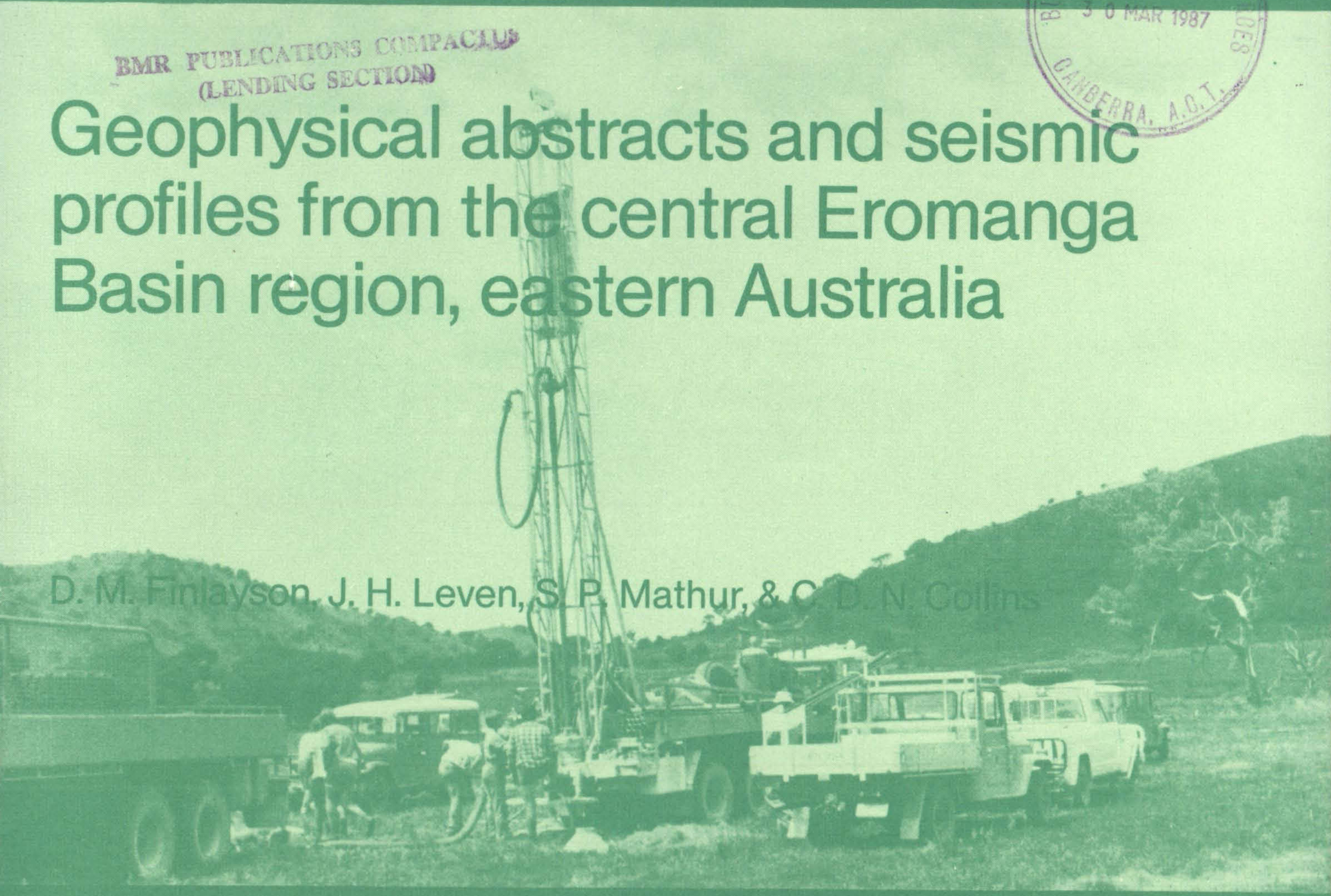
Report 278

Geophysical abstracts and seismic profiles from the central Eromanga Basin region, eastern Australia



D. M. Finlayson, J. H. Leven, S. P. Mathur, & C. D. N. Collins

Bureau of Mineral Resources, Geology and Geophysics

Department of Resources and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 278

GEOPHYSICAL ABSTRACTS AND SEISMIC PROFILES FROM THE CENTRAL EROMANGA BASIN REGION, EASTERN AUSTRALIA

by

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ABSTRACT

In 1980-82, for the first time, multiple-mode explosion seismic methods were applied to examine the structure and composition of a major intra-continental sedimentary basin (the Jurassic-Cretaceous Eromanga Basin), its infra-basins (the Adavale, Cooper and Galilee Basins), and the underlying lithosphere. In the central part of the Eromanga Basin, BMR recorded 1400 km of 20 s seismic reflection profiling data and 700 km of coincident, wide-angle reflection/refraction profiling data to provide an insight into the tectonic structure of the region. The results, to date, together with exploration industry data from a number of companies, have facilitated a regional analysis of sedimentary basin structures. This Report brings together in a single publication the abstracts of 23 papers published or to be published in scientific journals; these papers have largely resulted from BMR seismic work in the Eromanga Basin. Also in this Report are the BMR seismic data and background information on the BMR research project. The details of the various interpretations are available in the full papers published in the journals referred to in this Report.

At depths less than 10 km, the seismic data highlight four major tectonic episodes which have had an influence on structures proving attractive targets for hydrocarbon exploration. The basement rocks were extensively folded, faulted, and intruded during the early Palaeozoic to form the Thomson Fold Belt and have few reflecting horizons, but are shown to have significant lateral and vertical velocity (compositional?) variations. The Devonian sedimentary rocks of the Adavale Basin and its associated troughs, the Quilpie, Cooladdi, Warrabin, Westgate, and Barcoo Troughs, were deformed during two Carboniferous compressional events, the first producing major north-south thrust-faults, and the second producing major east-west folds. Only a thin cover of Permo-Triassic Cooper-Galilee Basin sedimentary rocks accumulated in the region, but, to the southwest outside the study region, the main Cooper Basin sequence is interpreted by other authors as having undergone transpressional deformation in the Late Permian and Triassic. In the mid-Tertiary a fourth major compressive regional tectonic event deformed the Jurassic-Cretaceous sedimentary rocks of the Eromanga Basin sequence and also the rocks of the older infra-basins. All these events are considered to be a result of deeper processes within the continental lithosphere.

The deep structures underlying the basins have a major velocity/compositional boundary at about 20-22 km depth, below which numerous discontinuous reflectors suggest possible mafic/felsic layering in the lower crust resulting from mantle-derived intrusive material. None of the deep seismic reflections continue through to near-surface structures but there is evidence that some features in the lower crustal reflections correlate with near-surface geology, emphasising the large-scale nature of the tectonic processes affecting the region. The velocity structure within the crust to depths of 36-40 km under major basement highs is shown to be different from that under the areas of Devonian sedimentation. Structural features at the margins between the basement highs and the basins can be seen in three-dimensional form on some traverse networks, and indicate that large lenticles or 'pods' of lower crustal rock exist under the basins. These deep lenticles have a significantly higher velocity than the upper crustal rocks.

PART 1: ABSTRACTS OF GEOPHYSICAL PAPERS BY BMR AUTHORS

INTRODUCTION

The interpretation of data from the 1980-82 BMR geophysical surveys has been an ongoing activity for several years, and papers have been published in a number of scientific journals. This Report collects together the abstracts of these papers in a single volume, so that they are readily available to industry and to other research workers.

The 23 abstracts are generally ordered such that papers concentrating on near-surface structures appear first, and those dealing with structures deeper within the crust and lithosphere appear later. Most papers deal mainly with seismic data, but one contains the interpretation of magnetotelluric data, and another is basically an interpretation of gravity data across the Canaway Fault. The seismic papers use a variety of seismic phases, some using predominantly common-depth-point continuous seismic profiling, others using predominantly wide-angle reflected and refracted phases and combinations of different phases in integrated interpretations.

The BMR investigations in the central Eromanga Basin highlight the necessity of using a variety of seismic techniques in the investigation of the structures in the continental lithosphere. Near-surface structures which are of immediate economic importance are linked to processes applying much deeper in the crust and lithosphere. No single technique can provide all the answers to questions regarding complex structures, compositions and evolutionary history, and ambiguities can be resolved only by using multi-mode seismic and other geophysical techniques.

The Australian central Eromanga Basin Project: an introduction.

F. J. Moss & K. D. Wake-Dyster.

Tectonophysics, 100, 131-145, 1983.

The Australian Bureau of Mineral Resources is carrying out a major multidisciplinary program of geological and geophysical studies in southwestern Queensland in cooperation with the Geological Survey of Queensland. The project is aimed at providing information on the regional structure and depositional history of the central Eromanga Basin and the underlying Adavale, Cooper and Galilee basins. The information being obtained is particularly relevant to a better understanding of petroleum prospectivity of the area.

The program includes geophysical surveys involving 1400 km of new six-fold CDP seismic reflection coverage on regional traverses up to 400 km long crossing the main structural elements of the area; gravity measurements along all new seismic reflection traverses; refraction surveys along two major east-west and north-south traverses and magnetotelluric soundings along the same major east-west traverse. LANDSAT imagery studies are providing new perspective on many regional structures when used in conjunction with seismic and gravity information.

Wireline logs and synthetic seismograms are being used with the new seismic data to re-examine stratigraphic correlations. Palynologic and lithologic studies are underway to assist in determining depositional environments. Source rock, maturation, hydrological and geochemical studies

are providing information on the generation and migration of hydrocarbons.

A significant feature of the program is the extension of the recording time of all new reflection data to 20 s to obtain good quality deep crustal reflection information comparable to that obtained on COCORP programs in the United States. The reflection data is being interpreted with the refraction, gravity and magnetotelluric data to investigate the relationship of deep crustal and upper mantle features to the sedimentary basins in the central Eromanga Basin area.

New seismic reflection results in the central Eromanga Basin, Queensland, Australia: the key to understanding its tectonic evolution.

K. D. Wake-Dyster, F. J. Moss, & M. J. Sexton.

Tectonophysics, 100, 147-162, 1983.

Regional seismic traverses were recorded from 1980 to 1982 by the Bureau of Mineral Resources, Geology and Geophysics as part of a major multidisciplinary program aimed at studying the geological evolution of the central Eromanga Basin area and its petroleum potential. Six-fold CMP reflection data were obtained to 20 s reflection time on 1400 km of traverses, up to 400 km long, crossing the main structural features of the area. Additional seismic reflection information to complement the study was obtained from 2300 km of older, mainly single coverage analogue data, which was transcribed to digital format and reprocessed.

The central Eromanga Basin area has a complex history and contains four Phanerozoic potentially hydrocarbon-bearing basins each separated by unconformities, i.e. the Devonian Adavale Basin, the Late Carboniferous to Triassic Cooper and Galilee basins, and the Jurassic-Cretaceous Eromanga Basin. The seismic results are being interpreted, with the aid of synthetic seismograms from key wells, to provide information on the extent, nature and relationship of these basins.

The quality of the reflection data from the Devonian sequence is generally very good and these data are proving to be most useful in the study. Thick Devonian sediments were deposited over a wide area well beyond the present confines of the Adavale Basin and its associated troughs. Intensive folding and faulting accompanied by major basement uplift, including the Canaway Ridge in the centre of the area, took place during the mid-Carboniferous Kanimblan Orogeny. This was followed by a period of erosion which truncated the Devonian sequence and resulted in separation of the Adavale Basin from the other Devonian troughs in the area.

The preliminary seismic results give some indication also of the extent and nature of the Cooper and Galilee basins sediments. These are generally thin in the central area and thicken to the west and east respectively where coal measures produce good lithologic and seismic markers. Gentle folding and minor faulting apparent in the seismic reflection sections from the overlying Eromanga Basin sequence have resulted mainly from basement uplift and minor movements along pre-existing faults continuing into the late mid-Tertiary, and possibly from some compaction of the thick sedimentary section.

The seismic information is also assisting in studies of the petroleum potential of the area, providing information particularly on structuring, timing and depth of burial of the prospective sediments.

Further more detailed interpretation of the seismic reflection results, integrated with other information obtained in the central Eromanga Basin project, which is currently in progress, will add significantly to a clearer understanding of the basin relationships and their history.

Structural styles and basin evolution in the Eromanga region, eastern Australia.

D. M. Finlayson, J. H. Leven, & M. A. Etheridge.

American Association of Petroleum Geologists Bulletin, in press.

The Eromanga region of eastern Australia has undergone at least four major tectonic cycles, the results of which are recognised in the structures seen on seismic records sections. The late Proterozoic-early Phanerozoic cycle ended with the formation of the Thomson Fold Belt which forms basement in the region. The subsequent reactivations of the fault systems within this basement and deeper lithosphere have produced the structural styles now so important as exploration targets. Most reactivations are interpreted as resulting from crustal shortening events affecting sedimentary strata deposited in an epicontinental, shallow-water environment, with small strike-slip adjustments affecting some structures.

The dominant style of deformation evident from the seismic sections is that seen across high-angle thrust faults in other parts of the world, with the amount of overthrusting being comparatively small. Generally the maximum throw on faults in the Devonian strata can be measured in 1000's of metres, whereas those in the Permo-Triassic and Jurassic-Cretaceous strata are a few 100's of metres at most.

The Devonian sequences of the Adavale basin and associated troughs were deformed during two Carboniferous events, the first with crustal shortening in a N-S direction and the second in an E-W direction. Associated small strike-slip movements were accommodated along a number of faults including the Warrego-Grenfield, Warbreccan and Canaway faults. Southwest of our study area, in the Permo-Triassic Cooper basin, others have interpreted a Late Permian NW-SE crustal shortening event and another wrench-induced, NE-SW crustal shortening in the Triassic. In mid-Tertiary time a crustal shortening event regionally affected the Jurassic-Cretaceous Eromanga basin sequence and older sedimentary rocks. This event is seen prominently in a deformation zone between the Canaway and Cunnavalla faults with the direction of crustal shortening being NE-SW. Small stike-slip movements are interpreted as partially decoupling events from neighbouring provinces, the Adavale basin and Cheepie shelf to the east and southeast respectively, and the Cooper basin and Warbreccan dome to the southwest and northwest respectively. In this respect the Canaway, Cunnavalla, Warrego and Warbreccan faults are interpreted as playing an important role.

The basin-modifying tectonic episodes within the lithosphere control the style of structures. These relatively small-scale events have resulted in structures which are providing attractive petroleum prospects.

Basement involved compression and the tectonic evolution of the southern Adavale Basin, Australia.

J. H. Leven, D. M. Finlayson, & M. A. Etheridge.

Submitted to Tectonics.

