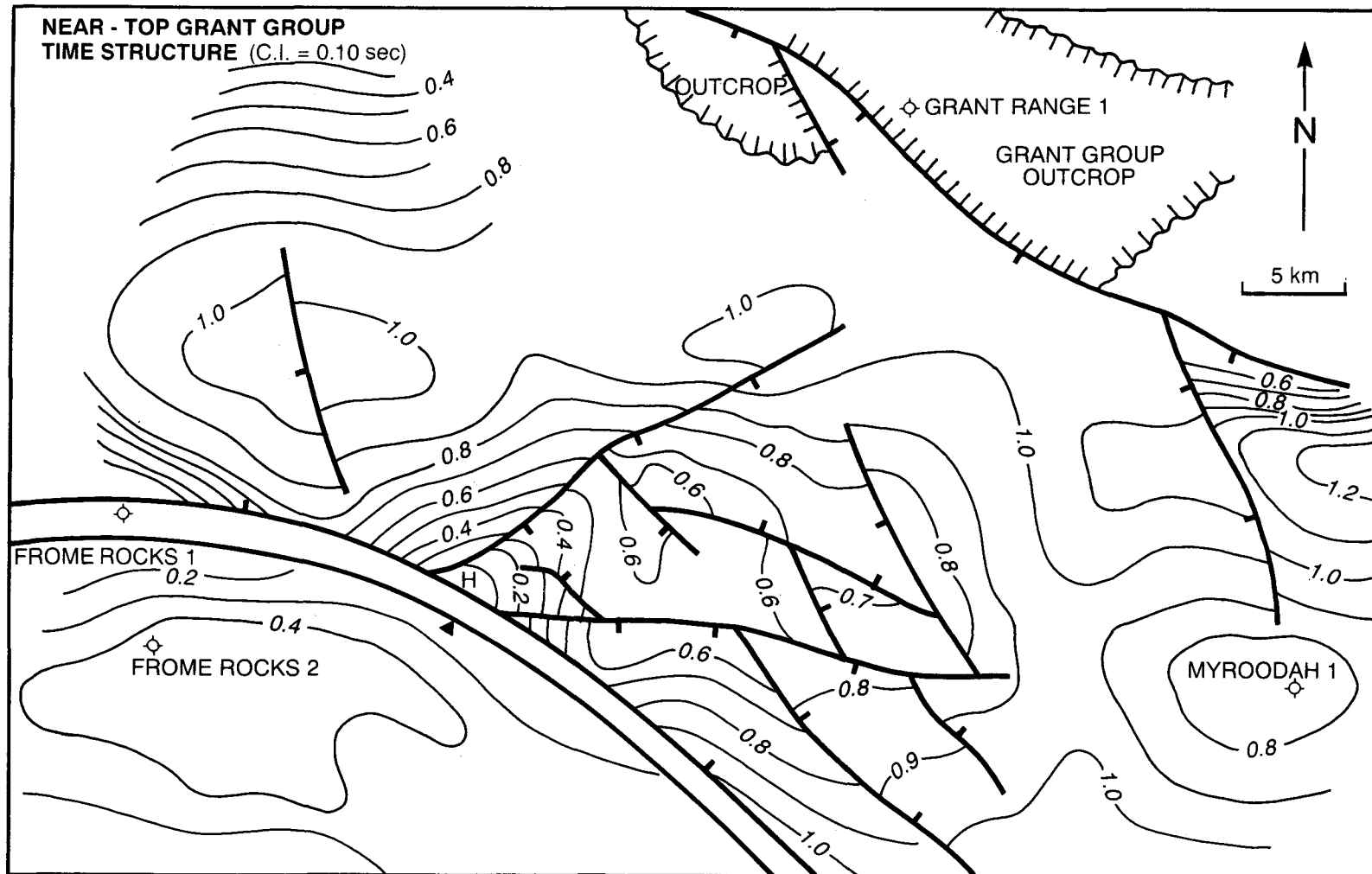


SECONDS

1 km

GSWA 26052

Figure 20. Seismic profile over the Fenton Fault, Myroodah area.



GSA 26053

Figure 21. Time structure: near-top Grant Group, Myroodah area.



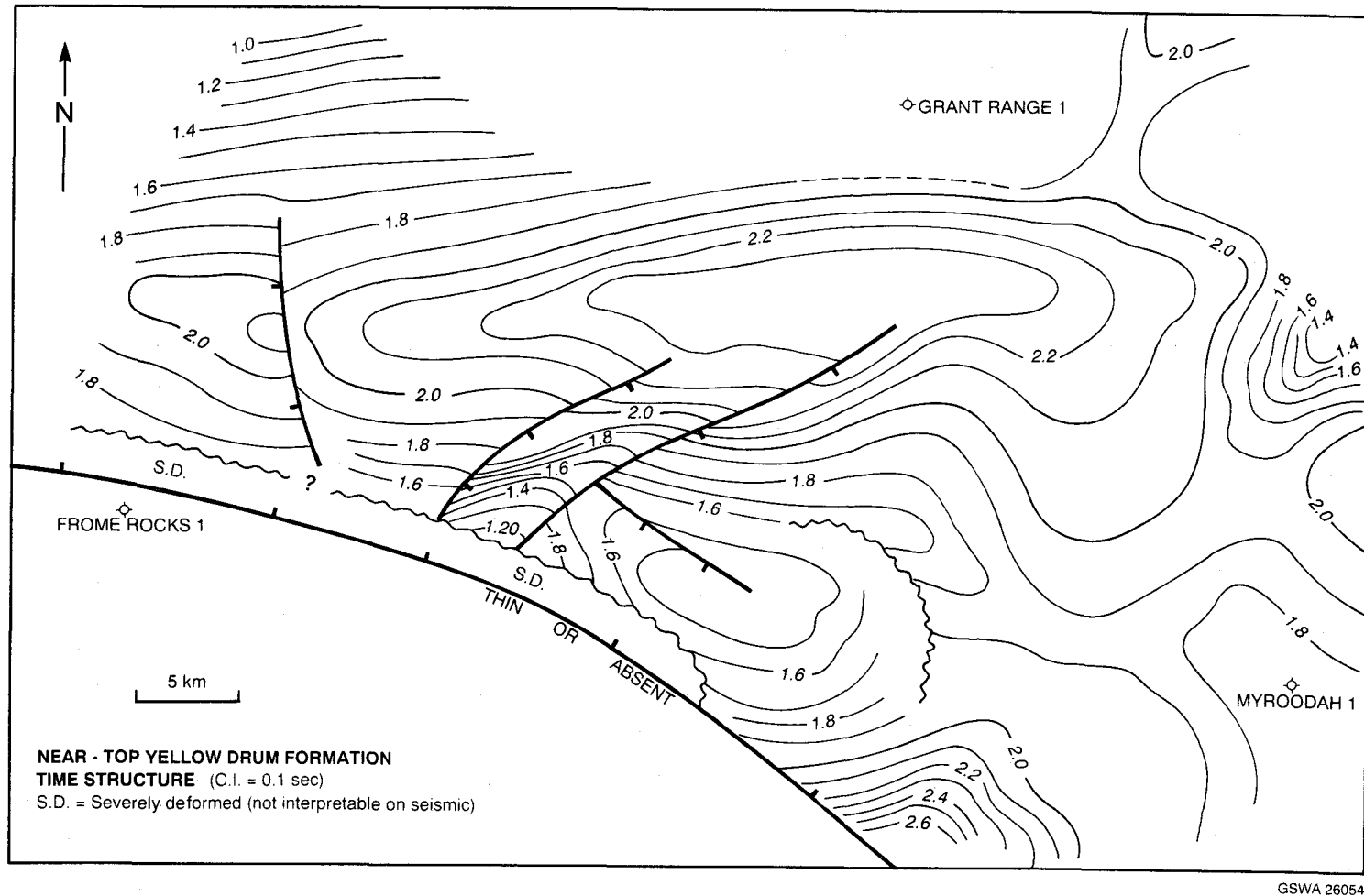
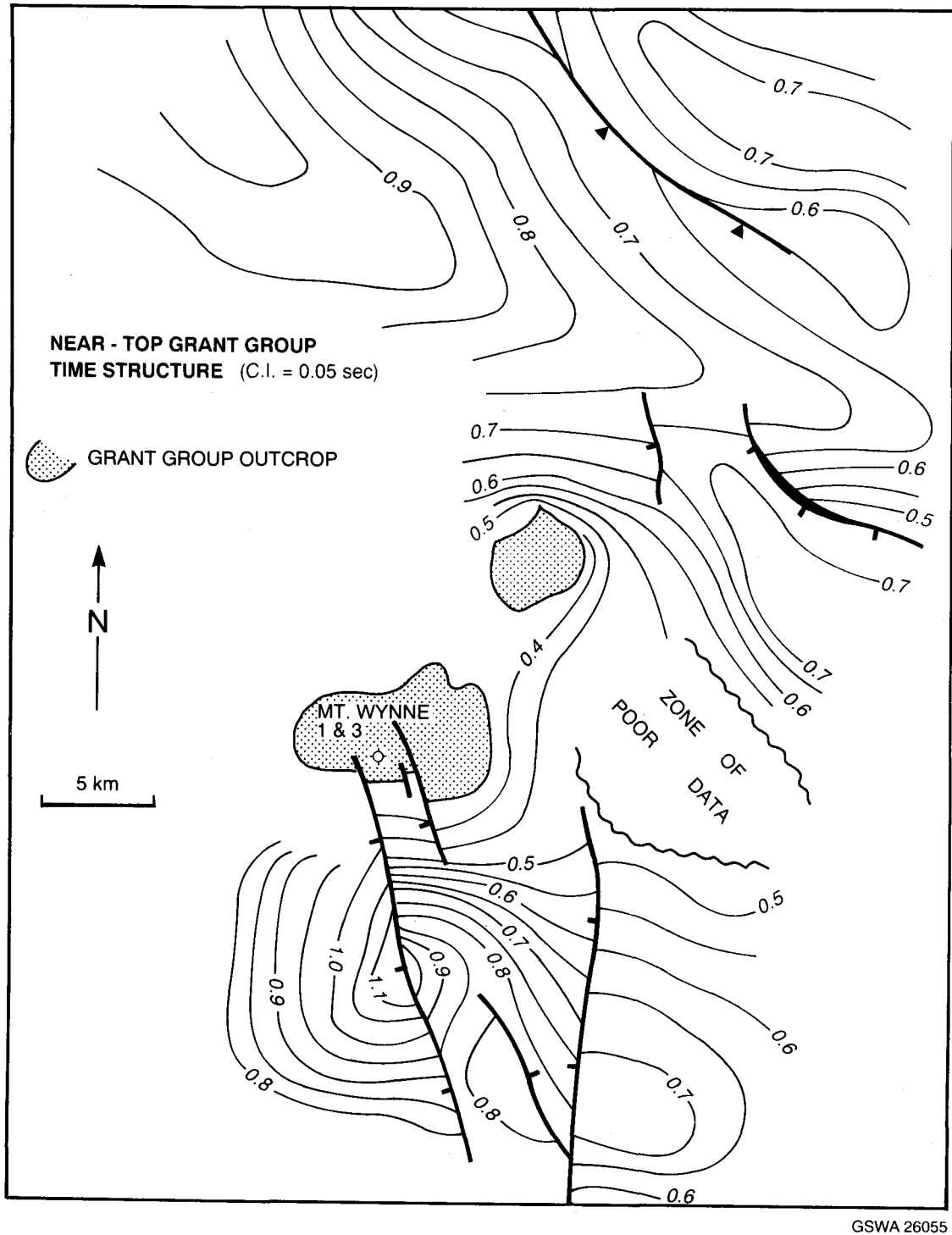
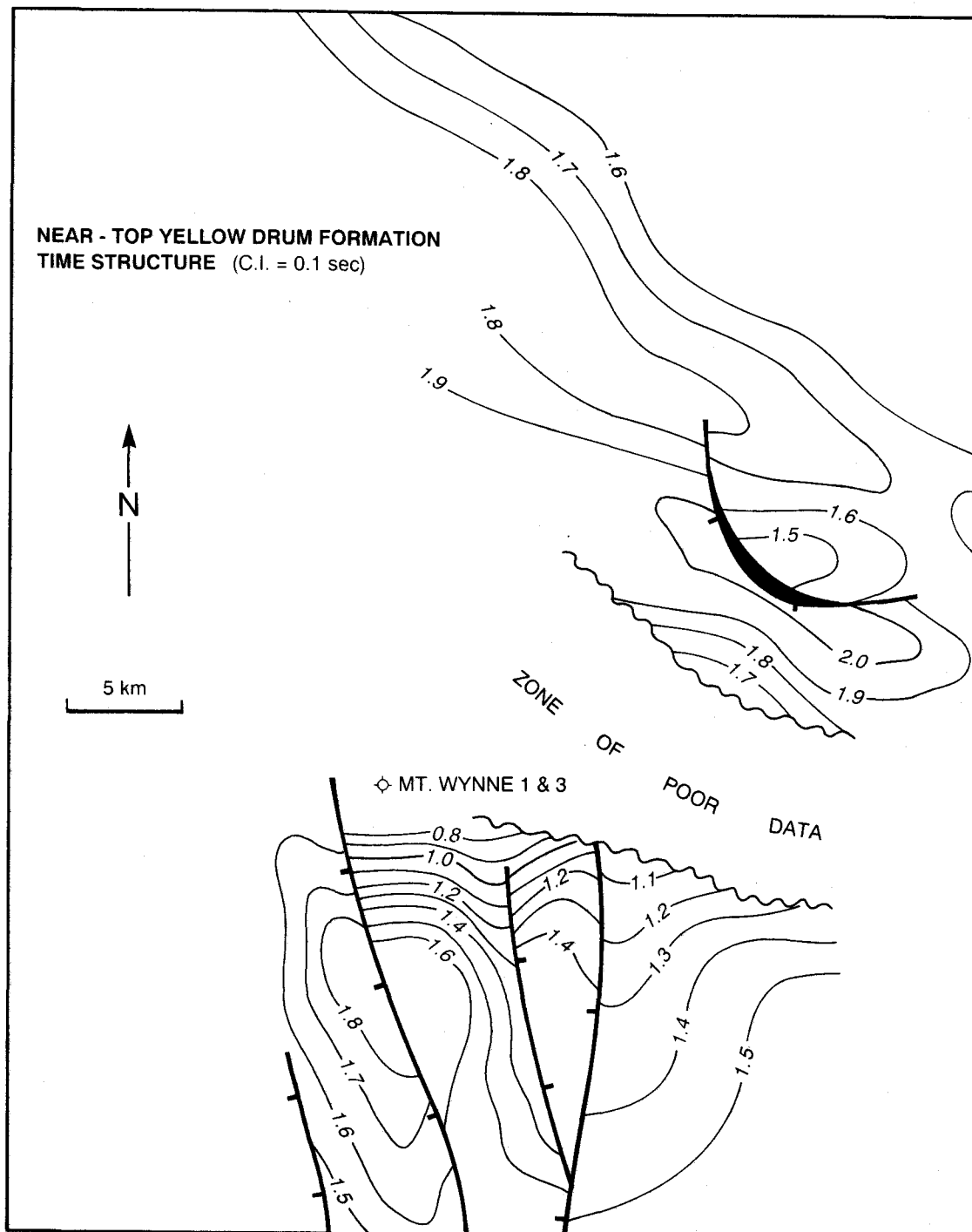