Major tectonic structures of the southern Adavale Basin are interpreted to have formed during two episodes of basement involved compression. The first episode created thrust faults in a weakly emergent to blind thrust front, which resulted from north-south compression commencing during the Lower Devonian. These thrust faults branch from a basal decollement fault which dips at around 20 degrees within the Thomson Fold Belt, and become significantly steeper within the Devonian sequence. The second compressional episode resulted in reactivation of the transfer faults of the previous episode as thrusts, and the large scale folding of the Devonian sediments during an east-west Late Devonian to Carboniferous compression. These basement faults played a continuing role in the subsequent evolution of this region through their reactivation during later tectonic episodes. Tertiary reactivation of these basement features has deformed the sediments of the Eromanga sequence forming the structures which are now important in the search for petroleum in this basin.

The structural development and hydrocarbon potential of the Palaeozoic source rocks in the Adavale Basin region.

V. L. Passmore & M. J. Sexton.

Australian Petroleum Exploration Association Journal, 24(1), 393-411, 1984.

The Adavale Basin of southwestern Queensland consists of a main depression and several isolated synclinal extensions, traditionally referred to as troughs. The depressions and troughs are erosional remnants of a once more extensive Devonian depositional basin, and are now completely buried by sediments of the overlying Cooper, Galilee and Eromanga Basins. Geophysical and drilling investigations undertaken since 1959 are the only source of information on the Adavale Basin. A single sub-economic discovery of dry gas at Gilmore and a few shows of oil and gas are the only hydrocarbons located in the basin to date.

In 1980, the Bureau of Mineral Resources in cooperation with the Geological Survey of Queensland commenced a major, multidisciplinary investigation of the basins in southwestern Queensland. Four long (>200 km) seismic lines from this study over the Adavale Basin region and geochemical data from 20 wells were used to interpret the Adavale Basin's development and its present hydrocarbon potential.

The new seismic reflection data allow the well explored main depression to be correlated with the detached troughs, some of which have little or no well information. The BMR seismic data show that these troughs were previously part of one large depositional basin in the Devonian, the depocentre of which lay east of a north-trending hingeline. Structural features and Devonian depositional limits and patterns have been modified from earlier interpretations as a result of the new seismic coverage. The maximum sediment thickness is re-interpreted to be 8500 m, considerably thicker than previous interpretations.

Two intra-Devonian unconformities are now recognised. The first one, a diachronous Middle Devonian unconformity, is the most extensive, and reflects the mobility of the basement during the basin's early history. The second unconformity within the Late Devonian Buckabie Formation reveals that there were two phases of deformation of the basin sediments.

The geochemical results reported in this study show that most of the Adavale Basin sediments have very low concentrations of organic carbon and hydrocarbon fractions. Maturity profiles indicate that the best source rocks of the basin are now in the mature stage for hydrocarbon generation. However, at Gilmore and in the Cooladdi Trough, they have reached the dry gas stage. The maturity data provide additional evidence for the marked break in deposition and significant erosion during the Middle Devonian recognised on the seismic records, and extend the limits of this sedimentary break into the northern part of the main depression.

Hydrocarbon potential of the Adavale Basin is fair to poor. In the eastern part of the basin, where most of the data are available, the prospects are better for gas than oil. Oil prospectivity may be improved in any exinite-rich areas that exist farther west, where palaeo-temperatures were lower.

Velocity/depth modelling using reflection and refraction data recorded in the central Eromanga Basin, Queensland, Australia.

J. Lock & C. D. N. Collins.

Tectonophysics, 100, 175-184, 1983.

Seismic refraction recordings along a line extending from Mt Howitt No. 1 well to Eromanga in southwest Queensland, over the Eromanga and Cooper basin sediments, revealed two intra-basement refractors not recorded by coincident reflection profiling. These refractors were recorded at 3.5 km and 5.0 km depth between the basin/basement unconformity at 2.4 km depth and a low velocity zone at about 8.0 km depth. Precise modelling of the refracted first-arrival times showed that the basin structure and faults seen on the reflection profile extended into basement to at least 5.5 km depth, with increasing displacement on the faults with depth, causing lateral variation of structure and velocity.

A feature of the seismic refraction data in this region is a series of up to five multiples which can be observed from 10 km to at least 40 km distance. Travel-time characteristics indicate that these multiples are waves refracted within basement and multiply reflected at the surface. Travel-time modelling of the refracted first-arrivals, multiples and two-way reflection times provides a tight constraint on velocity and structure to a depth of about 5.5 km.

A seismic refraction study of the Quilpie Trough and adjacent basement highs, Eromanga Basin, eastern Australia.

C. D. N. Collins & J. Lock.

Tectonophysics, 100, 185-198, 1983.

The Jurassic-Cretaceous Eromanga Basin in eastern Australia is a relatively undisturbed sedimentary sequence covering the Devonian Quilpie Trough and the Early Palaeozoic Canaway Ridge and Cheepie Shelf. Seismic refraction recording across these three features, with additional reflection, gravity, and well information, has been used to determine the velocity structure to a depth of 10 km. The thickness of the Eromanga Basin sequence along the traverse varies between 1.1 and 1.4 km, with P-wave velocities ranging from 2.0 to 3.8 km/s. The maximum thickness of the underlying Quilpie Trough is about 3.8 km, but the base of the trough is hard to define; the velocities in this Devonian sequence range from 4.0 to 5.0-5.5 km/s. Two small bodies with a velocity of 4.0-4.5 km/s occur immediately below the Eromanga Basin sediments on the Canaway Ridge and the Cheepie Shelf; they may be remnants of Devonian sediments on an erosion surface. The velocities within the ?Ordovician basement are less below the Canaway Ridge than under the Cheepie Shelf and Quilpie Trough. They reach 6.0 km/s at 7 km depth below the ridge, at 4 km depth under the shelf, and at an intermediate depth under the trough. From gravity modelling, the density of basement to the Quilpie Trough increases at a depth of about 7 km; this may be related to volcanics found in the basement further north. The Canaway Ridge has a lower density than the Cheepie Shelf or the basement of the Quilpie Trough; relative vertical movement between these three features may, in part, be related to these density differences.

Basement structure and velocities under the Eromanga Basin from seismic refraction studies.

J. Lock, C. D. N. Collins, & D. M. Finlayson.

Geological Society of Australia, Special Publication 12, 155-162, 1986.

Seismic refraction recordings along a line extending from Mt Howitt 1 to Eromanga, over Eromanga and Cooper Basin sediments, revealed two intra-basement refractors not recorded by coincident reflection profiling. These refractors were recorded at 3.5 and 5.0 km depth between the basal unconformity at 2.4 km depth and a low velocity zone at about 8.5 km depth. Faulting within the basin sediments extends into basement to at least 5.5 km, with increasing displacement with depth, causing lateral variation of structure and velocity. P-wave velocities increase gradationally with depth and average values along the traverse are 2.2 km/s at the surface to 5.0 km/s at the basal unconformity; below that, the velocity increases to 6.0 km/s above a low velocity zone. A sequence of up to five multiples can be observed from 10 km beyond the shot, to at least 40 km and possibly 50 km. Travel-time characteristics indicate that they are waves refracted within basement and multiply reflected at the surface. Travel-time modelling of the first arrivals, multiple arrivals, and two-way reflection times provide a tight constraint on the velocity and structure to a depth of about 5.5 km.

Lower crustal involvement in upper crustal thrusting.

J. H. Leven & D. M. Finlayson.

Geophysical Journal of the Royal Astronomical Society,
in press.

Basement structures mapped in the Devonian Adavale Basin, eastern Australia, indicate two styles of lower-crustal involvement in the formation of upper-crustal structures. The first style is typified by thrust features in the upper-crustal sedimentary section and basement; a response to lower-crustal shortening over an extended area. The second style includes lower-crustal thrusting and thickening in a limited region, with associated uplift of the upper crust. These two styles suggest that the upper and lower crust were mechanically decoupled during Palaeozoic compressive episodes.

Detailed seismic refraction studies in the central Eromanga Basin, Queensland.

C. D. N. Collins & J. Lock.

To be submitted to BMR Journal of Australian Geology & Geophysics.

In 1980/81 shallow refraction studies were undertaken in the central Eromanga Basin to obtain the velocity structure of the basin, the underlying sub-basins, and in particular, the basement. Recordings were made along a 262.5 km traverse coincident with six-fold CMP profiling and deep refraction. The traverse extended between Mt. Howitt No. 1 well in the west to GSQ Quilpie No. 1 well in the east, crossing the eastern margin of the Cooper Basin, the Warrabin Trough, Canaway Ridge, Quilpie Trough, and Cheepie Shelf. An iterative forward modelling approach was taken to interpret the data. The velocity/depth models were constrained by ray-tracing and computing synthetic seismograms to match the observed refracted and reflected arrivals, including multiples. The models were further tested by comparing their calculated gravity effect with the observed gravity.

The Jurassic-Cretaceous Eromanga Basin forms a continuous cover along the entire profile, varying from about 2 km thick in the west to 1 km in the east. The velocity at the surface varies from 2.0 to 2.4 km/s and increases to 3.8-4.2 km/s at the bottom of the sequence. Below the Eromanga Basin, the Permo-Triassic Cooper Basin sediments are about 550 m thick at Mt. Howitt, and gradually wedge out at the western margin of the underlying Devonian Warrabin Trough. The Warrabin Trough is bounded by high-angle faults, and varies in thickness from 1.1 to 3.0 km. The Canaway Ridge separates it from the Quilpie Trough, which is synclinal in form and varies in thickness from 0 to 3.8 km. The velocities in the troughs vary from about 4.3 km/s near the unconformity with the overlying Eromanga Basin, to between 5.0 and 5.5 km/s at the base. The bottom of the troughs is not clearly defined, but reflections interpreted as coming from the Gumbardo volcanics are assumed to be from near basement.

Velocities within the top of the basement vary from 4.8 km/s in the Canaway Ridge and Cheepie Shelf, to about 5.7 km/s beneath the troughs. The velocity increases with depth to 6.0 km/s at a depth of 4.0 km under the Cheepie Shelf, and over 8.0 km elsewhere. The higher velocities nearer the surface below the Cheepie Shelf coincide with a shallowing of mid-crustal reflections, from about 8 seconds two-way-time to about 6 seconds. Strong velocity gradients near the top of the basement may be due to weathering when the basement surface was exposed prior to deposition of the Eromanga Basin. This gradient, along with the low surface velocity, causes very prominent multiple refractions between the surface and the basement. Variations in observed gravity along the traverse can be satisfactorily attributed to the shallow structures within the top 10 km, with a slightly thinner crust in the west to account for a small regional gradient.

The Warrabin Trough, western Adavale Basin, Queensland.

J. Pinchin & B. R. Senior.

Journal of the Geological Society of Australia, 29, 413-424, 1982.

The Warrabin Trough in SW Queensland contains up to 3000 m of Devonian sedimentary rocks, and is a structural remnant of the formerly widespread Adavale Basin. Seismic data recently obtained by the Bureau of Mineral Resources enable reinterpretation of existing poorer quality seismic data, so that the structural framework and most of the trough margin can be mapped.

Sedimentary rocks in the trough are folded and are displaced by high-angle reverse faults, which were probably active during the Late Carboniferous. LANDSAT studies provide additional information on the position of faults, which on seismic records appear to be mainly contained within the trough sequence. Differential compaction, together with slight post-Cretaceous rejuvenation of some structures, may have given surface expression to some of these deep faults.

The western margin of the trough has been drilled, but only 775 m of the Devonian sequence was penetrated. The petroleum source-rock and maturation levels do not appear encouraging on the basis of this drilling. However, the thick sequence of arenites, lutites and carbonates, interpreted to occur in the trough, offer considerable potential for hydrocarbon source-rocks and reservoirs.

The Canaway Fault and its effect on the Eromanga Basin.

J. Pinchin & V. Anfiloff.

Geological Society of Australia, Special Publication 12, 163-173, 1986.

The Canaway Fault is a 250 km long north-trending near-vertical fault within the Eromanga Basin, Queensland. It forms the eastern margin of the Canaway Ridge which separates the Cooper Basin from the Galilee Basin. Recent seismic and gravity data show that the fault is in places associated with granitic intrusions, and that a palaeo-high below the Canaway Ridge had some effect on early deposition within the Adavale Basin. Seismic data also show that movement of the fault began in the mid-Carboniferous, followed by almost continuous movement from the Permian to the late Middle Tertiary. The Canaway Fault is unlikely to have acted as a total barrier to migration of hydrocarbons from depocentres of the Eromanga Basin because fault displacement of Jurassic reservoir rocks was only 47 m in Late Cretaceous times, and the monoclinal appearance on seismic sections suggest no complete break in these rocks. However, anticlines adjacent to the fault have not been fully explored and could present prospective exploration targets.

<u>**The mid-crustal horizon under the Eromanga Basin, eastern Australia.**</u>

D. M. Finlayson.

Tectonophysics, 100, 199-214, 1983.

Long-line explosion seismic recordings indicate that a major mid-crustal P-wave velocity increase exists under the Eromanga Basin which contrasts the crust of this region from its neighbouring tectonic provinces. The velocity increase is shown to be a regional feature and to correspond to the upper boundary of a zone of discontinuous seismic reflections characteristic of the lower crust. The velocity increase of 0.35-0.6 km/s occurs over a small depth range at an average depth of 24 km. This velocity gradient produces conspicuous wide-angle reflections at distances greater than 60 km from the shot point. The seismic data present the clearest evidence to date of the existence of a major mid-crustal horizon in continental Australia, a feature not prominent in other cratonic provinces which have been investigated in detail. The velocity in the lower crust below the horizon is 6.7-7.0 km/s. The horizon represents a boundary between the upper and lower crust which could imply a different tectonic history for these two zones.

<u>**Deep crustal reflection results from the central Eromanga Basin, Australia.**</u>

S. P. Mathur.

Tectonophysics, 100, 163-173, 1983.

From 1980 to 1982 deep seismic reflection profiles were recorded across the central Eromanga Basin in eastern Australia to study the regional structure, stratigraphy and geological history of the Eromanga Basin and infrabasins. The reflection data were recorded to 20 s to obtain additional information on the nature and structure of the crust below the sediments and their relationship to the development of the basins.

The seismic sections show good quality reflections from the deep crust as well as from the sedimentary layers. Based on the character, strength, coherence, continuity and spatial distribution of the reflections, the sections can be divided into four zones. The top zone between 0 and 2.5 s shows fairly uniform, coherent and continuous events which correlate with the Mesozoic and late Palaeozoic sediments. The zone from 2.5 to 8 s (4 to 22 km) does not show any primary reflections and is interpreted as the highly-deformed metasedimentary and metavolcanic rocks of the Early Palaeozoic Thomson Orogen underlying the sediments. Without any recognisable reflection or diffraction patterns in this zone, it is difficult to say whether the faulting and folding observed in the sediments extend into the upper crustal basement. The deeper zone of numerous reflection segments between 8 and 12.5 s (22 to 36 km) is interpreted as thin laminae of alternating low and high velocity (intermediate and basic) rocks, and correlates with the lower crust bounded by refraction velocity discontinuities. The lowest zone of no reflections below 12.5 s corresponds with the upper mantle.