Figure 22. Time structure: near-top Yellow Drum Formation, Myroodah area.



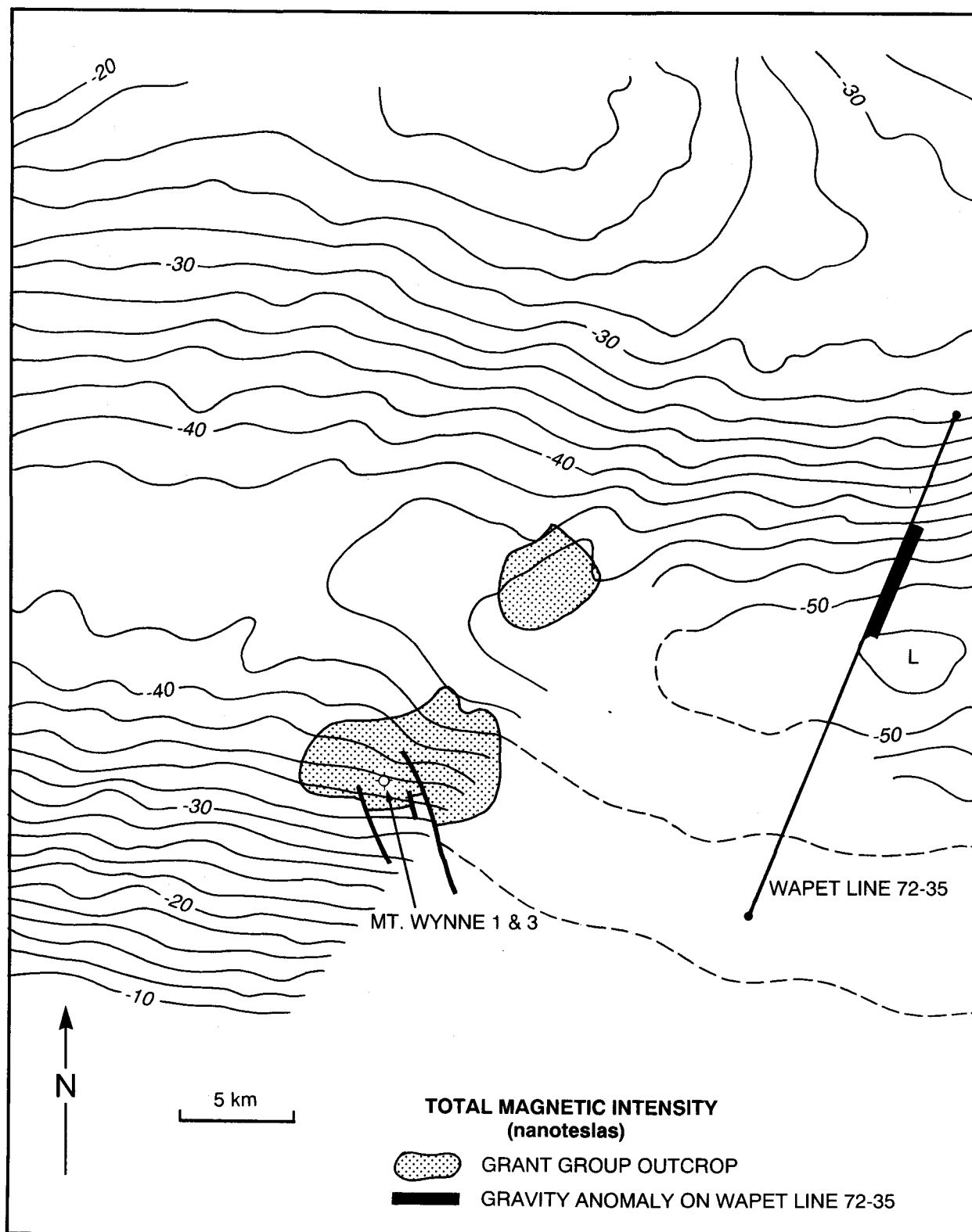
GSWA 26055

Figure 23. Time structure: near-top Grant Group, Mt Wynne area.



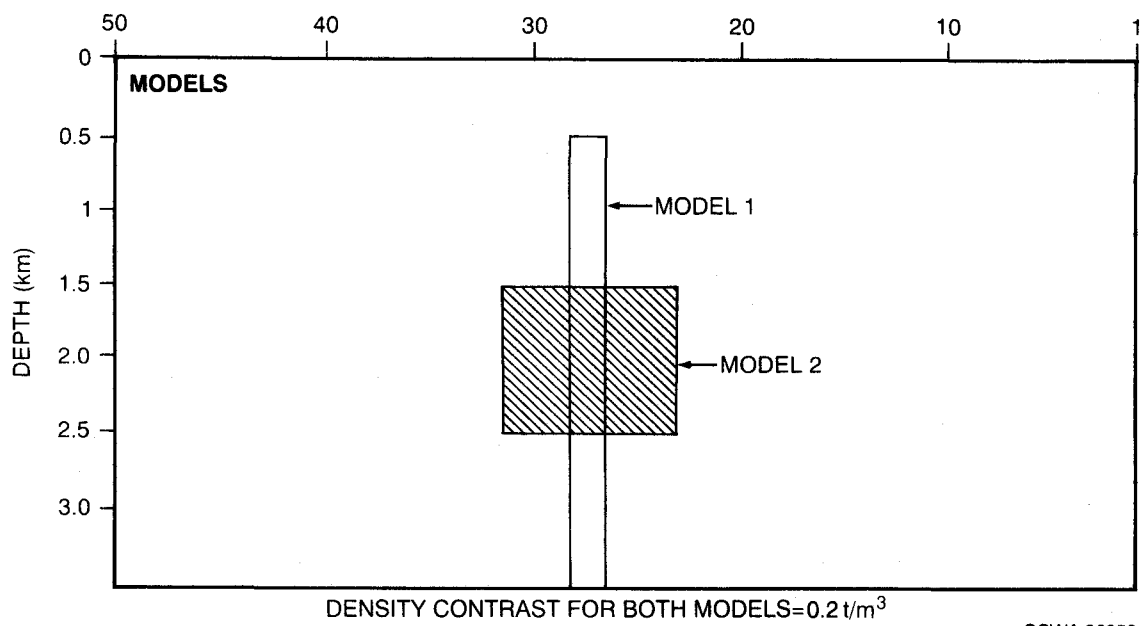
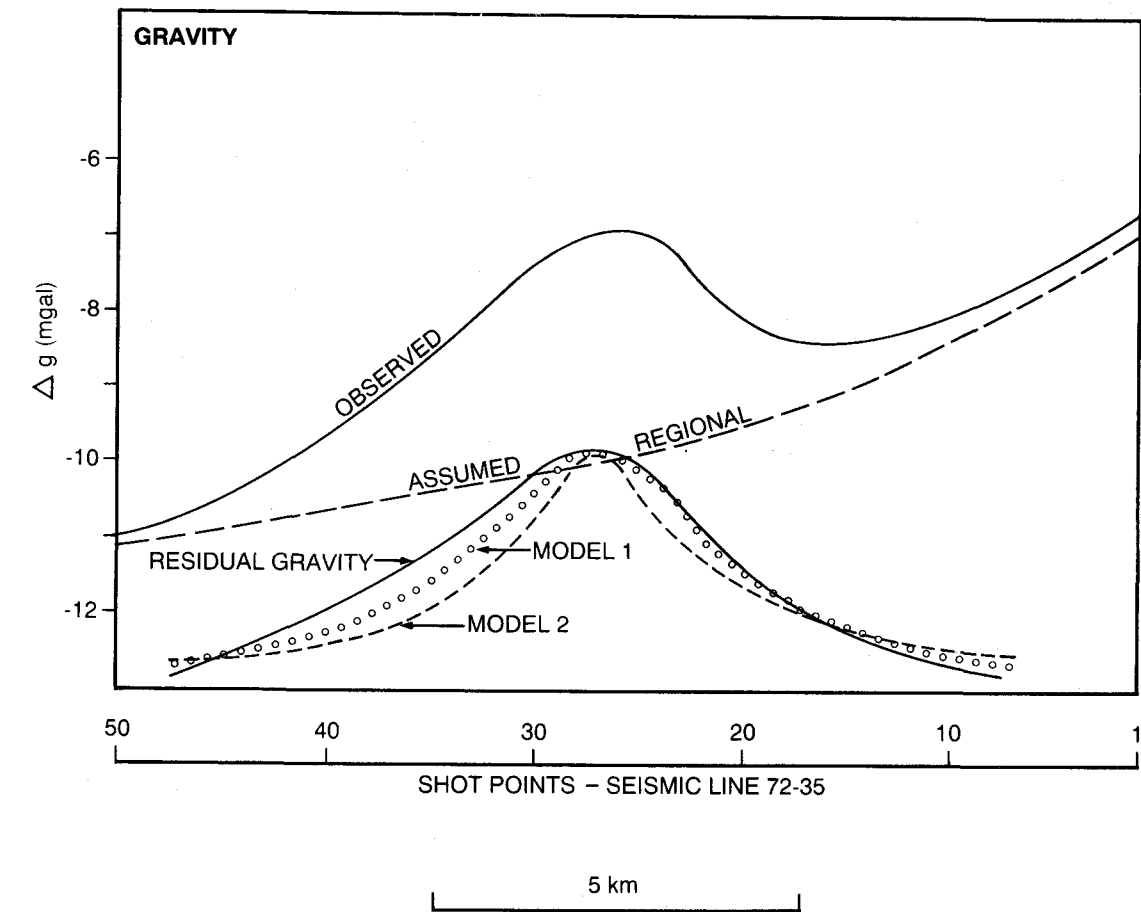
GSWA 26056

Figure 24. Time structure: near-top Yellow Drum Formation, Mt Wynne area.



GSWA 26057

Figure 25. Magnetic anomaly map, Mt Wynne area.



GSWA 26058

Figure 26. Gravity anomalies and various models, Mt Wynne area.

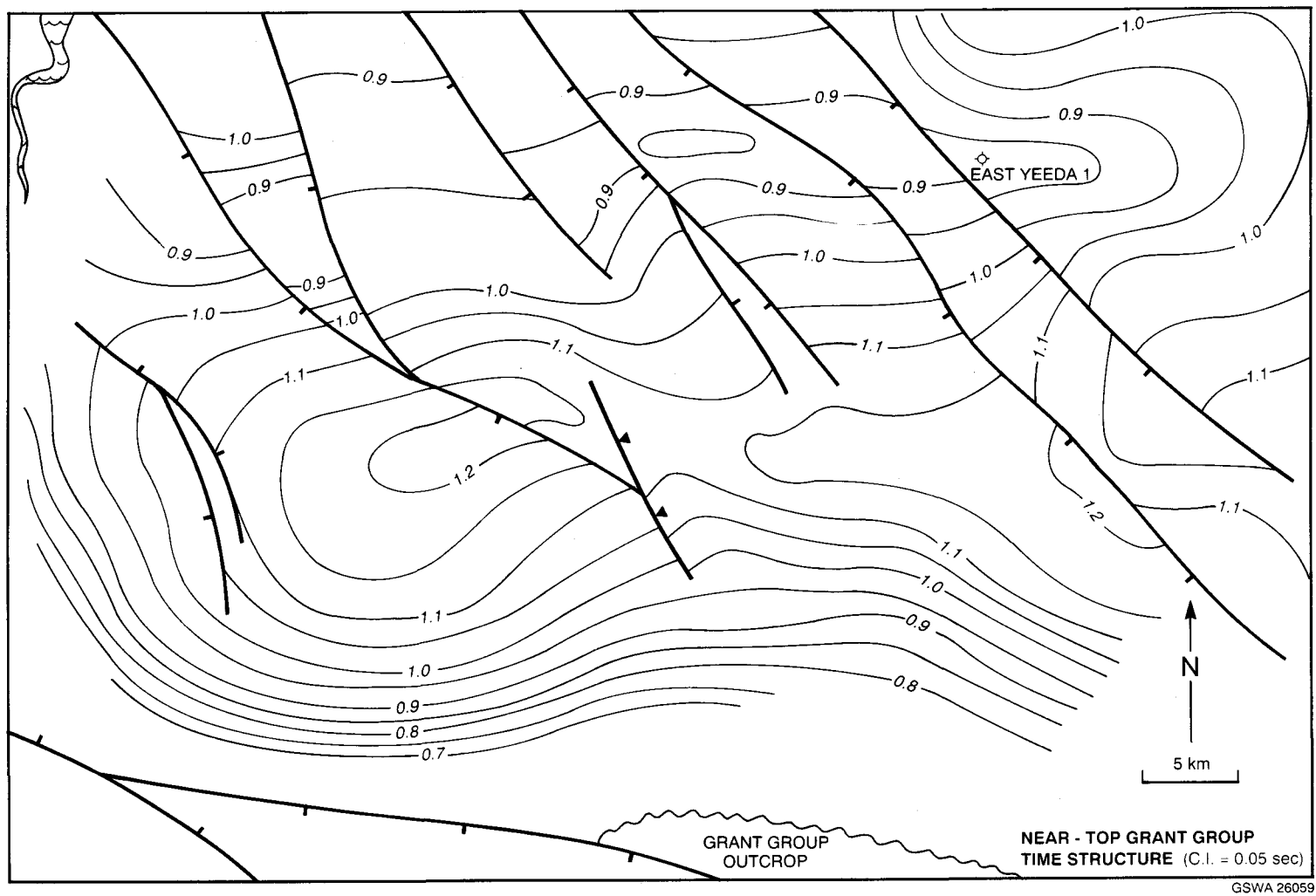


Figure 27. Time structure: near-top Grant Group, Yeeda area.

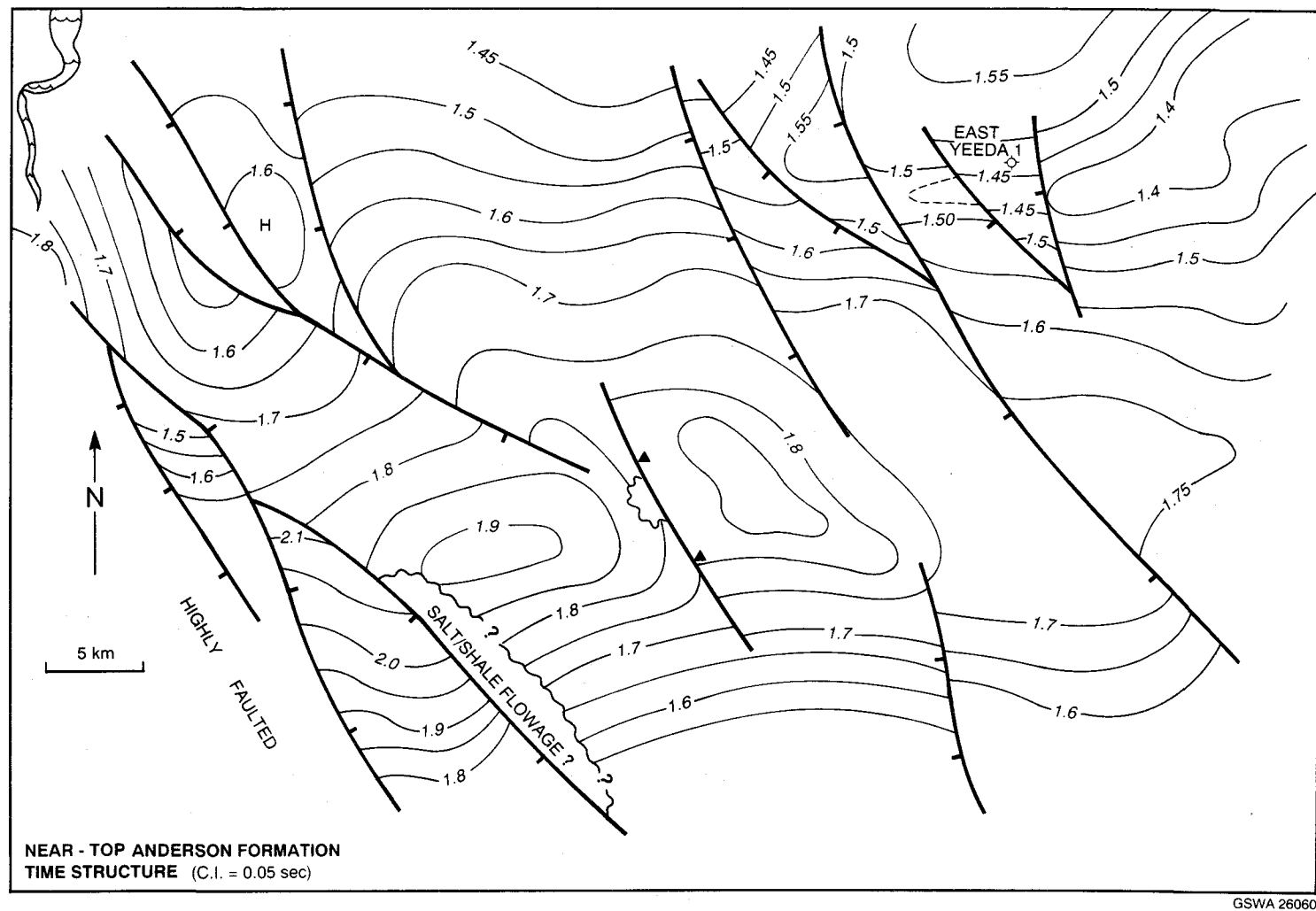
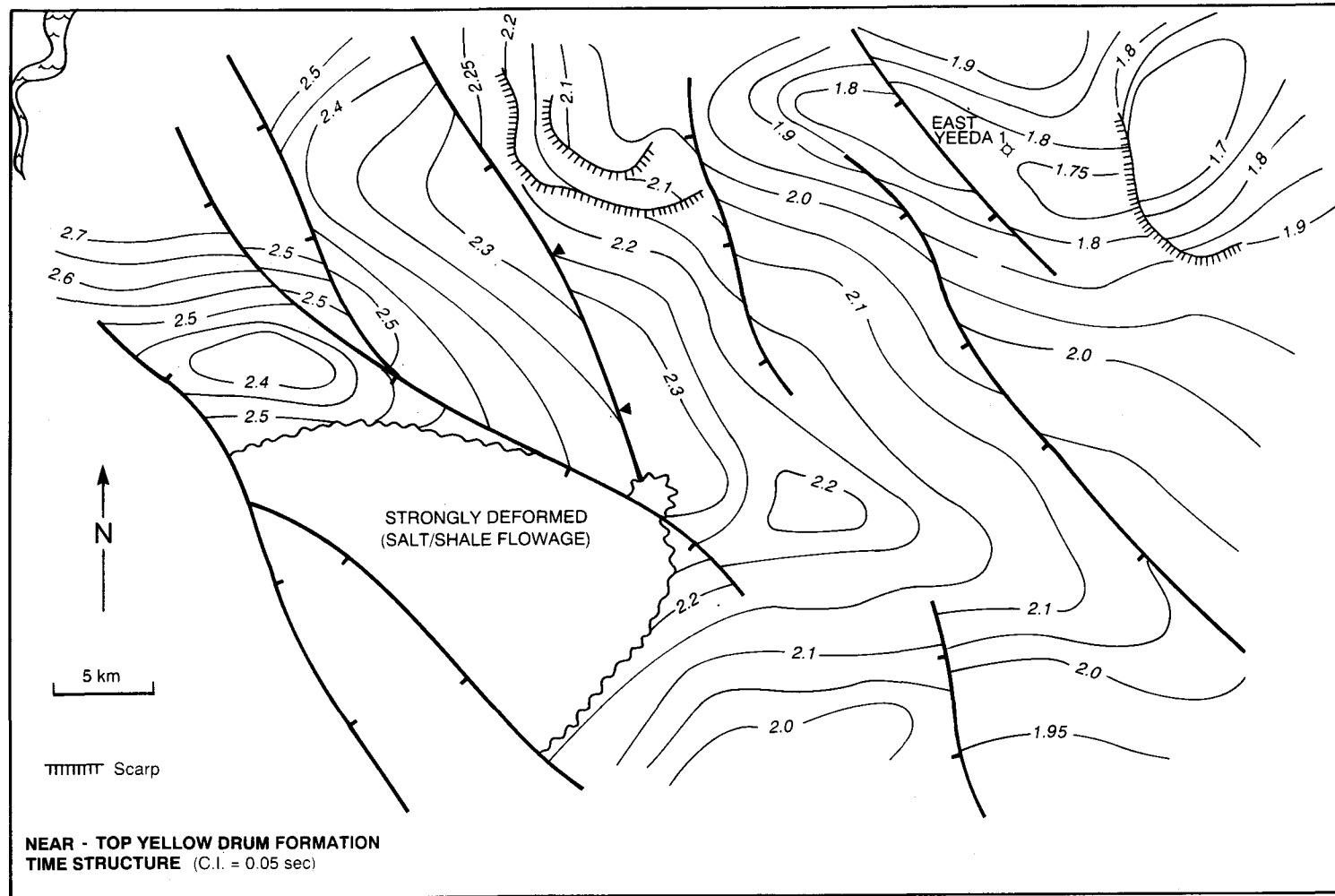