The reflection character and thickness as well as the refraction velocity structure of the crust under the central Eromanga Basin area are significantly different from those of the Precambrian crust under the Georgina Basin to the northwest. It is proposed that the crust under the Eromanga Basin is extensionally attenuated crust which had been intruded by sills of basaltic melt from the underlying asthenosphere.

Deep reflection probes in eastern Australia reveal differences in the nature of the crust.

S. P. Mathur.

First Break, 1(7), 6-16, 1983.

Since 1976 the Australian Bureau of Mineral Resources (BMR) has obtained good quality deep reflection data during sedimentary basin surveys using modern digital recording and processing techniques. Most of these recordings, made on an experimental basis, showed that good reflections could be obtained from the deep crust without extra effort other than increased recording time, and that such data over long traverses are required to study the deep crust and upper mantle in detail. The deep reflections discussed here were generally recorded over relatively short traverses and thus do not provide sufficient quantity of data to investigate the horizontal variation of the deep crustal structure. However, the strength, coherence, continuity and spatial distribution of the reflections from the deep crust provide valuable information on the nature of the crust in several areas of eastern Australia with a resolution higher than is possible from any other geophysical method.

In several sedimentary areas of eastern Australia zones of numerous, relatively short, sub-horizontal reflection segments in the middle and lower crust show significant differences in their reflection characteristics between the Phanerozoic and Precambrian domains.

In the Phanerozoic domain the crust is relatively thin (up to 13 sec or 43 km), the segments are up to 3 km long, strong, coherent and usually concentrated in bands 1-4.5 sec thick within the deep crust and limited to about 13 sec reflection time. The correlation of relatively sharp refraction boundaries with the bands of reflecting segments in the Phanerozoic domain suggests that the change in the rock types in the middle and lower crust occurs through transition zones which are composed of a mix of thin laminations of diverse rock types, and that the boundaries within the deep crust are broad zones in contrast to the sharp interfaces within the sediments. This correlation also suggests that the bands detected locally by the reflection method are long-range features of the crust as detected by the refraction method.

In the Precambrian domain the crust is thick (>16 sec or 50 km), the reflection segments are short (<1 km), weak and evenly dispersed throughout the deep crust. The absence of distinct bands of reflection segments and of sharp increases in the refraction velocities within the deep crust, suggests a more gradual change in the bulk composition of the rocks with depth through thin laminations of varying composition and velocity which are distributed throughout the middle and lower crust.

The general increase in strength, coherency, continuity and density of reflection segments with depth in both domains probably reflects the increasing effect of temperature and pressure in aligning laminations horizontally. It is not possible to interpret the deep reflection zones in terms of geology until such zones can be traced to the outcrops or to depths accessible by the drill.

The differences observed in the seismic reflection structure of the crust in the Phanerozoic and Precambrian domains is consistent with the differences observed in the refraction velocity and electrical conductivity structure of the crust and upper mantle, which are interpreted by others to suggest a shallower, active tectonic environment within the subcrustal lithosphere under eastern Australia than under the remainder of the continent.

P-wave velocity features of the lithosphere under the Eromanga basin, eastern Australia, including a prominent mid-crustal (Conrad?) discontinuity.

D. M. Finlayson, C. D. N. Collins, & J. Lock.

Tectonophysics, 101, 267-291, 1984.

The crustal structure of the central Eromanga Basin in the northern part of the Australian Tasman Geosyncline, revealed by coincident seismic reflection and refraction shooting, contrasts with some neighbouring regions of the continent. The depth to the crust-mantle boundary (Moho) of 36-41 km is much less than that under the North Australian Craton to the northwest (50-55 km) and the Lachlan Fold Belt to the southeast (43-51 km), but is similar to that under the Drummond and Bowen Basins to the east.

The seismic velocity boundaries within the crust are sharp compared with the transitional nature of the boundaries under the North Australian and Lachlan provinces. In particular, there is a sharp velocity increase at mid-crustal depths (21-24 km) which has not been observed with such clarity elsewhere in Australia (the Conrad discontinuity?).

In the lower crust, the many discontinuous sub-horizontal reflections are in marked contrast to lack of reflecting horizons in the upper crust, further emphasising the differences between the upper and lower crust. The crust-mantle boundary (Moho) is characterised by an increase in velocity from 7.1-7.7 km/s to a value of 8.15 ± 0.04 km/s. The depth to the Moho under the Canaway Ridge, a prominent basement high, is shallower by about 5 km than the regional Moho depth; there is also no mid-crustal horizon under the Canaway Ridge but there is a very sharp velocity increase at the Moho depth of 34 km. The Ridge could be interpreted as a horst structure extending at least to Moho depths but it could also have a different intra-crustal structure from the surrounding area.

The sub-crustal lithosphere has features which have been interpreted, from limited data, as being caused by a velocity gradient at 56-57 km depth with a low velocity zone above it.

Because of the contrasting crustal thicknesses and velocity gradients, the lithosphere of the central Eromanga Basin cannot be considered as an extension of the exposed Lachlan Fold Belt or the North Australian Craton. The lack of seismic reflections from the upper crust indicates no coherent acoustic impedance pattern at wavelengths greater than 100 m, consistent with an upper crustal basement of tightly folded meta-sedimentary and meta-volcanic rocks. The crustal structure is consistent with a pericratonic or arc/back-arc basin being cratonised in an episode of convergent tectonics in the Early Palaeozoic. The seismic reflections from the lower crust indicate that it could have developed in a different tectonic environment.

Crustal differences between the Nebine Ridge and the central Eromanga Basin from seismic data.

D. M. Finlayson & C. D. N. Collins.

Australian Journal of Earth Sciences, 34, in press.

The Nebine Ridge in southeastern Queensland has crustal velocity features determined from wide-angle reflection/refraction seismic data which contrast it with areas of thick sedimentation under the Eromanga Basin to the west. The depth to the crust/mantle boundary is at least 38 km; at this depth the interpreted P-wave velocity of 7.7 km/s is low by comparison with the 8.15 km/s upper mantle velocity under the Eromanga Basin, and is probably only a transitional value to a higher, true, upper mantle velocity at greater depths (40-45 km). There is no prominent mid-crustal velocity horizon under the Nebine Ridge as there is under the thick sediments of the central Eromanga Basin and its infrabasins, and the velocities in the lower crust are less under the Nebine Ridge. There are, however, similarities between the crustal velocity structure of the Nebine Ridge and the Canaway Ridge. It is evident that there are tectonic elements within the Tasman Geosyncline with quite different velocity features in the crust.

Seismic refraction and reflection features of the lithosphere in northern and eastern Australia, and continental growth.

D. M. Finlayson & S. P. Mathur.

Annales Geophysicae, 2(6), 711-722, 1984.

Seismic refraction and reflection data from a transect of the lithosphere across Proterozoic and Phanerozoic eastern Australia indicate that the depth to the upper mantle under outcropping igneous, metamorphic and fold belt provinces is 10-15 km greater than that under the intra-cratonic basins. This is probably a result of crustal underplating during episodes of high thermal flux from the mantle. Under the larger basins the upper crustal basement is mostly transparent to vertical seismic waves (i.e. there are few reflecting horizons) whereas the lower crust displays multiple reflecting horizons : the velocity boundary at mid-crustal depths is a prominent feature, seen also under intra-cratonic basins on other continents. The different character of reflecting horizons in the upper and lower crust suggests separate tectonic histories.

Under outcropping igneous, metamorphic and fold belt provinces their complex tectonic history is displayed in the multiplicity of both the upper and lower crustal velocity/depth distributions. In the lower crust the velocity changes are transitional rather than sharp : seismic reflecting horizons are shorter and more varied under the Proterozoic than under the Phanerozoic provinces, consistent with the relative youth of the latter.

In the sub-crustal lithosphere there are few, if any, seismic reflecting horizons but there are velocity changes with depth which indicate geochemical zonation. The upper mantle velocity under the Proterozoic crust is about 8.15 km/s on average and about 8.06 km/s under Phanerozoic Australia. There is no obvious difference between upper mantle velocities measured north-south from those measured east-west under the North Australian Craton. Deeper in the mantle there is an increase in velocity to about 8.3 km/s interpreted at its shallowest (55 km) under the central Eromanga Basin.

The crustal growth patterns indicated by the seismic data, together with xenolith studies, suggest that the Phanerozoic development of eastern Australia was propagated by episodes of high geothermal flux from the mantle rifting and underplating/intruding a pre-existing crust. The development of the major basins on the eastern margin of the Precambrian craton probably has analogues in central/western European basin development.

Improvements in seismic reflection techniques for studying the lithosphere in Australia.

S. P. Mathur.

Tectonophysics, 105, 373-381, 1984.

Over the last 25 years the Australian Bureau of Mineral Resources (BMR) has attempted to record seismic reflection data in several parts of Australia to determine if good quality near-vertical reflections could be obtained from the deep crust and upper mantle. Data recorded prior to 1976, using analogue instruments and large shots, did obtain good to fair quality deep events, but the short lengths of the traverses recorded did not allow discrimination between primary reflections and the coherent noise. The high cost of the special effort prevented recording of long traverses, and hence the study of the true nature of the deep reflections. From 1976 onwards, with the advent of digital recording and processing equipment and techniques, it became possible to obtain good quality deep reflection data on long traverses with the parameters such as small charges, short spreads, etc. which are normally used for recording good sedimentary reflections. The recent data allow better identification of reflections and study of their character, and provide a higher resolution picture of the nature and structure of the deep crust and upper mantle, than had been possible before. BMR is, therefore, now recording good deep reflection data on all traverses during normal sedimentary basin surveys, and accumulating the information necessary for studying the evolution of lithosphere in Australia.

Lithospheric velocity beneath the Adavale Basin, Queensland, and the character of deep crustal reflections.

D. M. Finlayson & C. D. N. Collins.

BMR Journal of Australian Geology & Geophysics, 10, 23-37, 1986.

Along a traverse across the main depression of the Devonian Adavale Basin in western Queensland, lateral variations in lithospheric velocity are predominantly displayed in the upper 15 km of the crust. In this region, Devonian sediments (up to 7 km thick) underlie the Jurassic-Cretaceous Eromanga sequence (up to 2 km thick) with only minor pockets of intervening Permo-Triassic sediments of the Cooper and Galilee Basins. P-wave velocity in the sediments ranges from 2.0 to 5.5 km/s. Underlying the Devonian sediments is a 2-3 km thick basement transition zone of highly folded, faulted, and sheared rocks, where metamorphic grade increases and weathering decreases with depth, and velocity increases from 5.6 to 5.85 km/s. Upper crustal basement extends to 24-25 km with velocity increasing from 5.9 km/s below the basement transition zone to 6.4 km/s above a mid-crustal horizon. Multiply refracted phases suggest the velocity gradient of 0.02-0.03 km/s/km in the upper crustal basement is fairly uniform along the traverse. The increase in mid-crustal velocity from 6.4 to 6.6-6.7 km/s is a prominent feature of the lithosphere. It marks the upper boundary of the lower crustal reflection zone evident from continuous reflection profiling. Within this zone the velocity increases to 6.8-7.1 km/s at the top of the crust/mantle transition zone at a depth of about 35 km. Neither the mid-crustal velocity horizon nor the Moho varies greatly in depth. The upper mantle velocity of 8.15 km/s is reached at 38-40 km depth, the same as that measured on an east-west cross traverse. The preferred interpretation of the lower crustal velocity gradient and reflections is that they arise from extensive lower crustal magma intrusion during the formation of quasi-continental crust and that subsequent thermal events have enabled isostatic readjustment and basin formation in a compressive regime.

The resistivity structure of the crust and upper mantle in the central Eromanga Basin, Queensland, using magnetotelluric techniques.

A. G. Spence & D. M. Finlayson.

Journal of the Geological Society of Australia, 30, 1-16, 1983.

Magnetotelluric data from the central Eromanga Basin indicate that one-dimensional resistivity models are appropriate for the region. The uppermost Jurassic-Cretaceous Eromanga Basin sequence contains flowing aquifers and has an average section resistivity in the range 1 to 7 ohm m with a mean of 4 ohm m. This overlies the older sedimentary sequences of the Cooper (Permo-Triassic) and Adavale (Devonian) Basins with resistivities in the range 10 to 400 ohm m, which present good resistivity contrasts for determining sub-surface morphology at the base of the Eromanga sequence. The depth extent of the older sequences is not well resolved because of the overlying highly conductive layers, but it appears to be greater than that determined from seismic reflection data in the Coonavalla Syncline and Warrabin Trough.

Basement rocks of the Thomson Fold Belt have resistivities in the range 750 to 3800 ohm m with an average of 1300 ohm m. This resistivity is evident to depths of 40-60 km, and consequently represents the resistivity of the Earth's crust in the region. No highly conductive layers were detected within this crustal sequence. In the depth range 60 to 150 km, resistivities decrease to less than 5 ohm m. Such resistivities at 150 km depth are in broad agreement with data obtained from magnetometer array studies in southeastern Australia, which are explained by other authors in terms of a 5% partial basalt melt.

3-dimensional image of the lower crust under an intra-continental basin in eastern Australia.

D. M. Finlayson & J. H. Leven.

Exploration Geophysics, 18, in press.

Seismic investigations of deep crustal features under the central Eromanga Basin in eastern Australia were conducted during 1980-82 and these provided a network of seismic reflection traverses with, in some places, coincident wide-angle reflection and refraction traverses. This network enables a new insight into deep structures under a major intra-continental sedimentary basin and at the intersection points of traverses the 3-dimensional structure of deep features can be examined.

Within basement BMR seismic data show that there are few reflections at two-way times of 3-8 seconds, this part of the crust being described as "transparent". However, at greater two-way times the character of the reflection events changes dramatically. Between 8 and 13 seconds there are many discontinuous sub-horizontal reflecting segments under the regions of Palaeozoic sedimentation such as the Adavale Basin and its associated Barcoo, Warrabin and Quilpie Troughs. Under adjacent basement highs such as the Grenfield Uplift, Pleasant Creek Arch, Windorah Anticline and Canaway Ridge there is a marked reduction in continuity and amplitude of deep reflections which seems unrelated to near-surface recording conditions.

These deep reflectors in the lower crust at depths of 20-40 km are not featureless. Bearing in mind the considerable geological complexities along raypaths through the upper crust, some events from the lower crust display considerable continuity as narrow bands of reflected energy 200-300 ms thick. These bands dip away from the central part of, for example, the Barcoo Trough and data from the traverse intersection point provides substantial confirmation that the events are primary reflections and result from structure within the lower crust.

The shallowing of the deep reflecting bands towards the centre of the Barcoo Trough with a minimum at 7.0-7.5 seconds suggests that the material in the lower crust is taking on a lenticular or "pod" shape, being thickest under the basin and almost disappearing under the basement highs to the west (Windorah Anticline) and east (Canaway Ridge). The lower boundary of the lenticle is the crust/mantle boundary where reflections disappear at about 13 seconds two-way time. Examples of lenticular structures are evident in the deep seismic data from other BMR traverses where they cross from basement highs into Palaeozoic basins or troughs.

The wide-angle reflection and refraction data coincident with BMR traverses 1, 9 and 10 show convincingly that the upper boundary of the lenticle coincides with a marked increase in crustal velocity and that the lower boundary corresponds to the transition from crustal velocities to upper mantle velocities. These data also indicate that the crustal velocity structure under the basement highs is significantly different from that under the Palaeozoic basins.

The uppermost deep reflections are interpreted as being from a major lithological discontinuity, for example, the top of a major intrusion. The fact that the character of reflections below this boundary contrasts strongly with the "transparent" nature of the overlying crust suggests that the development of the lower crust is a younger feature than that of the early

Palaeozoic Thomson Fold Belt rocks which form upper crustal basement. The lower crustal features are consistent with their development during Devonian basin evolution. The dipping upper boundary of the lenticle towards the edges of the basins and troughs is discordant with the relatively flat-lying crust/mantle boundary and suggests that this latter boundary is an even younger feature.

The possibility that the lower crustal reflections arise from a major fault extending through the crust such as that envisaged for extensional basins seems unlikely on present evidence. Also, the Eromanga lower crustal reflections have different characteristics from those on major thrusts extending through the crust such as the Wind River Thrust and the Flannan Fault. None of the Eromanga lower crustal reflections extend into the upper crust and the velocity contrast between the upper and lower parts of the crust suggest different evolutionary histories. Thrusting limited to the lower crust must, however, also still be considered a possibility.

Lithospheric structures and possible processes in Phanerozoic eastern Australia from deep seismic investigations.

D. M. Finlayson & J. H. Leven.

Tectonophysics, 133, in press.

The Eromanga Basin in eastern Australia developed during four major episodes on the rifted eastern margin of the Australian Precambrian craton. Seismic reflection profiling, together with coincident wide-angle reflection/refraction profiling, indicates structures and compositions in the crust which are dominant in various depth ranges. Some structural features seem to be limited to the upper crust. Other deep reflection events and high crustal velocities predominate in the lower crust with mafic intrusion from upper mantle sources being one preferred interpretation. These features emphasize the difference in structures and composition between the upper and lower parts of the crust. Yet other structural and deep reflection features are interpreted as being truly lithospheric in scale because they seem to have seismic expression right from the surface to the upper mantle. Similar interpretations are made for other continental regions indicating that lithospheric processes affect different depth ranges of the crust and upper mantle in a variety of ways; any modelling of such processes in the lithosphere must lead to these quite different end results at appropriate depth ranges.

PART 2: SEISMIC PROFILES FROM THE CENTRAL EROMANGA BASIN REGION

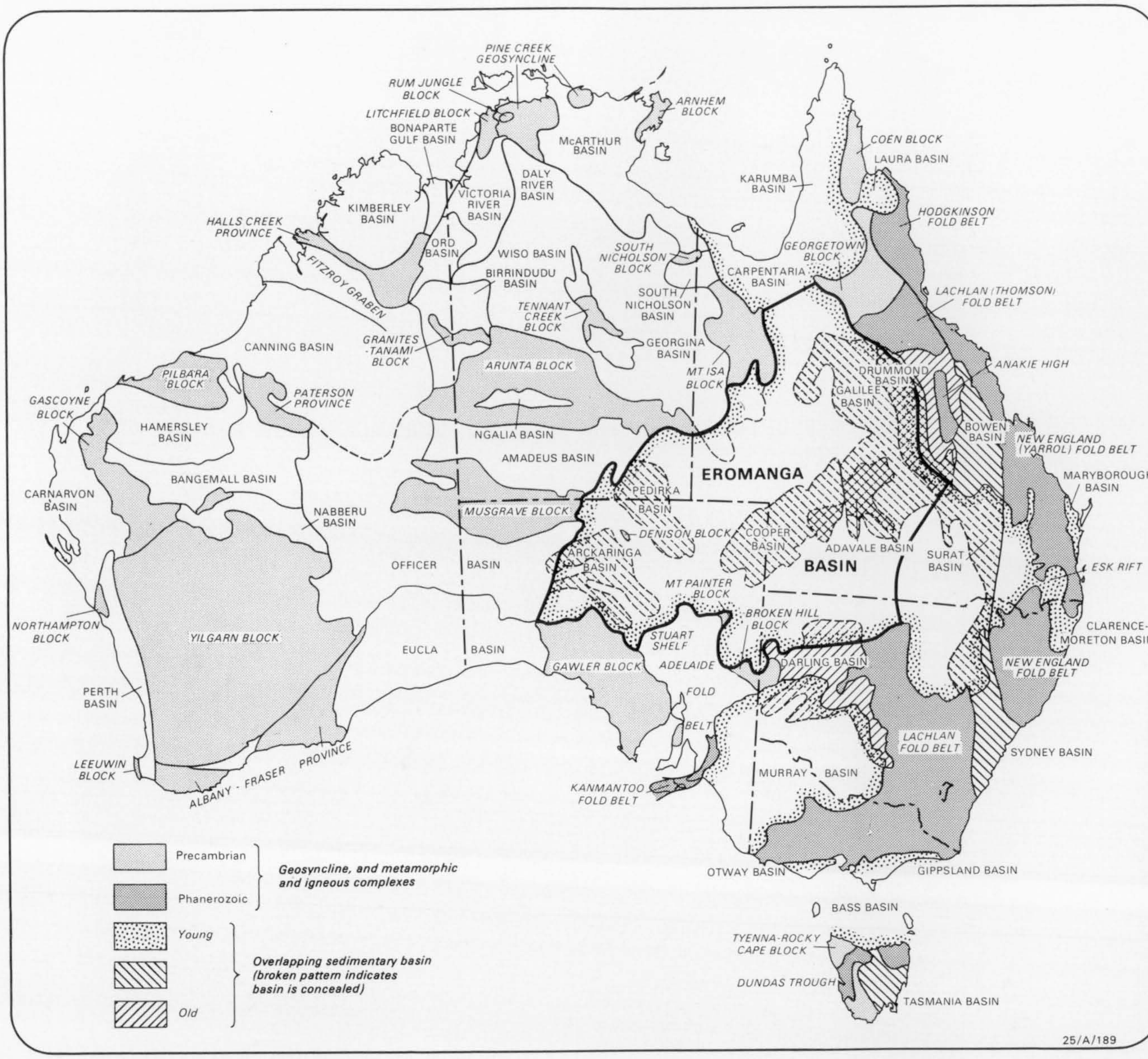


Fig. 1. The Eromanga Basin in relation to other Australian geological provinces.

INTRODUCTION

The Eromanga Basin in eastern Australia is large by world standards and covers an area of about 1 000 000 square kilometres. This area is of considerable interest to the hydrocarbon exploration industry because the southwestern part of the basin is the location of Australia's principal onshore oil and gas production wells (Fig. 1, Moore & Mount, 1982). In 1980-82 BMR conducted a program of seismic investigations in the central Eromanga Basin region (Fig. 2) as part of a multi-disciplinary investigation into the structure and evolution of the region (Moss & Wake-Dyster, 1983). This seismic program included the recording of 1400 km of six-fold CDP reflection profiles along 13 traverses (Fig. 2). Recording times on these traverses were 20 s two-way-time (TWT), so that structures within basement underlying the basin sediments could be investigated. The seismic program also included 700 km of wide-angle reflection/refraction profiling along three traverses, to determine the velocities deep in the underlying basement (Fig. 3), and two expanded-spread reflection profiles to determine more precisely the stacking velocities for use with the six-fold CDP reflection profiling data from the deeper sedimentary sequences and basement. This seismic survey was the first in which there were successful attempts to integrate a number of controlled source seismic methods in the investigation of the structure of a major continental basin.

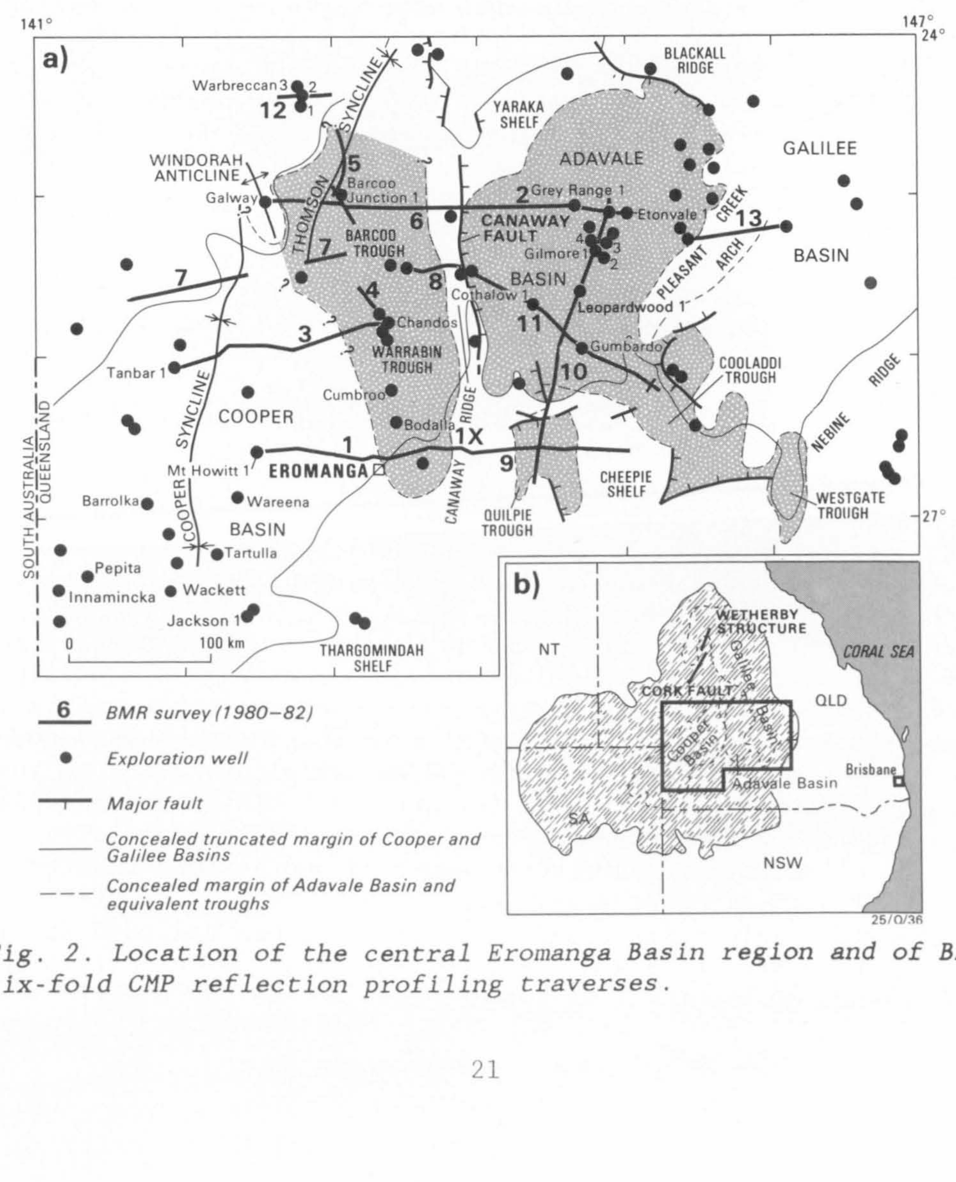


Fig. 2. Location of the central Eromanga Basin region and of BMR six-fold CMP reflection profiling traverses.

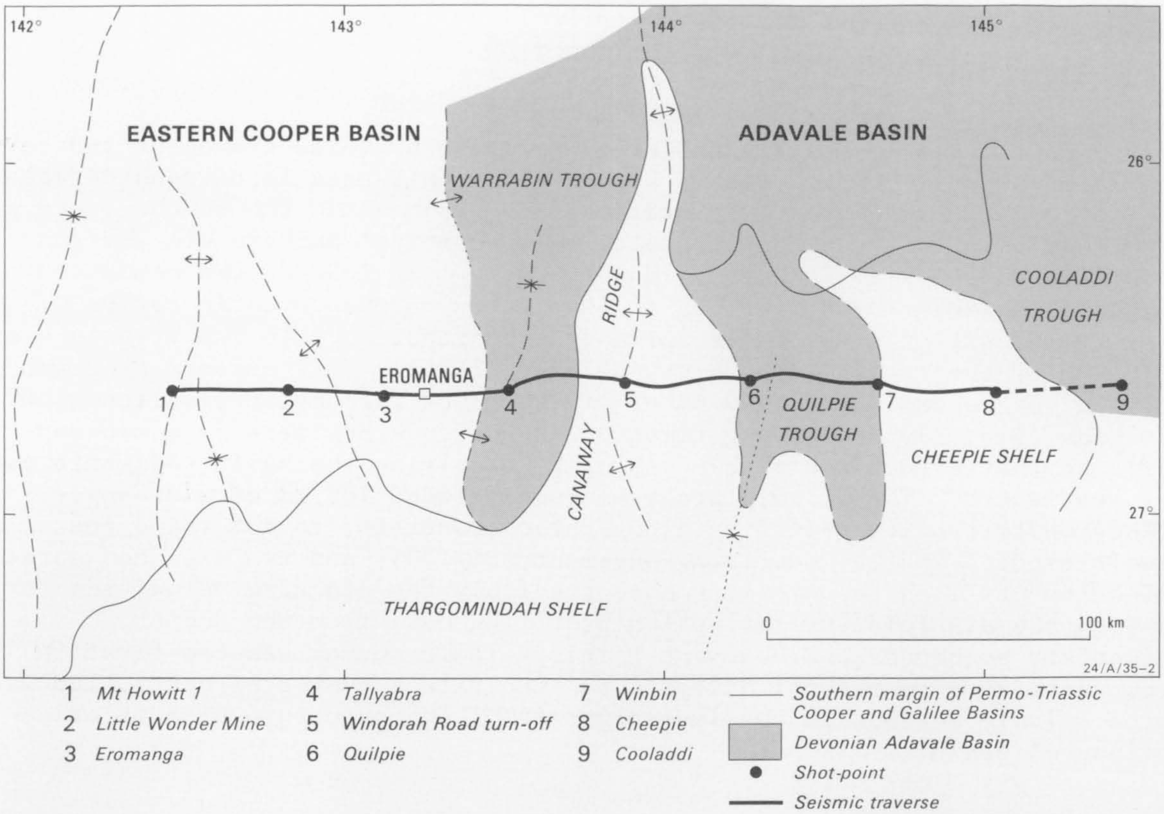


Fig. 3a. Location of short-distance wide-angle reflection/refraction traverses.