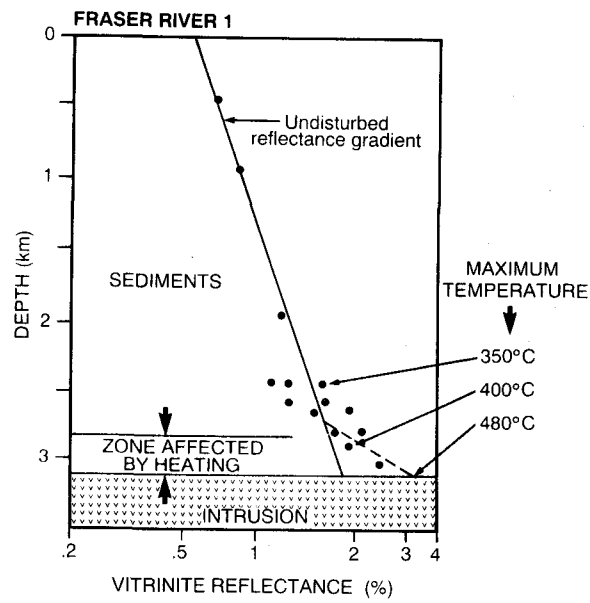
Figure 28. Time structure: near-top Anderson Formation, Yeeda area.



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Figure 29. Time structure: near-top Yellow Drum Formation, Yeeda area.

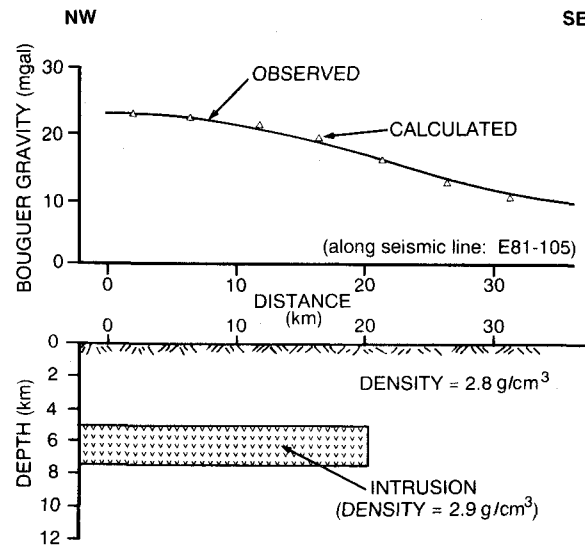




• Data from Reeckmann and Mebberson (1984)

GSWA 26062

Figure 30. Thermal and vitrinite reflectance models of the Fraser River structure.



GSWA 26063

Figure 31. Gravity model of the Fraser River structure.

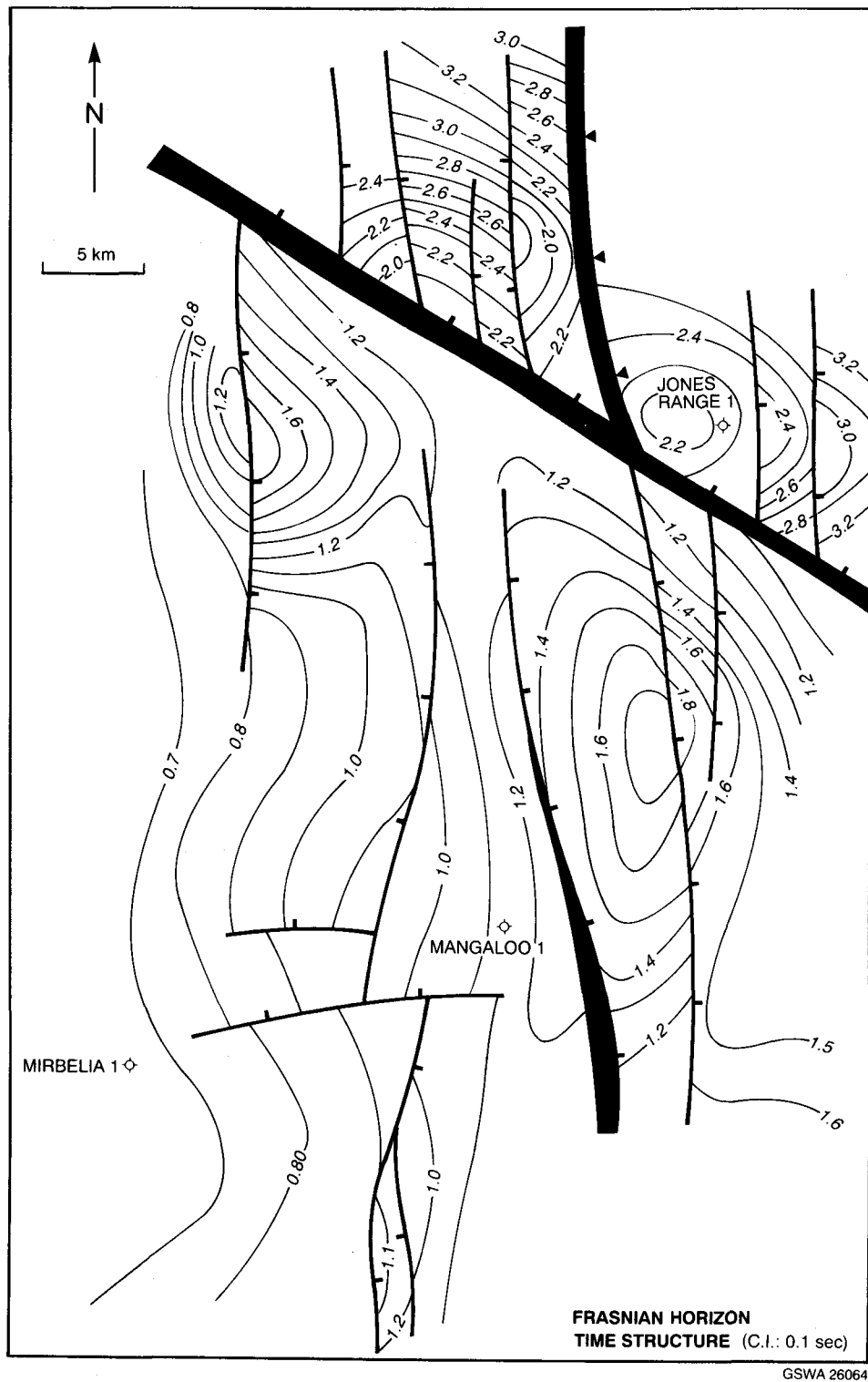


Figure 32. Time structure: near-top Frasnian, Jones Range area.