The seismic research in the central Eromanga Basin provides a data set which forms the basis for examining, in some detail, the deep structures underlying a major sedimentary basin. Part 2 of this Report presents much of the seismic data, together with a commentary on the geological processes which may be contributing to the structures of the region. The data set constitutes a major Australian contribution to the analysis of the structure of intra-continental basins, and as such is published here for wider comment by geoscientists. Over 1000 km of seismic reflection profiling is presented in the form of seismic record sections.

Harrison & others (1980) presented a background document to the seismic survey program in the central Eromanga Basin region. Before the BMR survey, only small parts of the region had been explored by multiple-fold common-mid-point (CMP) reflection seismic methods; the region was divided into a large number of exploration leases, none of which spanned the whole basin; and the Jurassic-Cretaceous Eromanga Basin had a number of older infrabasins which were ill-defined (Fig. 4). Hence, there was a need for a number of regional seismic reflection traverses to be recorded. The BMR traverses were designed to provide, to the exploration industry, regional information on stratigraphy and structure, which in turn would yield valuable information about the processes occurring within basement to the sedimentary sequences. Consequently, a seismic program was arranged to facilitate research into the deeper features of the region, so that further constraints could be placed on evolutionary models for the Eromanga Basin and its infrabasins. The reflection mode of seismic investigation was regarded as important to determine deep structures where significant subhorizontal impedance contrasts exist, and the wide-angle reflection/refraction mode was regarded as important to further constrain structure and provide information on velocities, and hence compositions, of the rocks in the basement to the basins.

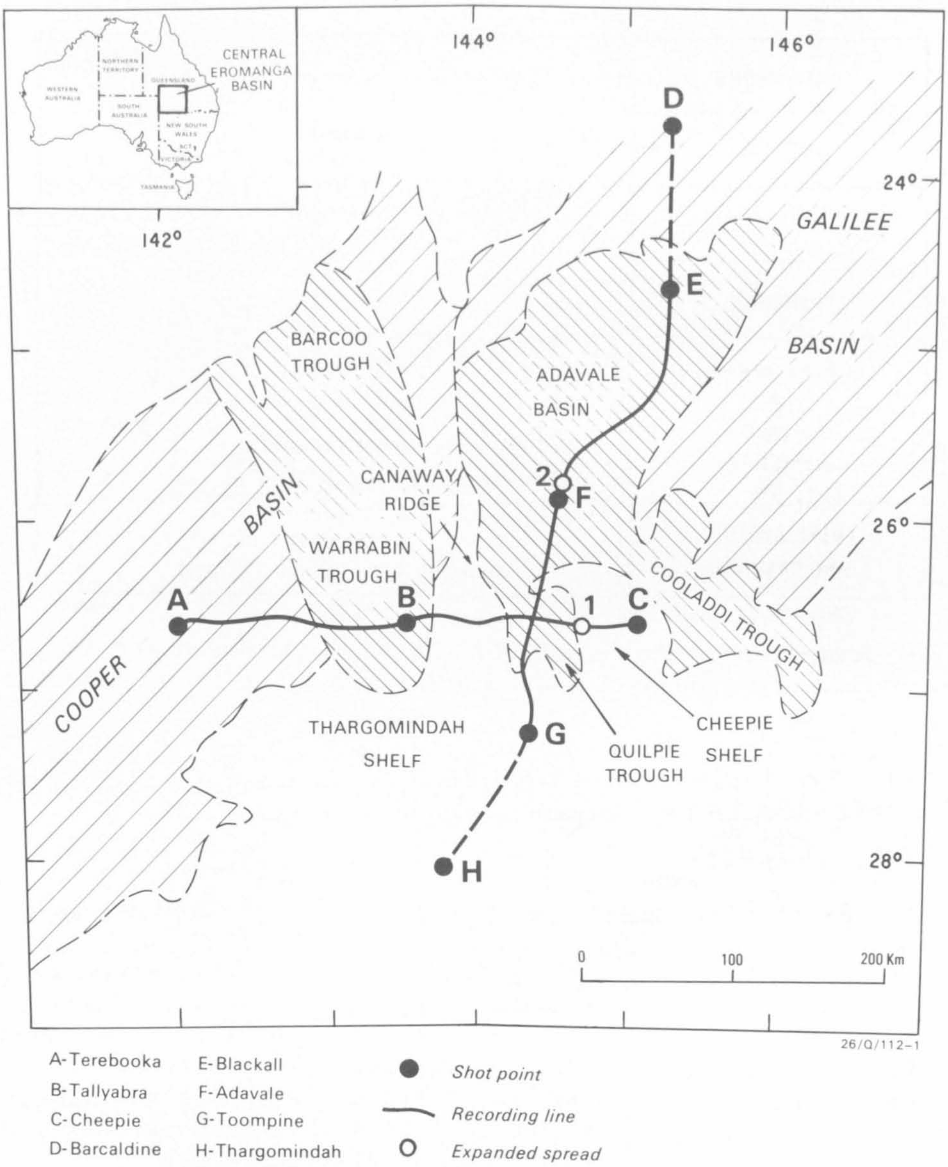


Fig. 3b. Location of long-distance wide-angle reflection/refraction traverses and expanded-spread traverses. 1 = BMR traverse 9 expanded spread; 2 = BMR traverse 10 expanded spread.

GEOLOGICAL BACKGROUND

An interpretation of the early Palaeozoic tectonic evolution of the central Eromanga Basin region is hindered by a scarcity of outcrop and drillcore. However, in the time interval 600 to 130 Ma, during which the sedimentary basins of the region were formed, Australia, along with India and Antarctica, was part of eastern Gondwanaland (Embleton, 1984). If the palaeolatitude of the region is assumed to have followed that of eastern Gondwanaland, then it varied from 5-30 degrees north during the Cambrian and Ordovician and then drifted southward from the Silurian onwards, reaching a maximum of 80 degrees south in the Early Triassic before returning to its present latitude of about 24 degrees south. The possibility of elements of Palaeozoic eastern Australia being displaced terranes accreted to the main Australian continent cannot be discounted. The first phase of major rifting in eastern Gondwanaland occurred

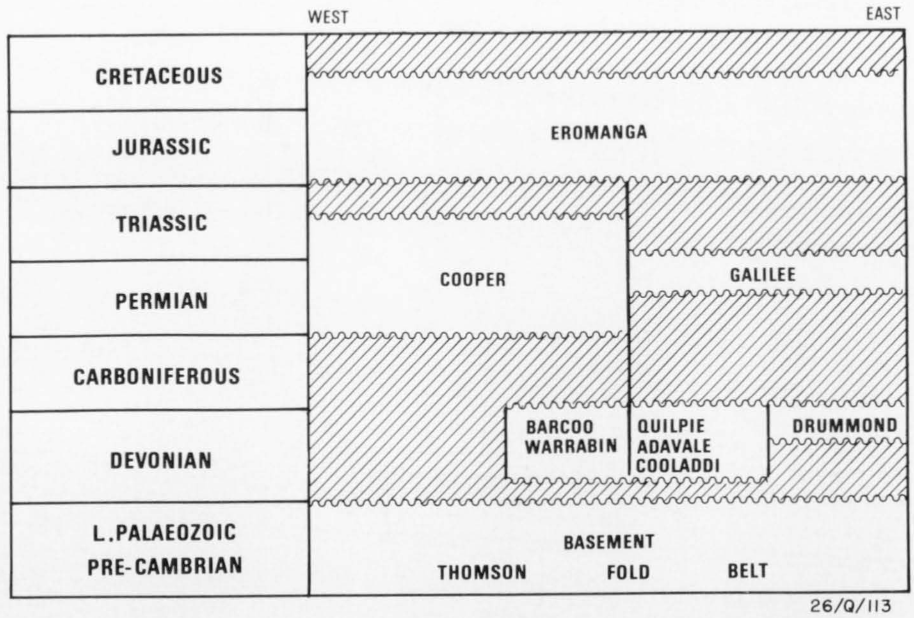


Fig. 4. Simplified stratigraphy of the Eromanga Basin and its infra-basins and troughs. Shaded areas are times of non-deposition.

about 118 Ma with the separation of India and Australia, after the Eromanga Basin and its infra-basins had formed (Johnson & Veevers, 1984).

Late Proterozoic-early Palaeozoic

The earliest tectonic events recognised for the central Eromanga Basin region occurred in the period 650-575 Ma (Fig. 5). Veevers & Powell (1984) envisaged a series of rifting events along the eastern Precambrian Australian craton, followed by a divergent episode. This series of rifts is the present eastern boundary of the known Precambrian terranes, known as the Tasman Line. In the Eromanga Basin region, this line is defined by the Cork Fault/Wetherby Structure (Murray & Kirkegaard, 1978; location diagram in Fig. 2).

By the Middle Cambrian the region was an epicontinental shallow sea which decreased in area during the Late Cambrian. Harrington (1974) postulated a shallow sea formed behind an early island arc (Nebine Island Arc) for the period 516-508 Ma, as part of a region of plate convergence; Veevers & Powell (1984) likened the tectonic setting to that of the Ryukyu island arc in the East China Sea (Fig. 6). The Nebine Island Arc is postulated to have migrated eastwards until the end of convergence at about 500 Ma (Fig. 5).

The Ordovician history of the central Eromanga Basin region is inferred largely from events outside the region (Veevers & Powell, 1984). A narrow marginal sea is believed to have separated the Precambrian craton along the Tasman Line from a north-northeast-trending volcanic arc to the east. The source of sediment for this marginal sea is assumed to have been the mature continental area to the west. By the end of the Ordovician a period of deformation and metamorphism had started, possibly contemporaneous with the Early Silurian Benambran Orogeny in southeastern Australia.

The region, during its early development, is perhaps best categorised according to the classification of Kingston & others (1983) as a continental interior fracture basin which was subsequently tectonically modified in a

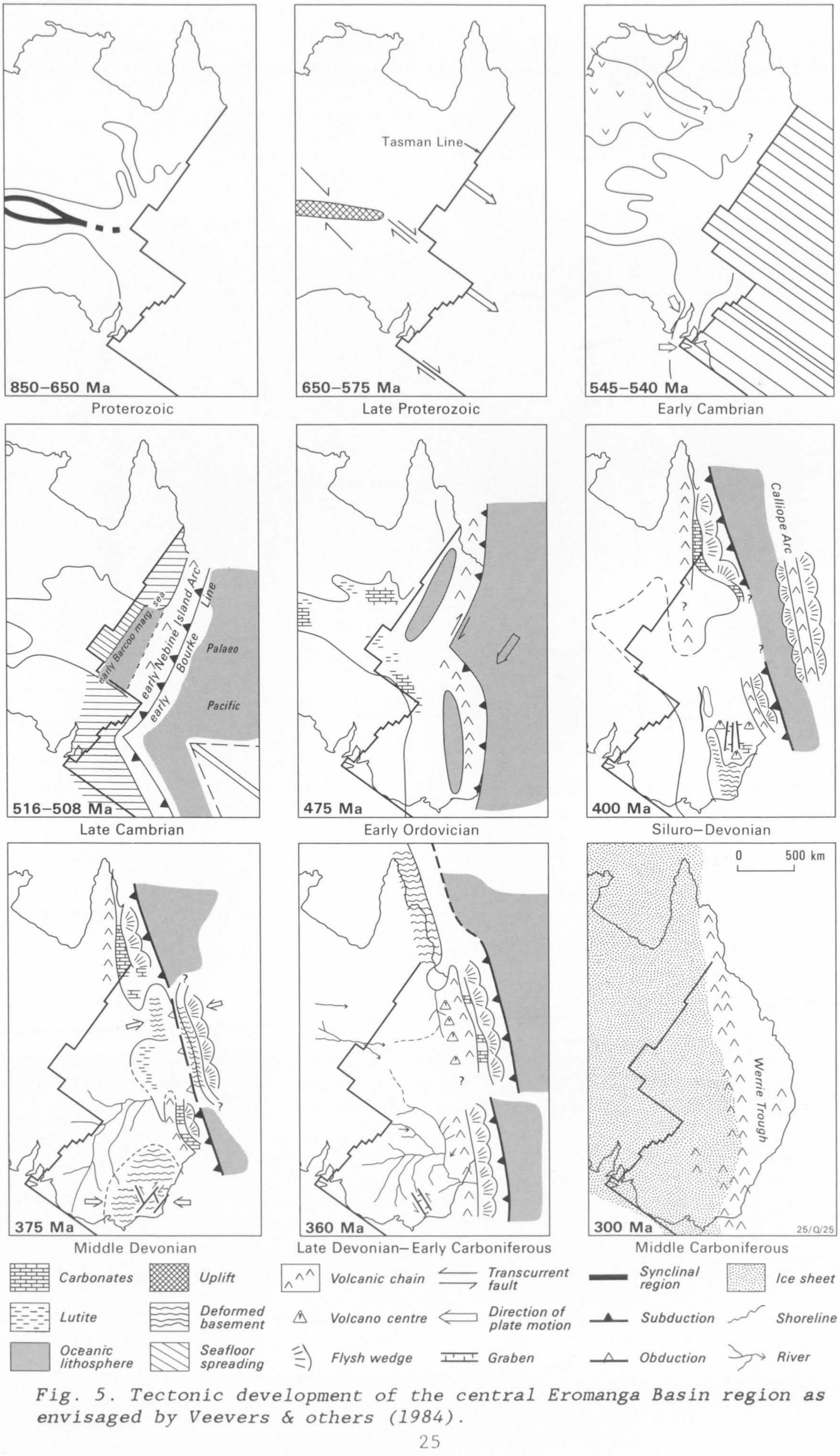


Fig. 5. Tectonic development of the central Eromanga Basin region as envisaged by Veevers & others (1984).

back-arc wrench or shear environment with subsequent crustal shortening to form a fold belt, the Thomson Fold Belt, described by Murray & Kirkegaard (1978).

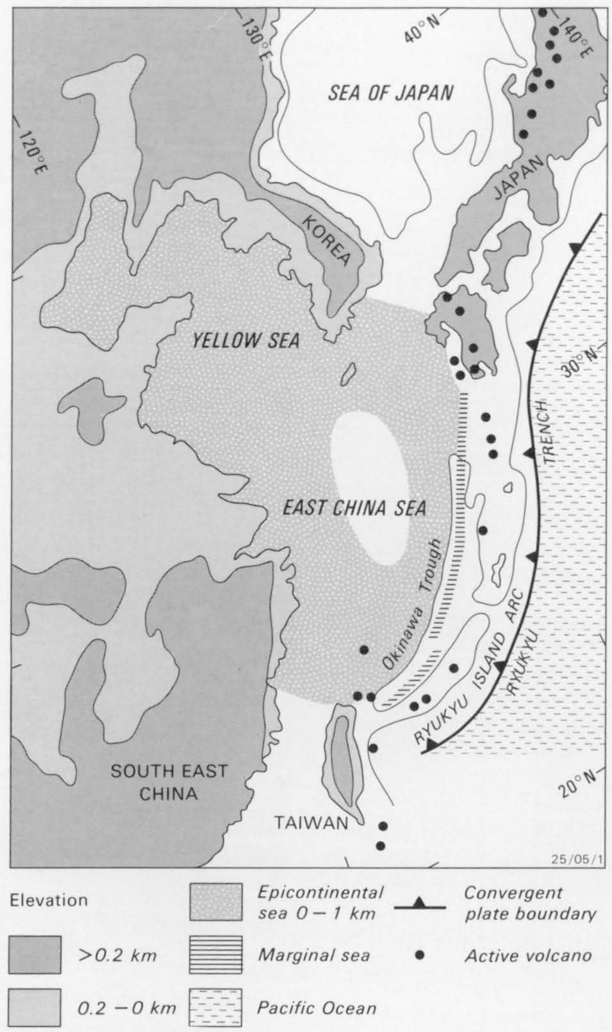


Fig. 6. The Ryukyu Island Arc and East China Sea analogue for the central Eromanga Basin region during the Cambrian (after Veevers & Powell, 1984a).