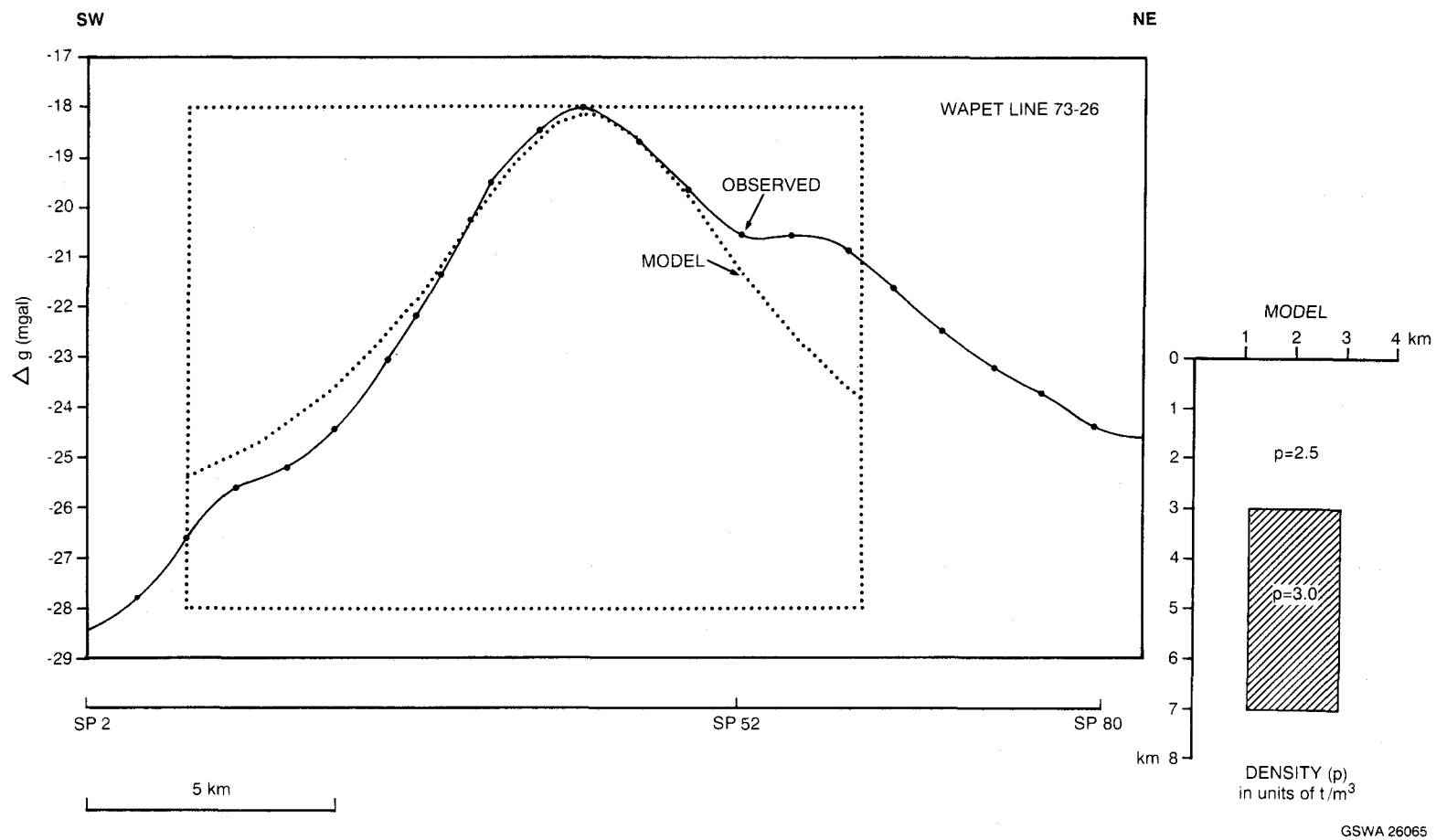
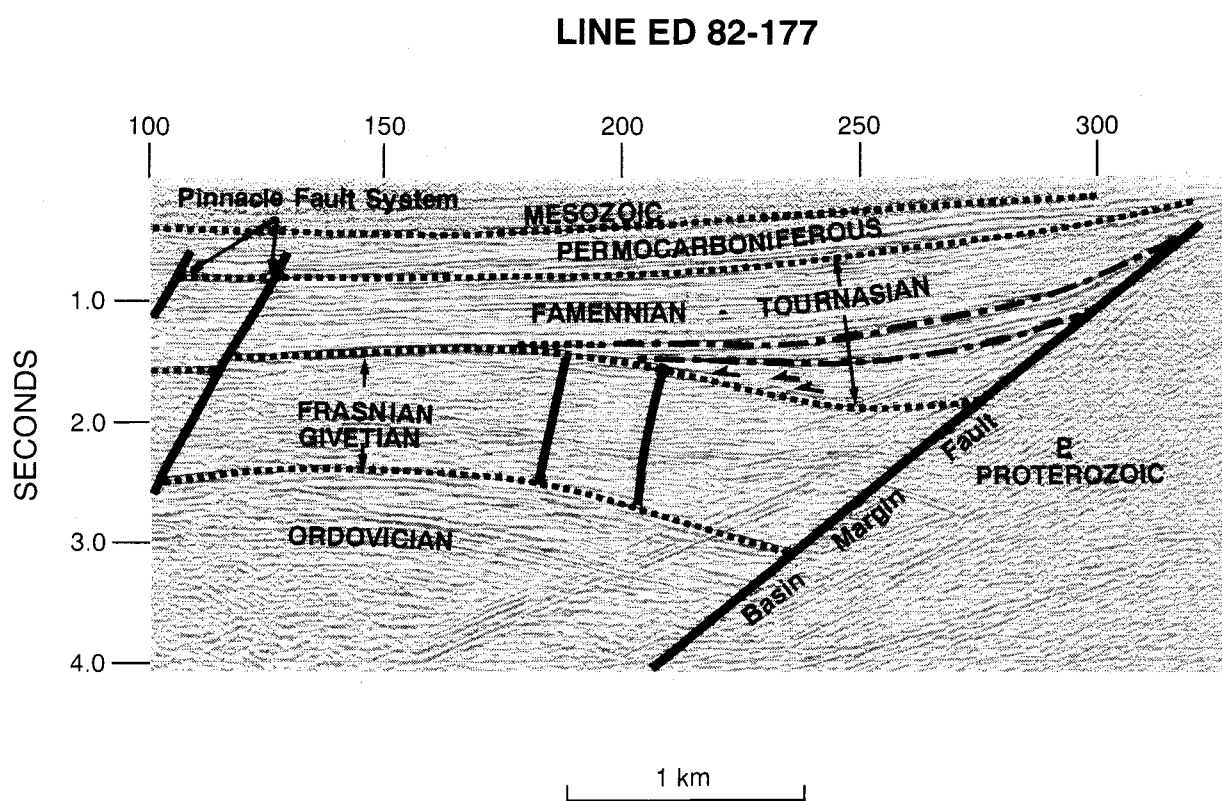
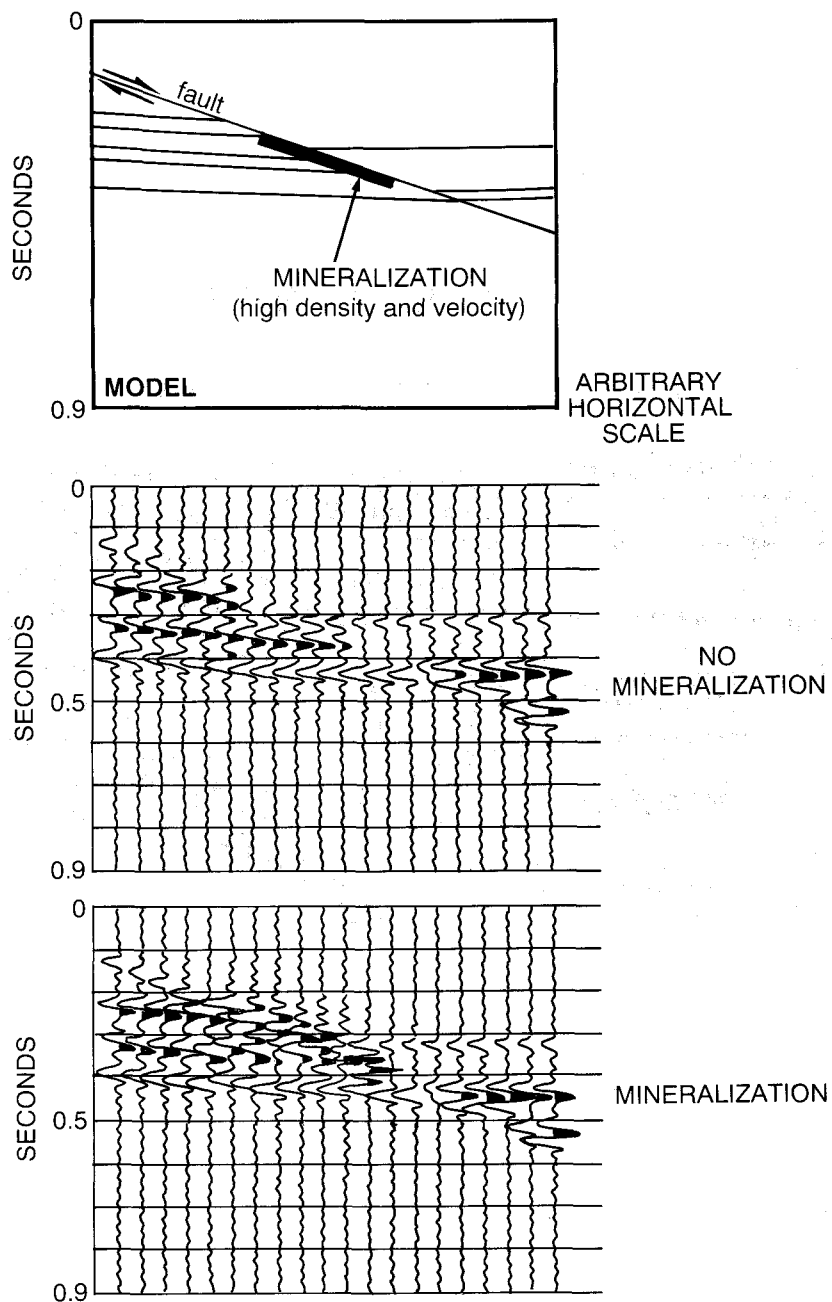


Figure 33. Jones Range gravity anomaly and interpretative model.



GSWA 26066

Figure 34. Seismic section, near Mimosa 1, showing Frasnian structure on the Lennard Shelf.



GSWA 26067

Figure 35. Seismic models of mineralization in fault zones.

## **Part 3. Tectonic evolution**

### **Introduction**

This section discusses various tectonic models proposed for the formation of the northern Canning Basin. Although detailed knowledge of the geology of the basin has increased immensely with the data released after the petroleum and base-metal exploration effort of the 1980s, the interpreted geological history of the basin has not changed greatly. However, the new data has significantly advanced our knowledge of the tectonics influencing the formation of the basin.

Deep seismic-reflection data (Drummond et al., 1991), has tended to confirm the views proposed herein for the tectonic evolution of the basin. Not so clear are the timing of heating and movement of fluids through the basin sediments, although it is logical for these to be associated with the major periods of tectonism.

### **Tectonic models**

#### **Early wrench models**

Initial studies of the tectonic history of the northern Canning Basin concentrated on the Triassic - Jurassic wrench event (Smith, 1968; Rattigan, 1967). These workers concluded from fault and fold patterns that a right-lateral wrench movement had occurred in the Fitzroy Trough. Rixon (1978) confirmed these findings using a clay modelling technique.

#### **Brown et al. 1984 model**

Brown et al. (1984) proposed a generalized model of formation for the Canning Basin entailing five major stages:

- A. Ordovician -- epeiric sea
- B. Silurian and Early Devonian -- thermal upwarp phase
- C. Late Devonian -- main rifting phase
- D. Early Carboniferous -- rift infill phase

**E. Middle Carboniferous to Holocene - North West Shelf margin rifting and breakup phase**

The principal problems with the model are the implication of Devonian igneous activity and failed spreading, and the 'initial upwarp phase' of the North West Shelf margin rifting occurring 150 million years prior to the rifting. Falvey (1974) placed a maximum value of only 50 million years on thermal upwarp due to rifting and sea-floor spreading activity.

**1984 Symposium models (Purcell, 1984)**

Various models were presented in Purcell (1984) for specific regions of the Canning Basin. The most significant models bearing on the study area are:

- A. Smith (1984) -- detailing wrench tectonics in the Gregory Sub-basin
- B. Horstman (1984) -- detailing post-Permian epeirogenic uplift in the Fitzroy Trough region
- C. Reeckmann and Mebberson (1984) -- detailing the structural and thermal effects of the Carboniferous to Permian basic igneous intrusions in the northwestern region of the basin.