Silurian-Carboniferous

For the Late Silurian, Veevers & Powell (1984) envisaged the Rio Grande Rift and Colorado Plateau in the western USA as being modern analogues of the central Eromanga Basin region, which, at that time, had northwesterly aligned principal regional stresses (compressional and tensional).

During the Early Devonian the oldest depositional unit of the Adavale Basin (the Gumbardo Formation) accumulated, consisting of terrestrial andesitic lava flows and lithic tuffs grading eastwards into arkosic clastics (Passmore & Sexton, 1984; Table 1). The overlying Middle Devonian rocks testify to the transgression of a shallow sea over the Gumbardo Formation: lower sandstone and shale units underlie upper shallow-water limestone and dolomite units (Bury Limestone and Cooladdi Dolomite). The Upper Devonian Etonvale and Buckabie Formations were deposited in shallow-marine and terrestrial environments. Passmore & Sexton (1984) identified a Middle Devonian angular unconformity below the Etonvale Formation, and, less reliably, a younger unconformity within the Buckabie Formation.

Table 1

Stratigraphy of the central Eromanga Basin and infra-basins (from Moss & Wake-Dyster, 1983). The numbered seismic reflectors identify horizons annotated on Plates in this Report.

Age	Basins and stratigraphic units			Seismic reflectors
Quaternary Tertiary	Eyre Basin (Unnamed sediments) Whitula Fm Eyre Fm			
	Eromanga Basin			
Late Cretaceous Early Cretaceous	Rolling Downs Group	Winton Fm Mackunda Fm Allaru Mudstone Toolebuc Fm Wallumbilla Fm	 Coreena Mbr Doncaster Mbr	1 2
		Cadna-Owie Fm	Wyandra Sst Mbr	3
		Hooray Sst		
Late Jurassic Middle Jurassic	Injune Creek Group	Westbourne Fm Adori Sst Birkhead Fm		
Early Jurassic		Hutton Sst Evergreen Fm Precipice Sst		4
	Cooper Basin		Galilee Basin	
Late Triassic		(Unnamed sediments)	Moolayember Fm Clematis Sst	
Middle Triassic		Nappamerri Fm *	Dunda Beds	
Early Triassic			Rewan Fm	
Late Permian	Gidgealpa Group	Toolachee Fm *	Bandanna Fm Colinlea Sst	5
Early Permian	Gidgealpa Group	Daralingie Beds Roseneath Shale Epsilon Fm Murteree Shale Patchawarra Fm Moorari Beds Tirrawarra Sst	Joe Joe Group: Aramac Coal Measures Jochmus Fm Edie Tuff Mbr Jericho Fm Oakleigh Sltst Mbr	
Late Carboniferous		Merrimelia Fm	Lake Galilee Sst	6
	Adavale Basin and associated troughs			
Late Devonian		Buckabie Fm		7
		Etonvale Fm	Shale/siltstone Mbr Sandstone Mbr Boree Salt Mbr	8
		Cooladdi Dolomite Lissoy Sandstone	Bury Limestone	9
Middle Devonian		Log Creek Fm	"Deltaic" facies Marine facies	10
		Eastwood Beds		
Early Devonian		Gumbardo Fm	Red bed unit Volcanic unit	11
Silurian Ordovician	Basement		Granitoids Metamorphics and volcanics	12

Deposition in the Drummond Basin, to the northeast of the central Eromanga Basin region, occurred in the Late Devonian to Early Carboniferous, and may have overlapped in time with deposition in the Adavale Basin. Powell (1984) described the Drummond Basin as a classical foreland basin with up to 12 km of fluviatile sedimentary rocks derived from the silicic volcanics of the Anakie Island Arc. The Adavale Basin was described as an epicratonic basin between the magmatic arc in the east and the Precambrian craton to the west.

According to Powell (1984) the entire Adavale and Drummond Basin region was deformed by generally east-west compression as part of a continent-wide event (the Kanimblan Orogeny) in the mid-Carboniferous (340-320 Ma). After this event the region was effectively part of cratonic Australia, and subsequent major tectonic events took place to the east. The Late Carboniferous glaciation of the Australian continent (Veevers & Powell, 1984) continued into the Permian, and provided an important unconformity (top Devonian unconformity) which is identified on seismic sections throughout the central Eromanga Basin region.

Permo-Triassic

The Early Permian to Late Triassic Cooper and Galilee Basins overlie the Devonian sequences in parts of the study area (Fig. 1). The Cooper and Galilee Basin sequences are contiguous across the Canaway Fault (Fig. 2) in the northern part of the study area. Pinchin & Senior (1982) have discussed the boundary of the Cooper Basin in the Warrabin Trough. Generally the thickness of Cooper Basin sedimentary rocks increases towards the west of the region, where thick coal measures give rise to a prominent seismic horizon. The Galilee Basin lies to the east of the Canaway Fault, and is relatively thin over the region.

Jurassic-Cretaceous

The ubiquitous Eromanga Basin sequence consists essentially of conformable Early Jurassic to Late Cretaceous sedimentary rocks. The Jurassic rocks are mainly terrestrial; the Early Cretaceous, shallow marine; and the Late Cretaceous grades from paralic to fluvial and lacustrine (Senior & others, 1978). The thickness of the Eromanga Basin sequence is generally between 1 and 2 km in the region. The structures evident in this sequence are assuming great importance as targets for oil exploration.

Cainozoic

Tertiary and Quaternary deposits cover parts of the region. The weathering in these deposits is important for defining the latest phase of faulting. Thus, based on the fault movements that have disrupted the profile of the last severe weathering episode, Pinchin & Anfiloff (1986) have dated the latest movement on the Canaway Fault as postdating 30 Ma BP (Oligocene).

Palaeoclimate

In the period 575 to 65 Ma the palaeoclimate of the region underwent a number of extreme changes (Quilty, 1984). The Cambrian (575-500 Ma) was warm/hot and arid, and was followed by a warm climate in the Ordovician (500-435 Ma). The Silurian (435-410 Ma) and Devonian (410-360 Ma) had similar palaeoclimates - namely, warm waters with evaporitic and possibly aeolian environments, e.g. the evaporites in the mid-Devonian of the Adavale Basin. The Carboniferous (360-290 Ma) saw the onset of colder climates, leading to the most extensive glaciation (during the Permian, 290-245 Ma) in Palaeozoic history. In the Late Permian, warmer conditions contributed to the main interval of coal deposition, coinciding with high water-tables and poor drainage. The Triassic (245-200 Ma) was somewhat drier, but conditions in the basins were still conducive to coal formation. During the Jurassic (200-129 Ma) and Cretaceous (129-65 Ma) the climate was mainly temperate to hot. These

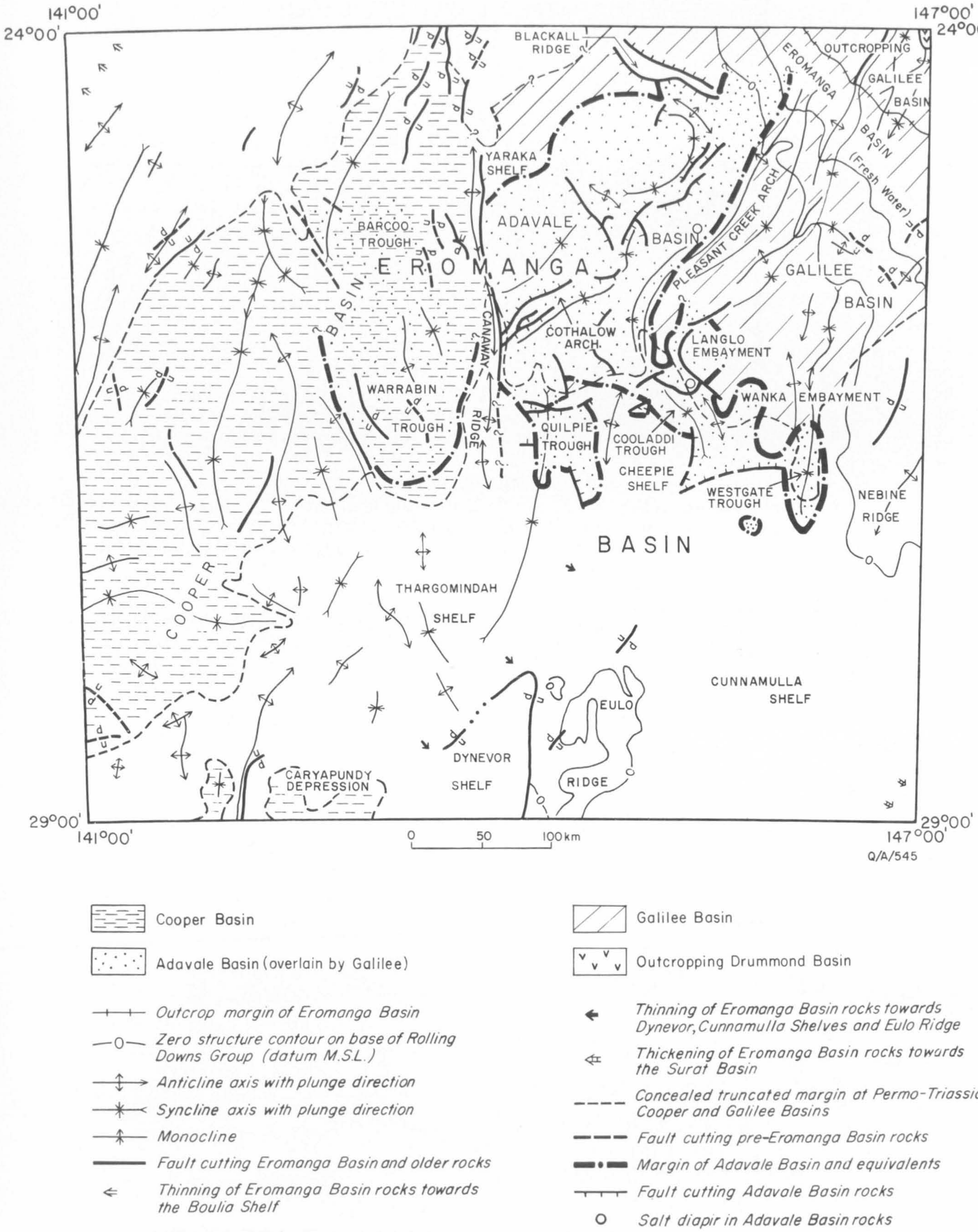


Fig. 7. Structural sketch map of the central Eromanga Basin region (adapted from Senior & others, 1978).

palaeoclimates are consistent with the palaeolatitudes determined from the palaeomagnetic data described above.

Structure

The general tectonic history of the central Eromanga Basin region has been described by many authors, and summarised in review papers by Kirkegaard (1974), Harrington (1974), Doutch & Nicholas (1978), Sprigg (1982), Veevers & others (1982), and O'Driscoll (1983). The history of the region is included in the textbook edited by Veevers (1984) on the whole of Phanerozoic Australia.

Many of the more detailed descriptions of structures in the central Eromanga Basin region (Fig. 7) have been compiled as part of the exploration for oil and gas using seismic record sections; most of the exploration targets are structural traps. The structures in the Adavale Basin and its adjacent troughs have been described by Slanis & Netzel (1967), Marsden (1972), Auchincloss (1976), Paten (1977), Pinchin & Senior (1982), Wake-Dyster & others (1983), Passmore & Sexton (1984), Powell (1984), and Leven & Finlayson (1986). The main part of the Cooper Basin, southwest of the region of this Report, is described by Battersby (1976), Gray & Roberts (1984), Gravestock & Morton (1984), and Kuang (1985). The structure of the Eromanga Basin has been described by Exon & Senior (1976), Senior & others (1978), Senior & Habermehl (1980), Armstrong & Barr (1982), Bowering (1982), and Finlayson & others (in press).

Most geoscientists concur that the structures which they describe in the central Eromanga Basin region reflect processes that have affected basement rocks. The region has undergone at least four major tectonic cycles, which

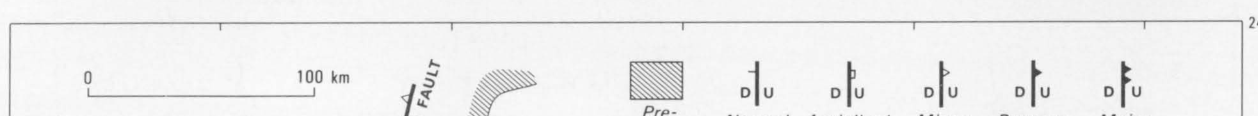


Fig. 8. Generalised fault structure in the central Eromanga Basin region (from Finlayson & others, in press).

can be identified on seismic record sections. The Late Proterozoic-early Palaeozoic cycle ended with an episode of crustal shortening which resulted in the highly deformed basement rocks of the region, the Thomson Fold Belt. The subsequent reactivations of the fault systems within basement and the deeper lithosphere have produced structural styles which are important in identifying exploration targets. The majority of these reactivations are evident as compressional features affecting sedimentary rocks originally deposited in an epicontinental shallow-water environment; Finlayson & others (in press) and Kuang (1985) speculated that a shear component also affected the structures.

Several basement highs dominate the tectonics of the region; the major ones are the Canaway Ridge and the Pleasant Creek Arch. The Devonian sequences of the Adavale Basin and its associated troughs (Warrabin, Barcoo, Quilpie, Cooladdi, and Westgate Troughs) were deformed by compression during the Carboniferous (Fig. 8). Leven & Finlayson (1986) have resolved the general compressional deformation into two components affecting the southern Adavale Basin region during the Devonian-Early Carboniferous; one was a Devonian north-south compressional episode producing thrust faults; the other was a Late Devonian-Early Carboniferous east-west folding episode. The Canaway Ridge, the Pleasant Creek Arch, and the Cheepie Shelf are areas where severe glaciation removed all Devonian rocks and exposed basement during the Early Permian. This erosion surface is recognised on seismic record sections as the 'top Devonian unconformity'. This unconformity is indicated in the structural diagrams of shallow seismic profiling data included in this Report (Plates 7-12). Examples of the styles of faulting and folding during the two Devonian-Early Carboniferous compressional episodes are shown in Figure 9.