Although these models are internally consistent, they must also be consistent with any general tectonic model for the northern Canning Basin. While the Smith (1984) and Horstman (1984) models are consistent with our knowledge of the Triassic - Jurassic Fitzroy movement, the Reeckmann and Mebberson (1984) hypothesis, relating Permian igneous activity to continental breakup of the North West Shelf in the Jurassic, remains to be substantiated.

**Begg 1987 model**

Begg (1987) proposed a model of rifting of the Fitzroy Trough during the Devonian. The model is based on the model of the Bass Basin proposed by Etheridge et al. (1985). Furthermore, Begg proposed that extensive zones of poor data are due to massive carbonate buildups, which is in conflict with interpretation given by Purcell and Poll (1984). The Bass Basin model is inappropriate, as the Fitzroy Trough is not a symmetric graben, has no evidence

of contemporaneous igneous activity, and does not have numerous tilted fault blocks dipping into a deep depocentre.

#### **BMR 1988 model**

Drummond et al. (1987) and Drummond et al. (1988) proposed a model for the formation of the Fitzroy Trough which involved asymmetric extension. They suggested that half-graben symmetry alternates at transfer faults located at intervals along the trough. This model to some degree is similar to the Bass Basin model of Etheridge et al. (1985). However, unlike the model of Begg (1987), and indeed the Bass Basin model, the Fitzroy Trough is grossly asymmetric, and is not constituted of numerous tilted fault blocks.

Figures 15, 16 and 36 demonstrate the asymmetric nature of the trough, with the southern faulted margin of the trough (Fenton Fault System) being the line of major faulting. The northern margin of the trough varies along its length from a flexured margin in the northwest to a substantially faulted margin in the southeast. Although Drummond et al. (1987) and Drummond et al. (1988) expressed the view that the Fenton Fault System alternated between a faulted margin and a flexured margin along its length, evidence from the current study suggests that the Fenton Fault System is a faulted margin along its total length. Later salt or shale movement appears to give the appearance of a flexured margin at various localities (Figs 22 and 29).

#### **Proposed tectonic model**

Combined data from the northern Canning Basin and surrounding geological provinces suggest a convergent tectonic model rather than a 'failed rift' or aulacogen model for the formation of the Ordovician to Middle Devonian structures in the northern Canning Basin. The difficult problem to resolve in the formation of the northern Canning Basin is the effect of the major orogenic event, the Alice Springs Orogeny, within 100 km of its southeastern margin. A collisional or compressional tectonic regime becoming an extensional, and perhaps a proto-spreading, regime within 100 km is difficult to explain in a plate tectonic scenario. McKenzie and Morgan (1969) have shown that a convergent plate boundary and a divergent plate boundary are unstable, and therefore short



lived, unless there is significant subduction such as on the west coast of central America (Atwater, 1970). The tectonic development of western and central Australia appears to be controlled by compressional tectonics and the differential movement between lithospheric blocks. The tectonic scenario is shown in Figure 37, which summarizes the regional tectonic information for western and central Australia in the Late Devonian. Essentially, four lithospheric blocks were responding to the pushing southwards of the 'Sturt Block' into the 'Australian Craton'. These terms and the terms 'Kimberley Block' and the 'northern Bonaparte Block' are used loosely to describe the lithospheric blocks interacting during the Devonian and Carboniferous (Fig. 37).

The movements of these blocks appears to have caused the orogenic activity in central Australia and the formation of extensional basins in Western Australia and the Timor Sea. The major movement was on the Sturt Block, which moved southward to collide with the Australian Craton. Lambeck (1983, 1984) has described a tectonophysical model for this compressional event, and Shaw et al. (1984) and Tessier (1985) have described the geology of the central Australian region resulting from this tectonic event. At the same time as this movement, the Kimberley Block and the northern Bonaparte Block experienced some relative movement southward, but appreciably less than the Sturt Block. A transcurrent fault accommodated these movements along the Halls Creek Mobile Zone which appears to be a long-existing transition zone between the Kimberley Block and the Sturt Block.

The transcurrent fault probably extended further northward beyond the northern Bonaparte Block and the differential movement appears to have also caused the formation of the Money Shoals Basin in the Timor Sea.

The available data from the northern Canning Basin suggest (i) a broad (200 km-wide) asymmetrical sag developed in the Early and Middle Devonian; and (ii) a narrow (70 - 100 km wide) asymmetrical graben system (Fitzroy Trough) developed in the Late Devonian to Permian.

The Devonian sag appears to have developed in response to mantle downwelling associated with the Alice Springs Orogeny, possibly due to the descending-plume mechanism proposed by Middleton (1989). After the Alice Springs Orogeny, the compression in northwestern and central Australia was released, and an extensional basin formed along the axis of the previous sag

(Fig. 38). The timing of change from sag to interior fracture is probably the Frasnian, during the Pillara Cycle deposition.

Igneous activity occurred as the extension continued through the Permian and mantle material upwelled beneath the basin. The Late Carboniferous to Permian, tectonism follows the Benue Trough aulacogen model (Grant, 1971; Adigije, 1981). The Benue Trough in northwestern Africa has similar dimensions to the northern Canning Basin depocentres, and igneous activity associated with its formation. The regional tectonic model for the formation of the northern Canning Basin is shown in Figure 38.

## **Discussion**

The formation of the Fitzroy Trough appears to be adequately explained by the model proposed above. The wrench model described by Rattigan (1967), Smith (1968), and Rixon (1978) needs refinement in that a series of right-lateral strike-slip fault zones developed due to compression on the northern Canning Basin along a northerly trending axis.

A thermal pulse may have occurred during the Late Mesozoic or Early Tertiary, as suggested by Ellyard (1984), but no direct evidence is available for this pulse. The heating proposed by Ellyard may be the sum of any wrench-associated heating and the lamproite-intrusion episode, but may also be due to erroneous assumptions entailed in vitrinite reflectance modelling using the Lopatin method.

## **Implications for exploration**

Large structures in the northern Canning Basin do not have good potential for petroleum, as the companies who have explored the basin over the last 50 years have found. Small structures on the Lennard Shelf, Jurgurra and Barbwire Terraces, and the Broome Platform, together with stratigraphic plays, appear the most prospective targets for the future. Nevertheless, future detailed mapping of the complex wrench-induced structures may reveal fault blocks in orientations more ideal for petroleum entrapment. Small structures in the Fitzroy Trough, which have not been severely faulted, and were formed essentially by folding

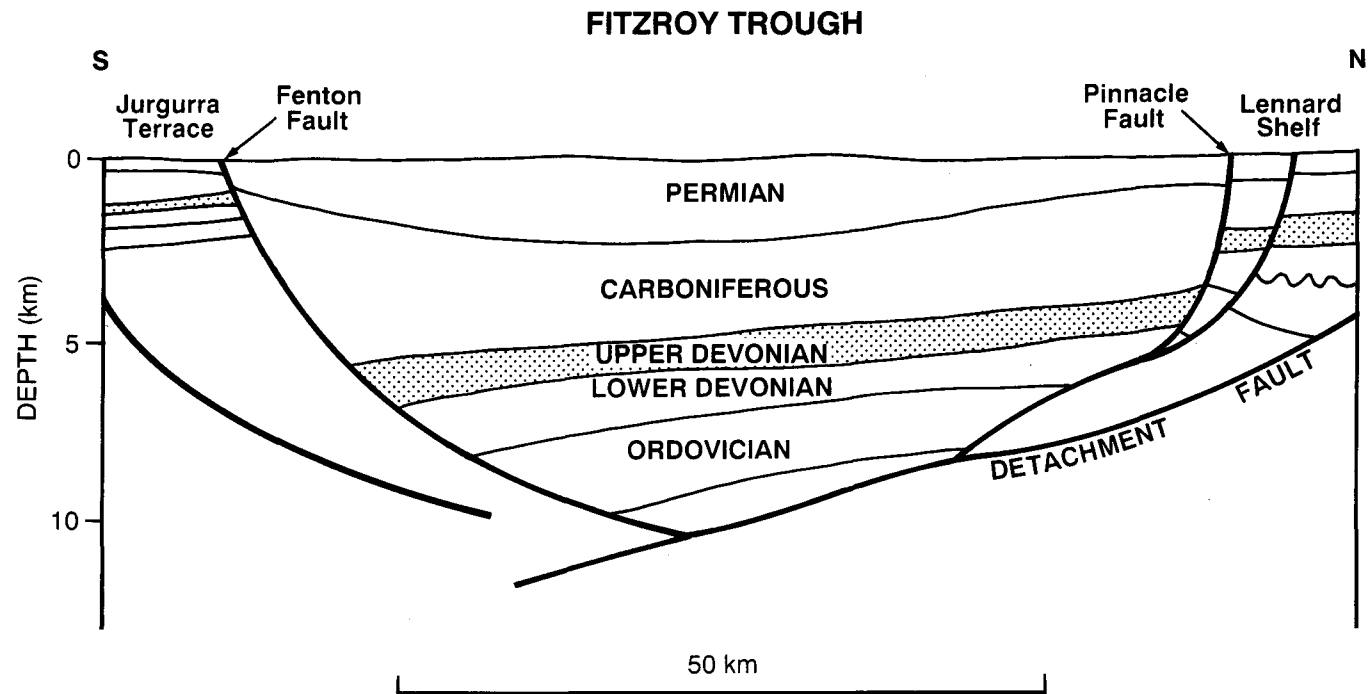
alone, may be prospective targets. An example of such a small anticline is given in Figures 28 and 29. Submarine fans, some of which are clearly visible on the seismic sections and maps presented herein, are as yet untested plays.

Mineralization appears to occur on brecciated fault zones. The timing of movement of mineralizing fluids is unrelated to thermal events, as the mineralization is low temperature (Lambert and Etminan, 1986) and the mineralizing fluids appear to have been expelled from basinal sediments by compaction, and moved upwards along brecciated fault zones. Movement of fluids within the basin probably occurred during four main stages:

- (i) during compaction of the Devonian and Early Carboniferous sediments during the Carboniferous;
- (ii) during the Permian igneous intrusion episode in the northwestern part of the study area;
- (iii) during the wrench movement and any associated thermal pulse;
- (iv) during the Miocene lamproite-intrusion episode.

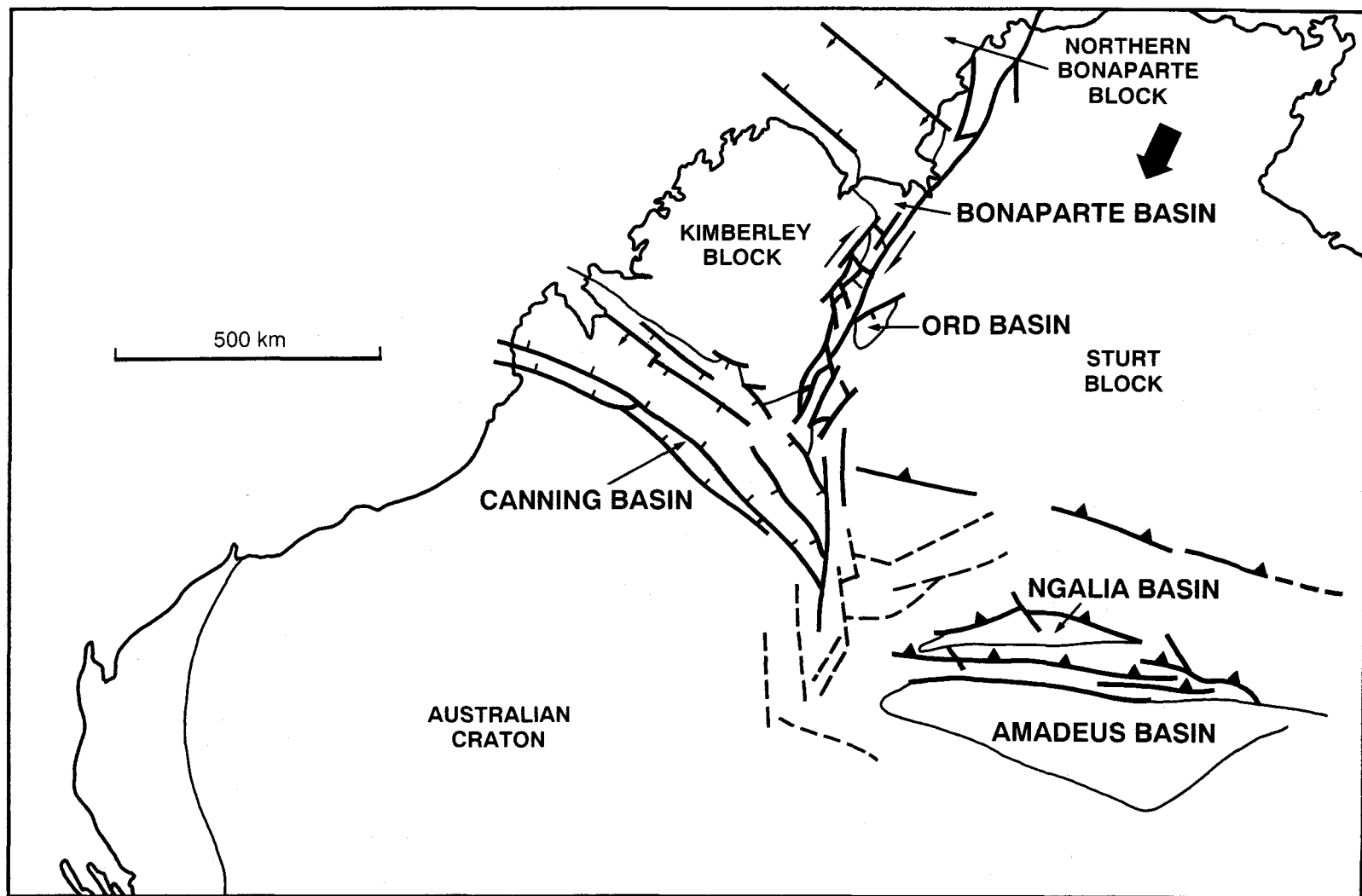
Seismic-reflection surveying is capable of detecting mineralized fault-zones, and may provide a valuable exploration and development tool.

Transfer faults, initially proposed by Wapet geologists in the 1950s, and further developed by Begg (1987), probably exist as tension gashes in the basin at various localities and were reactivated during the compressional event. The number of transfer faults is considerably less than proposed by Begg (1987) and, according to Playford (1987, pers. comm.), do not extend into the Devonian outcrop area of the Lennard Shelf.



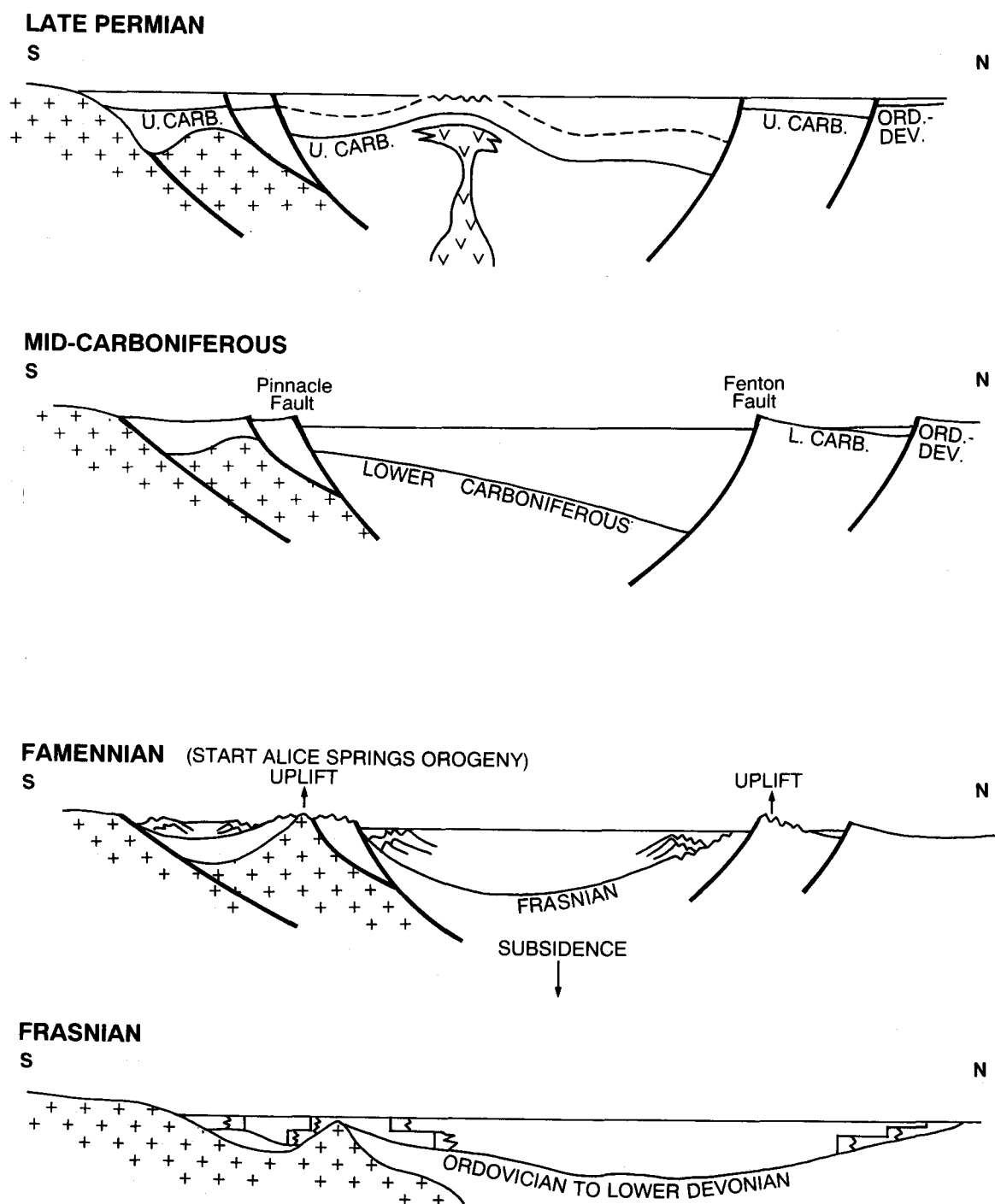
GSWA 26068

Figure 36. Summary cross-section showing the major structural details of the Fitzroy Trough.



GSWA 26069

Figure 37. Tectonic scenario for the northwestern part of Western Australia and central Australia, for the Devonian and Carboniferous.



GSWA 26070

Figure 38. GSWA tectonic model for the formation of the Canning Basin during the late Palaeozoic.

## References

- ADIGIJE, C. I., 1981, A Gravity interpretation of the Benue Trough, Nigeria, *Tectonophysics*, v. 79, p. 109 - 128
- ANSTEY, N. A., 1986, Field techniques for high resolution: The Leading Edge, v. 5, p. 26 - 34.
- ATWATER, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: *Bulletin Geological Society America*, v. 81, p. 3513 - 3536.
- BEGG, J., 1987, Structuring and controls on Devonian reef development on the north-west Barrow and adjacent terraces, Canning Basin: *APEA Journal*, v. 27, p. 137 - 151.
- BENN, C. J., 1984, Facies changes and development of a carbonate platform, east Pillara Range, *in The Canning Basin, W.A. edited by P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings*, p. 223 - 228.
- BROWN, L. F., Jr., and FISHER, W. L., 1977, Seismic-stratigraphic interpretation of depositional systems: examples from Brazilian rift and pull-apart basins, *in Seismic stratigraphy - applications to hydrocarbon exploration edited by C. E. PAYTON: AAPG Memoir 26*, p. 213 - 248.
- BROWN, S. A., BOSERIO, I. M., JACKSON, K. S., and SPENCE, K.W., 1984, The geological evolution of the Canning Basin - Implications for petroleum exploration, *in The Canning Basin, W.A. edited by P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings*, p. 85 - 96.

- COOPER, A. W., HALL, W. D. M., and STYLES, G. R., 1984, The Devonian stratigraphy of the Central Pillara Range, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 229 - 234.
- DRUCE, E. C., and RADKE, B. M., 1979, The geology of the Fairfield Group, Canning Basin, Western Australia: Australia BMR, Bulletin 200.
- DRUMMOND, B. J., ETHERIDGE, M. A., and MIDDLETON, M. F., 1987, The geometry of extensional structures in the Fitzroy Trough, Canning Basin: Australia BMR, Record 1987/51.
- DRUMMOND, B. J., ETHERIDGE, M. A., MIDDLETON, M. F., and DAVIES, P. J., 1988, Half-graben model for the structural evolution of the Fitzroy Trough, Canning Basin and implications for resources exploration: APEA Journal, v. 28 (1), p. 76 - 86.
- DRUMMOND, B. J., SEXTON, M. J., BARTON, T. J., and SHAW, R. D., 1991, The nature of faulting along the margins of the Fitzroy Trough, Canning Basin, and implications for the tectonic development of the trough: Exploration Geophysics, v. 22 (1), p. 111 - 115.
- ELLYARD, E. J., 1984, Oil migration in the northern Canning Basin - a regional review, *in* The Canning Basin, W.A. *edited by* P.G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 359 - 375.
- ETHERIDGE, M. A., BRANSON, J. C., and STUART-SMITH, P. G., 1985, Extension basin-forming structures in Bass Strait and their importance for hydrocarbon exploration: APEA Journal, v. 26 (1), p. 344 - 361.
- FALVEY, D. A., 1974, The development of continental margins in plate tectonic theory: APEA Journal, v. 14 (1), p. 95 - 106.
- FORMAN, D. J., and WALES, D. E., 1981, Geological evolution of Canning Basin, Western Australia: Australia BMR, Bulletin 210.



- GLEADOW, A. J. W., and DUDDY, I. R., 1984, Fission track dating and thermal history analysis of apatites from wells in the north-west Canning Basin, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 377 - 385.
- GOGUEL, J., 1976, Geothermics: McGraw-Hill, New York, 200p.
- GRANT, N. K., 1971, South Atlantic Benue Trough and Gulf of Guinea Cretaceous triple junction: Geological Society America Bulletin, v. 82, p. 2295 - 2298.
- HALL, W. D. M., 1984, The stratigraphy and structural development of the Givetian-Frasnian reef complex, Limestone Billy Hills, western Pillara Range, W.A., *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 215 - 222.
- HORSTMAN, E. L., 1984, Evidence for post-Permian epeirogenic uplift in the Canning Basin from vitrinite reflectance data, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 401 - 409.
- ISLES, D., WATT, M., HARMAN, P., and LEBEL, A., 1987, Geophysical experience from the Blendevale Deposit, W.A: Exploration Geophysics, v. 18, p. 108 - 110.
- JAQUES, A. L., LEWIS, J. D., and SMITH, C. B., 1986, The kimberlites and lamproites of Western Australia: Western Australia Geological Survey, Bulletin 132.
- KERANS, 1985, Petrology of Devonian and Carboniferous carbonates of the Canning and Bonaparte Basins, Western Australia: Western Australian Mining and Petroleum Research Institute, (WAMPRI (now MERIWA)) Report 12, 203 p.