Even though the Permo-Triassic sequences in the central Eromanga Basin region are relatively thin, they were affected by regional compressional events. The Cooper Basin, southwest of the central Eromanga Basin region, developed rapidly during the Late Carboniferous and Early Permian, with associated faulting effected by processes within basement. Kuang (1985), in his analysis of the deformational events in the Cooper Basin, recognised two Permo-Triassic events producing structures within the Cooper Basin sequence: a mid-Permian, northwest-southeast compressional event, which is evident in sub-crop at the unconformity above the Daralingie beds; and a Triassic wrench-induced northeast-southwest compressional event, which resulted in the basin-wide Nappamerri unconformity. Both these events were considered to have produced a structural style dominated by thrusting and wrenching mechanisms.

In the central Eromanga Basin region, the most prominent post-Devonian deformation (mid-Tertiary) is evident in the Jurassic-Cretaceous Eromanga Basin sequence. An example of the style of deformation is shown in Figure 10. The style of deformation is controlled by basement structures, and therefore affects not only the Eromanga Basin but also its infrabasins. The deformation is most evident in the area between the Canaway and Cunnavalla Faults (Fig. 8). This mid-Tertiary deformation, postdating 30 Ma BP (Pinchin & Anfiloff, 1986), can be traced for considerable distances along the strike of faults in the area between the Canaway and Cunnavalla Faults; Finlayson & others (in press), for example, have traced the mid-Tertiary deformation on the Harkaway Fault along a distance of about 120 km (Fig. 8).

Finlayson & others (in press) indicated the direction of mid-Tertiary compression as northeast-southwest. One feature of the deformation in the central Eromanga Basin region is the change in style of faulting across the Canaway and Cunnavalla Faults (Fig. 8). Between these faults, in the central part of the region, fault trends are northwest-southeast, swinging to east of north in the northern part of the region; in the south, fault trends are

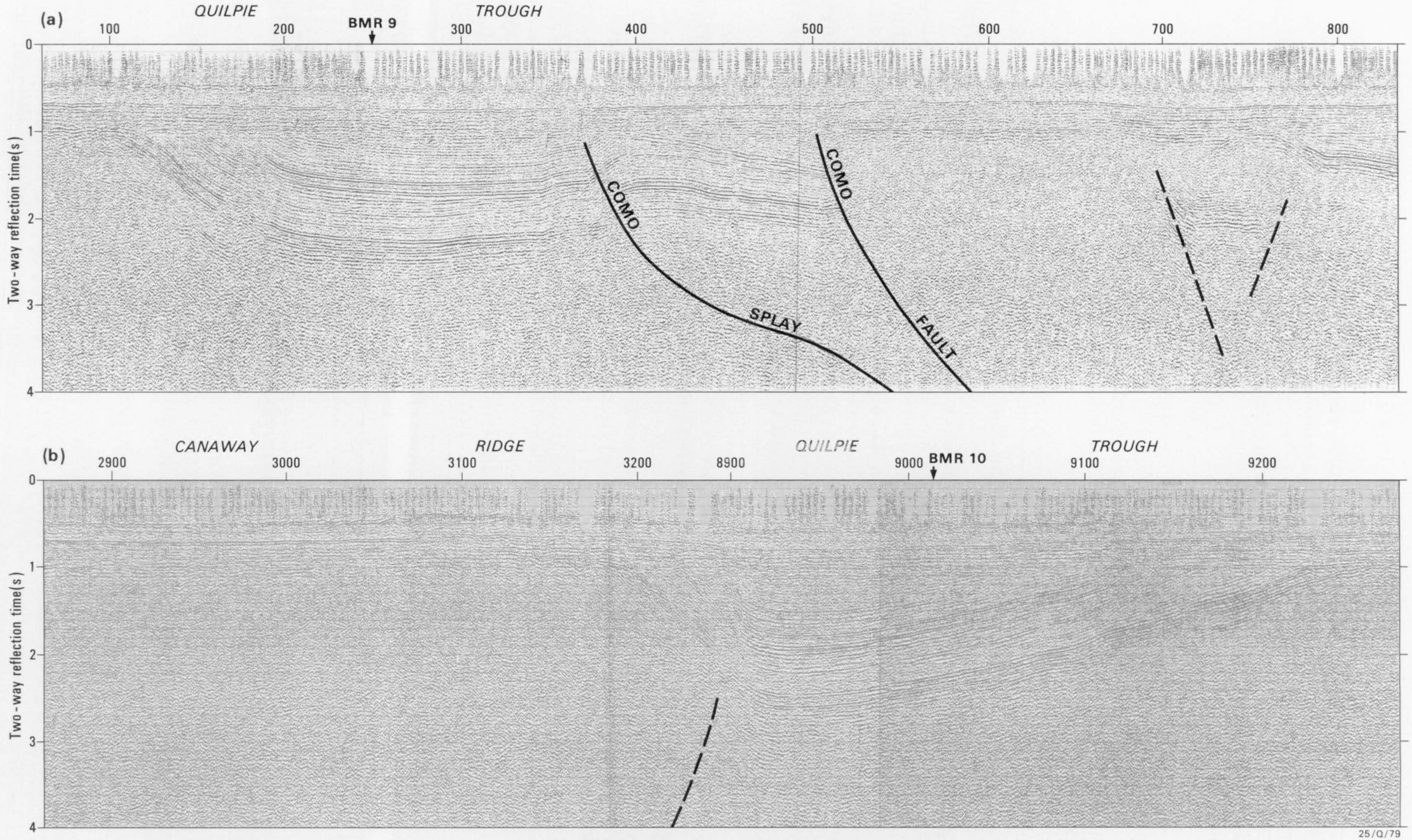


Fig. 9. Examples of the style of deformation caused by compressional events during the Carboniferous:
a) thrust-faulting over the Como structure (BMR traverse 10; from Leven & Finlayson, in press), and
b) folding across the Quilpie Trough (BMR traverse 9). Arrows indicate the cross-over points of other BMR traverses.

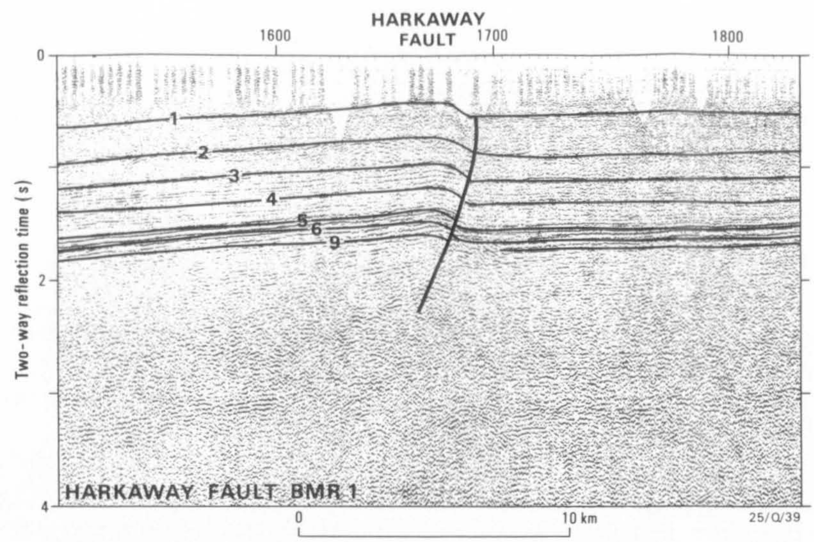


Fig. 10. Style of deformation over the Harkaway Fault (BMR traverse 1; from Finlayson & Leven, in press).

affected by structures at the southern margin of the Warrabin Trough. This central deformation zone seems to be partly decoupled from the areas to the west (the main part of the Cooper Basin) and east (the main part of the Adavale Basin) by what Finlayson & others (in press) speculatively interpreted as north-south-trending transcurrent movements along the Canaway and Cunnavalla Faults.

Mid-Tertiary movements are by no means restricted to the central deformation area described above. Kuang (1985) has described the style of mid-Tertiary deformation in the Cooper Basin to the west, and Leven & Finlayson (1986) have discussed the extent of mid-Tertiary deformation in the Adavale Basin to the east. What is evident from studies of the whole region is that the amplitude of structural deformation of post-Carboniferous events was considerably less than that of the Carboniferous events which affected Devonian sequences.

SEISMIC TRAVERSES

Objectives of the seismic program

Harrison & others (1980) outlined program proposals for seismic work in the central Eromanga Basin region. At that time, there were quite major deficencies in the state of geoscientific knowledge in the region. They listed for investigation 14 'specific problems', which are listed below as objectives for an explosion-seismology-based program designed to determine the regional tectonic framework of the central Eromanga Basin and its infra-basins.

1. Identify and determine the distribution of pre-Permo-Triassic rocks in the Westgate, Cooladdi, Quilpie, and Warrabin Troughs (Fig. 7).
2. Identify the nature of sedimentary sequences along the northwest Yaraka Shelf margin.
3. Determine the occurrence of evaporites and salt diapirs on the eastern margin of the Yaraka Shelf.
4. Determine the structure and Devonian stratigraphy east of the Pleasant Creek Arch.

5. Assess the importance of the Pleasant Creek Arch and other structural highs in the overall depositional history of the region.
6. Determine the thickness of Permo-Triassic (Cooper Basin) sedimentary rocks in the Thomson Syncline.
7. Determine the total sedimentary history along the axis of the Queensland section of the Cooper Basin.
8. Examine whether Cooper Basin rocks are present in the Caryapundy Depression (Fig. 7).
9. Examine the structural and stratigraphic relationships between the Cooper and Galilee Basins.
10. Examine the structural relationships at the concealed margins of the Cooper Basin in Queensland.
11. Assess the stratigraphy and extent of Galilee Basin sedimentary rocks in the central Eromanga Basin region.
12. Provide information on the distribution of Lower Jurassic rocks in the central Eromanga Basin region.
13. Assess the overall thickness and extent of hydrocarbon source rocks within the Eromanga Basin sequence.
14. Investigate the idea of minor faulting in the Eromanga Basin sequence forming structural and stratigraphic barriers to groundwater flow with possible stagnation and hydrocarbon entrapment.

Vertical-incidence six-fold CMP reflection profiling

With the above objectives in mind, a seismic reflection profiling field program was undertaken over the three years 1980-82. Not all the objectives mentioned above were investigated.

Much of the previous seismic recording in the central Eromanga Basin region had been single-fold recording that provided inadequate resolution below the extensive Permo-Triassic coal measures because of poor energy penetration. The six-fold CMP recording procedures adopted by BMR were expected to improve penetration, and enable structural detail at much greater depth to be investigated.

The BMR seismic reflection profiling traverses (Fig. 2) were sited in an attempt to obtain regional coverage, in some places in association with exploration company traverses. All BMR seismic reflection profiling data were recorded to 20 s two-way recording time, so that structural features within basement could be investigated; these were regarded as important targets in assembling a basin history. It was recognised that large regional features may be present; for this reason, it was regarded as important to complete long traverses across the regional geological strike because these would be more likely to detect possibly very large structures with considerable areal extent.

The principal objective of the BMR seismic program was to complete four major east-west tie-lines across the survey region, extending from the Cooper Basin to the eastern margin of the Adavale Basin. The traverses were tied to petroleum exploration wells wherever possible, either directly or through exploration company multiple-coverage seismic lines (Pinchin, 1980; Mathur & Sexton, 1981). In some places, it was necessary to record on north-south lines where there were inadequate tie-lines between major traverses, and in the Adavale Basin, where only single-fold data from previous surveys had resulted in poor penetration below the Permo-Triassic sequences.

Expanded-spread recording

In addition to the normal six-fold CMP reflection profiling traverses described above, two expanded-spread reflection data sets were recorded (Fig. 3b; Sexton & Taylor, 1983). The concept of expanded-spread recording is described by Musgrave (1962). The principal purpose for making the recordings in the central Eromanga Basin was to assist with the determination of average velocities to major horizons within basement. These velocities could then be used in the processing of the six-fold CMP reflection profiling data at two-way times of 4 to 20 seconds. The maximum shot-to-geophone offset was 20-25 km, and the two expanded-spread recordings were centred on shot-point 9333 on BMR traverse 9 and on shot-point 1384 on BMR traverse 10.

Short-distance wide-angle reflection/refraction profiling

Wide-angle reflection and refraction profiling methods were regarded as an important part of the seismic investigation of crustal-scale features under the central Eromanga Basin region. These seismic methods provide additional information in terms of velocity variations, both vertically and horizontally. The velocity boundaries determined by these methods can be used to complement interpretations of the structures apparent on the six-fold CMP reflection profiles. In addition, the wide-angle reflection and refraction data provide velocity information in parts of the crust which are devoid of reflections on profiling record sections, a common situation in the upper crustal basement of the central Eromanga Basin region.

The wide-angle reflection/refraction profiling was divided into two series of recordings. The first, at short distances, was designed to examine the upper crustal basement, and the second, at long distances, was designed to examine the middle-lower crust and upper mantle (see below).

The first series of recording traverses involved shots at 37.5 km intervals along a line between Mount Howitt No.1 exploration well and Cooladdi, a total of about 260 km (Fig. 3a). These traverses coincided with the BMR reflection profiling traverses 1, 1X and 9 (Fig. 2). Recording stations were 1.875 km apart. Reversed, overlapping traverses with shot-offsets at 37.5 km from the ends of recording lines allowed a maximum shot-recorder distance of 75 km (Lock, 1983). At this offset distance the maximum depth of penetration of refracted seismic rays was less than 10 km.

Long-distance wide-angle reflection/refraction profiling

The second series of two wide-angle reflection/refraction profiles was recorded at long distances to determine the general velocity structure throughout the Earth's crust and upper mantle under the central Eromanga Basin region. One profile was a 300 km east-west traverse coinciding with the BMR reflection profiling traverses 1, 1X, and 9 and the short-distance refraction recording described above (Fig. 3b). The shot-points were at Terebooka, Tallyabra and Cheepie and the maximum recorder station separation was 7.5 km. The second profile was oriented north-south across the main part of the Adavale Basin (Fig. 3b). It was recorded in the central 300 km section of the traverse between Toompine and Blackall. Shots were fired at Toompine, Adavale, and Blackall, and offset shots were fired 100 km to the north and south at Barcaldine and Thargomindah respectively. Approximately 150 km of the southern part of the wide-angle reflection/refraction recording traverse coincides with BMR reflection profiling traverse 10 (Fig. 2).