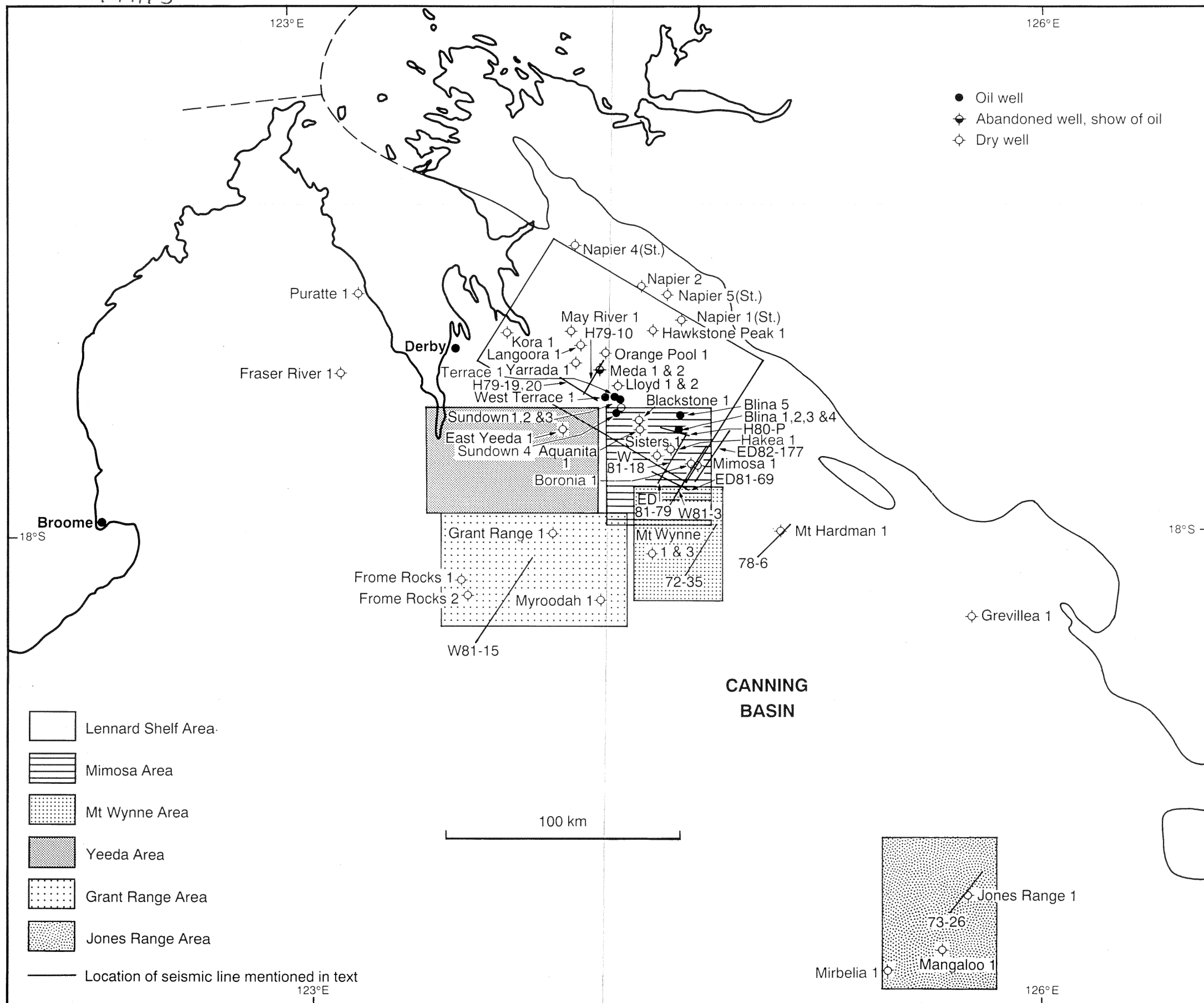
- LAMBECK, K., 1983, Structure and evolution of the intra-cratonic basins of central Australia: *Geophysical Journal of the Royal Astronomical Society*, v. 74, p. 843 - 886.
- LAMBECK, K., 1984, Structure and evolution of the Amadeus, Officer and Ngalia basins of central Australia: *Australian Journal Earth Sciences*, v. 31, p. 25 - 48.
- LAMBERT, I. N., and ETMINAN, H., 1986, Diagenetic and mineralising processes in Devonian carbonates, Canning Basin, W.A: Abstracts of "Sediments Down-Under", 12th International Sedimentological Congress, Canberra, Australia, August, 1986.
- McKENZIE, D., 1978, Some remarks on the development of sedimentary basins: *Earth and Planetary Science Letters*, v. 40, p. 25 - 32.
- McKENZIE, D., and MORGAN, W. J., 1969, Evolution of triple junctions: *Nature*, v. 224, p. 125 - 133.
- MIDDLETON, M. F., 1982, Tectonic history from vitrinite reflectance: *Geophysical Journal of the Royal Astronomical Society*, v. 68, p. 121 - 132.
- MIDDLETON, M. F., 1984, Seismic geohistory analysis - a case history from the Canning Basin, Western Australia: *Geophysics*, v. 49, p. 333 - 343.
- MIDDLETON, M. F., 1985, A rheological model of the northern Canning Basin, *in Rheology of the Lithosphere and Australian Earthquakes: Australia BMR, Record 1985/31*.
- MIDDLETON, M. F., 1987a, Seismic stratigraphy of the northern Canning Basin: *Exploration Geophysics*, v. 18, p. 141 - 144.
- MIDDLETON, M. F., 1987b, Seismic stratigraphy of the Devonian reef complexes of the northern Canning Basin, Western Australia: *American Association of Petroleum Geologists, Bulletin*, v. 71, p. 1488 - 1498.

- MIDDLETON, M. F., 1987c, Seismic stratigraphic plays in the northern Canning Basin, *in* Petroleum in Western Australia: Oil and Gas Australia, July, 1987, Supplement, p. 56 - 58.
- MIDDLETON, M. F., 1989, A model for the formation of intracratonic sag basins: *Geophysical Journal International*, v. 99, p. 665 - 676.
- MIDDLETON, M. F., 1990, Canning Basin, *in* Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3.
- MITCHUM, Jr., R. M., and VAIL, P. R., 1977, Seismic stratigraphy and global changes in sea level, Part Seven: Seismic stratigraphic interpretation procedure, *in* Seismic stratigraphy - applications to hydrocarbon exploration, *edited by* C. E. PAYTON: American Association of Petroleum Geologists, Memoir 26, p. 135 - 143.
- MOORS, H. T., 1986, The Yellow Drum Formation - a hydrocarbon reservoir, Canning Basin, Western Australia: *APEA Journal*, v. 26, p. 310 - 318.
- MOORS, H. T., GARDNER, W. E., and DAVIS, J., 1984, Geology of the Blina Oilfield, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 277 - 283.
- MURPHY, G. C., BAILEY, A., and PARRINGTON, P. J., 1986, The Blendevale carbonate-hosted zinc - lead deposit, Pillara, Kimberley region, Western Australia: Publications of the 13th Congress of the Council of Mining and Metallurgical Institutions, v. 2, p. 153 - 161.
- PLAYFORD, P. E., 1980, Devonian "Great Barrier Reef" of the Canning Basin, Western Australia: American Association of Petroleum Geologists, Bulletin, v. 64, p. 814 - 840.
- PLAYFORD, P. E., 1982, Devonian reef prospects in the Canning Basin: implications of the Blina oil discovery: *APEA Journal*, v. 22, p. 258 - 272.

- PLAYFORD, P. E., 1984, Platform-margin and marginal-slope relationships in Devonian reef complexes of the Canning Basin, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 189 - 214.
- PLAYFORD, P. E., and LOWRY, D. E., 1966, Devonian reef complexes of the Canning Basin, Western Australia: Western Australia Geological Survey, Bulletin 118.
- PLAYFORD, P. E., HURLEY, N. F., KERANS, C., and MIDDLETON, M. F., 1989, Reefal platform development, Devonian of the Canning Basin, Western Australia, *in* Controls on Carbonate Platform and Basin Development *edited by* P. D. CREVELLO, J. F. SARG, J. L. WILSON, and J. F. READ: Society of Economic Palaeontologists and Mineralogists, Special Publication, No. 44, p. 187 - 202.
- PURCELL, P. G., 1984, The Canning Basin, W.A. - an introduction, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, 582 p.
- PURCELL, P. G., and POLL, J., 1984, The seismic definition of the main structural elements of the Canning Basin, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 73 - 84.
- RASIDI, J. S., 1978, Buried reef structures in the Lennard Shelf, Canning Basin, Western Australia: Australia BMR Journal of Australian Geology and Geophysics, v. 3, p. 80 - 83.
- RATTIGAN, J. H., 1967, Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia: Australasian Institute of Mining and Metallurgy, Proceedings, v. 233, p. 17 - 22.

- REECKMANN, S. A., and MEBBERSON, A. J., 1984, Igneous intrusions in the north-west Canning Basin and their impact on oil exploration, *in* The Canning Basin, W.A. *edited by* P. G. PURCELL: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 389 - 399.
- RIXON, L. K., 1978, Clay modelling of the Fitzroy Graben: Australia BMR Journal of Australian Geology and Geophysics, v. 3, p. 71 - 76.
- SHAW, R. D., STEWART, A. J., and BLACK, L. P., 1984, The Arunta Inlier: a complex ensialic mobile belt in central Australia. Part 2: tectonic history: Australian Journal of Earth Sciences, v. 31, p. 457 - 484.
- SMITH, G., 1984, The tectonic development of the Gregory Sub-basin and adjacent areas, Northeast Canning Basin, *in* The Canning Basin, W.A. *edited by* P. G. Purcell: Geological Society of Australia and Petroleum Exploration Society of Australia; Canning Basin Symposium, Perth, W.A., 1984, Proceedings, p. 109 - 120.
- SMITH, J. G., 1968, Tectonics of the Fitzroy wrench Trough, Western Australia: American Journal Science, v. 266, p. 766 - 776.
- TESSYIER, C., 1985, A crustal thrust system in an intra-cratonic tectonic environment: Journal of Structural Geology, v. 7, p. 689 - 700.
- VAIL, P. R., MITCHUM, Jr, R. M., TODD, R. G., WIDMIER, J. M., THOMPSON, III, S., SANGREE, J. B., BUBB, J. N., and HATLELID, W. G., 1977, Seismic stratigraphy and global changes to sea level, *in* Seismic Stratigraphy - applications to hydrocarbon exploration *edited by* C. E. PAYTON: American Association Petroleum Geologists, Memoir 26, p. 49 - 205.

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Enclosure 1. Part of Canning Basin showing locations of wells, seismic lines, and areas of detailed seismic mapping.