SEISMIC DATA ACQUISITION SYSTEMS

The BMR seismic data from the central Eromanga Basin region were recorded in three modes, 1) continuous multiple-coverage CMP reflection profiling, 2) expanded-spread reflection recording, and 3) wide-angle reflection/refraction profiling. All modes of data acquisition used explosive seismic sources. The reflection profiling was conducted during 1980 (Pinchin, 1980; Wake-Dyster & Pinchin, 1981), 1981 (Sexton & Taylor, 1983; Mathur & Sexton, 1981), and 1982 (Sexton & Taylor, in preparation). The expanded-spread recording was conducted during 1981 and 1982 (Sexton & Taylor, 1983, in preparation). The wide-angle reflection/refraction profiling field operations were conducted during two field seasons in 1980 and 1981 (Lock, 1983).

Continuous six-fold CMP reflection profiling

Continuous reflection profiling data were acquired using a Texas Instruments DFS-IV data acquisition system with six-fold CMP subsurface coverage. Analogue visual monitoring was available from SIE-type ERC-10C and TRO-6 cameras. Geophone takeout spacing was 83.3 m, and 48 channels were recorded on the DFS-IV. Sixteen geophones (type GSC-20D, 8 Hz) per channel were set in-line at 5.5-m intervals. Recording was conducted mostly along bulldozed tracks, and surveying was conducted by the Australian Survey Office.

Shots were drilled into the ground at 666-m intervals to a depth of 40 m so that the explosive charges were below the base of surface weathering. In difficult conditions some holes were drilled only to 25-m depth. Four or five truck-mounted drilling rigs (Mayhew 1000) were generally available at any one time for shot-hole drilling. Charge sizes varied from 7 to 20 kg of (commonly) ICI Anzite Blue; the average size was about 8 kg during 1980, and about 12 kg in subsequent years. In this shooting configuration, about 21-23 shots were fired per day - i.e., about 7-8 km of subsurface coverage per recording day.

Recording was at 2 ms sampling rate in SEG-B format, on 9-track tape at 1600 b.p.i. Input filters were set for low cut at 12 hz in 1980 and 8hz in subsequent years. High-cut filters were set at 124 hz.

Seismic data processing and record section production were by contract with Geophysical Services International (GSI), Sydney, and Digital Exploration Ltd (Digicon), Brisbane. Static corrections, including elevation and weathering corrections, were calculated in the field using up-hole recordings. A replacement velocity of 2000 m/s was used to correct to a datum of 183 m above sea level. The processing sequence for the seismic sections to 4 s two-way reflection time (TWT) was as follows:

1. Line file map computation
2. Crooked line file production
3. Six-fold CMP gather
4. Trace amplitude recovery
5. Time variant scaling
6. Brute stack with field statics and normal moveout (NMO) velocities
7. Velscans - 1st pass
8. Residual static computations
9. Velscans - 2nd pass
10. NMO and static corrections
11. Six-fold CMP stack
12. Time variant deconvolution
13. Time variant filter
14. Time variant scaling
15. Display

The 20-s TWT sections were resampled at 4-ms intervals and processed by Digicon with the following additional processing:

1. Time variant filtering,

	0.0 s	20-80 hz
	1.0 s	20-70 Hz
	1.4 s	15-70 Hz
	2.4 s	10-60 Hz
	4.0 s	10-50 Hz
greater than	4.0 s	10-30 Hz

2. Time variant equalisation with 1-s gate length
3. Coherency scaling
4. Display

Expanded-spread recording

The data acquisition system for the expanded-spread recordings was the same as that for the continuous six-fold CMP profiling except that 35-s recordings were made. The maximum shot-geophone offset was about 21.2 km. Shot-recorder synchronisation was achieved using the normal automatic VHF-radio shot-firing link between the recording truck and the shot-firing vehicle. This usually limited expanded-spread recordings to line-of-sight radio links (about 20-25 km).

Wide-angle reflection/refraction profiling

The third mode of operation, for wide-angle reflection/refraction profiling, employed 21 BMR remote seismic tape recording systems. Each system was a 'stand alone' four-channel seismic recorder with a single vertical component seismometer, together with an internal clock and radio time signal receiver (Finlayson & Collins, 1980). A Willmore Mk2 or Mk3A seismometer was used in each system, and signals were amplified through a BMR-type TAM-5 amplifier. Seismic signals were recorded at two gain levels, high gain being 24 dB above low gain, so that a saturated high-gain signal could be recovered on the low-gain channel. Signals were frequency-modulated, and recorded on slow-speed tape recorders operating at 15/256 inches per second. Signals were bandpass-filtered in the range 0.01 to 20.0 Hz.

Each recording system had its own internal clock controlled by a temperature-compensated crystal. The clock time code was recorded on a third channel. Absolute timing over the whole survey region was achieved by recording Telecom Australia's radio time signal, VNG. This time signal was recorded continuously on the fourth recorder channel, continuity being preserved using the internal clock during periods of poor radio reception.

BMR remote seismic tape recording systems operated from 12-V truck batteries, and could be deployed for up to a week at a time on long traverses with difficult access.

Playing back tapes from the remote recorders was conducted in BMR (Liu & Seers, 1982). Seismic signal recovery was achieved with tape-speed compensation, and digital files were created on the BMR general-purpose computer based on a Hewlett-Packard 21MX. Files were then recovered and displayed as required with various normalisation and filtering options.

Explosives used for the wide-angle reflection/refraction shots were drilled into the ground in patterns to a depth of 40-60 m; up to 30 holes were drilled in any one pattern. Between 100 and 150 kg of ICI Anzite Blue explosive was placed at the bottom of each 11.5-cm (4.5-inch) diameter drillhole. Generally, shot-holes were about 10 m apart. Large shots were made by connecting the required number of explosive charges in series.

Shot sizes used to record over the various distances were as follows:

Distance (km)	Shot size (kg)
37.5	200
75	400
150	750 - 900
300	2500 - 3000
450	3400

Shots were fired electrically from a blasting box. Shot timing was achieved by having a geophone, amplifier, and chart recorder operating with a radio time-signal receiver tuned to Australia Telecom VNG time-signal frequencies.

WIDE-ANGLE REFLECTION/REFRACTION PROFILING RESULTS

Results from the wide-angle reflection/refraction profiling have been divided into two sections, the first dealing with results from recordings made at distances of 75 km or less, and the second dealing with results at distances greater than 75 km. Generally speaking, the interpretations of the results at distances less than 75 km indicate that the structures being examined are at a depth of 10 km or less - i.e., within the upper crustal basement or the deep sedimentary sequences. The interpretations of data recorded at distances greater than 75 km indicate that structures in the depth range 10 to 60 km are being examined.

Short-distance profiling

In 1980 and 1981, detailed refraction studies were undertaken in the central Eromanga Basin to obtain a velocity structure of the basin and its infrabasins, and in particular the basement. These studies were made along an east-west traverse coinciding with six-fold CMP profiling (Sexton & Taylor, 1983) and deep refraction profiling (Finlayson & others, 1984).

The reflection profiles contain almost no reflections from within the basement, and only rarely can faults be traced from the overlying Eromanga and Adavale Basins into the basement. The basement is deformed by upthrown and downthrown blocks, and it was expected that these blocks might be evident at depth from velocity changes. The velocities derived from the detailed refraction profiles were also used to correct the deeper refraction data for the effects of the overlying upper crustal sedimentary rocks. The data have been interpreted by Lock & Collins (1983), and Collins & Lock (1983; in preparation).

Interpretation techniques. Approximate models of depths and velocities were derived initially assuming planar dipping layers between shot-points. The station spacing was too large to resolve the detailed structure within the Eromanga Basin sequence. Two prominent reflectors within the Eromanga sequence are the Toolebuc Formation and Wyandra Sandstone Member of the Cadna-Owie Formation. Depths and velocities to these reflectors were tied at the three wells along the line - Mount Howitt No. 1, GSQ Eromanga No. 1 and GSQ Quilpie No. 1. Velocity information for the wells was available from well shoots (Velocity Data Pty Ltd, 1982; Hegarty, 1983). If the velocities above and below these reflectors do not vary significantly along the traverse, the reflectors can be regarded as iso-velocity lines on the reflection section. Agreement of the velocities in the wells from one end of the traverse to the other confirms the validity of this assumption. Using the combined reflection and refraction data in this manner allows a detailed velocity/depth profile for the Eromanga Basin sequence to be determined.

Well velocity information was not available below the Eromanga Basin sequence. Prominent reflectors within the Warrabin and Quilpie Troughs were used to control the detailed velocity/depth structure in the Devonian rocks. The reflectors used were the Etonvale and Buckabie Formations, the Cooladdi Dolomite or equivalent Bury Limestone, and the Gumbardo Formation at the base of the Devonian sequence.

An iterative forward-modelling approach was used to interpret the data shown in Figures 11-17, taking the simple layered models as the starting model. Ray-tracing was used to calculate travel-times through the model from each shot-point. The model was then modified and retested until close agreement with the observed arrivals was achieved. Ray-tracing was also used to calculate the two-way travel-times to the prominent reflecting horizons in the model. This provided an added constraint on the model as the seismic ray paths are different from the ray paths of the refracted arrivals. Again, the model was modified where necessary.

Synthetic seismograms were computed from the model for some of the shot-points, so that the amplitudes of the various seismic phases could be compared with the real data. These were computed by the program of McMechan & Mooney (1980), which uses asymptotic ray theory to calculate travel-times and amplitudes in laterally varying media.

Prominent multiple refracted arrivals are evident in the record sections. Their amplitudes vary with location; for example, over the Quilpie Trough they are large (Fig. 16), while over the Canaway Ridge and Cheepie Shelf they are much smaller (Figs. 14, 15 and 17). Up to five sets of multiples are apparent on some records.

Multiples of this type have been discussed by Meissner (1965) and McMechan & Mooney (1980). Their generation and propagation depends on a high velocity gradient at the base of the sedimentary sequence and/or top of the basement, and a low velocity at the surface. The first requirement is best fulfilled where the Eromanga Basin sequence is underlain by earlier infrabasins - i.e., the Cooper or Adavale Basins; this is why the multiples are less prominent from the Canaway Ridge and the Cheepie Shelf. The second requirement is fulfilled throughout the Eromanga Basin, where surface velocities are around 2.0 km/s. The geometry of the sedimentary rock/basement interface also affects the generation and propagation of the multiples.

Travel-times of multiples generated by ray-tracing through the interpreted model can be compared with the observed multiples. Since the ray-paths of multiples through the model are different from both the first refraction arrivals and the vertical reflections, they provide an additional constraint on the interpretation.

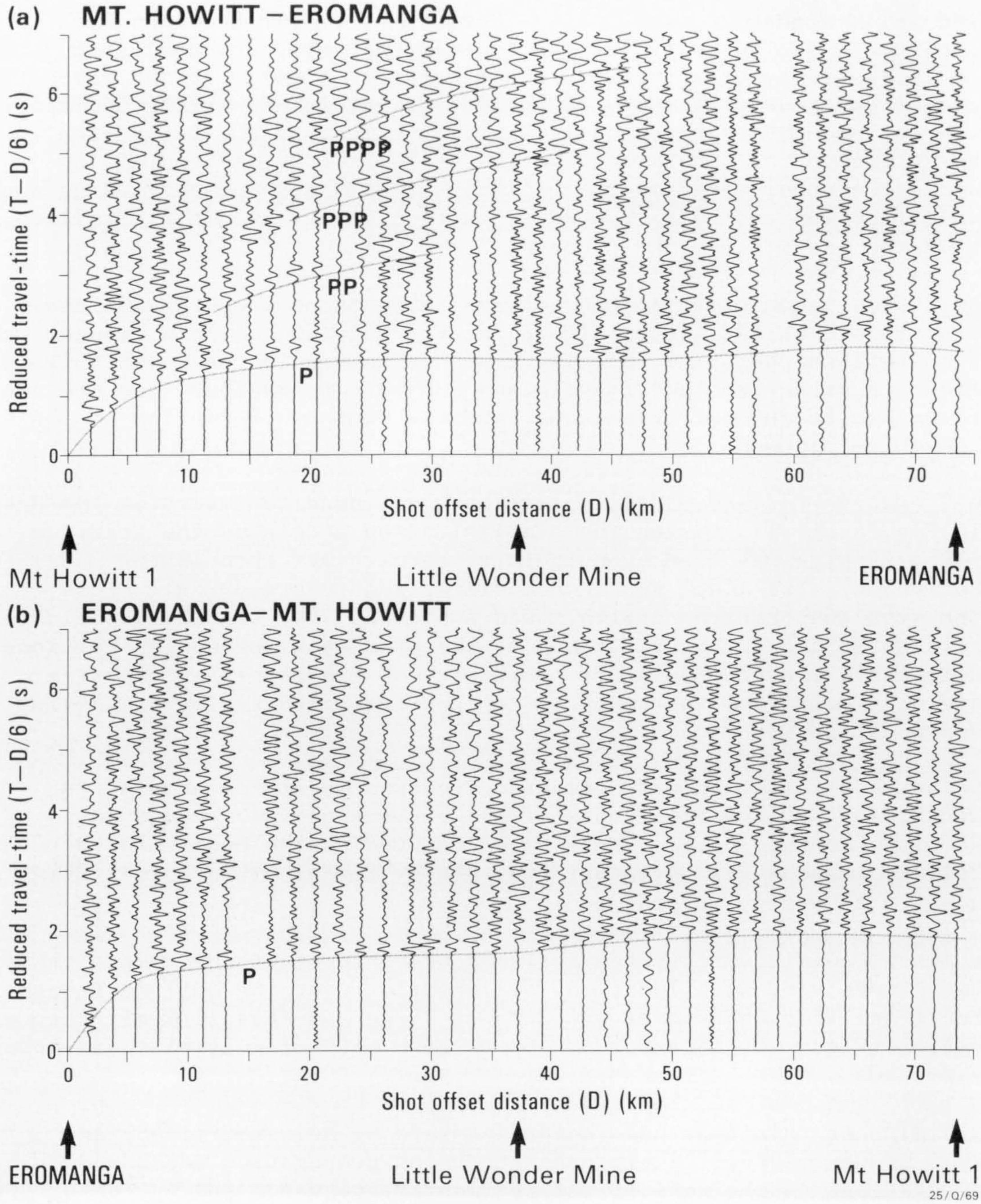


Fig. 11. Wide-angle reflection /refraction record section from a) shots at Mount Howitt No. 1 well recorded towards Eromanga (for locations see Fig. 3a), and b) shots at Eromanga recorded towards Mount Howitt No. 1 well. Explanatory notes on the principal seismic phases indicated on the sections are contained in the text.

<u>Summary of velocity/depth structure.</u> The Eromanga Basin sequence forms a continuous cover along the entire profile, varying from about 2 km thick in the west to 1 km in the east. The velocities generally decrease from west to east. At the surface the velocity varies from 2.2 to 2.0 km/s, while at the base of the sequence the velocity varies from about 4.2 to 3.8 km/s. Below the Eromanga Basin, the Permo-Triassic Cooper Basin rocks are 549 m thick in Mount Howitt No. 1 well, and gradually wedge out at the western margin of the Warrabin Trough.

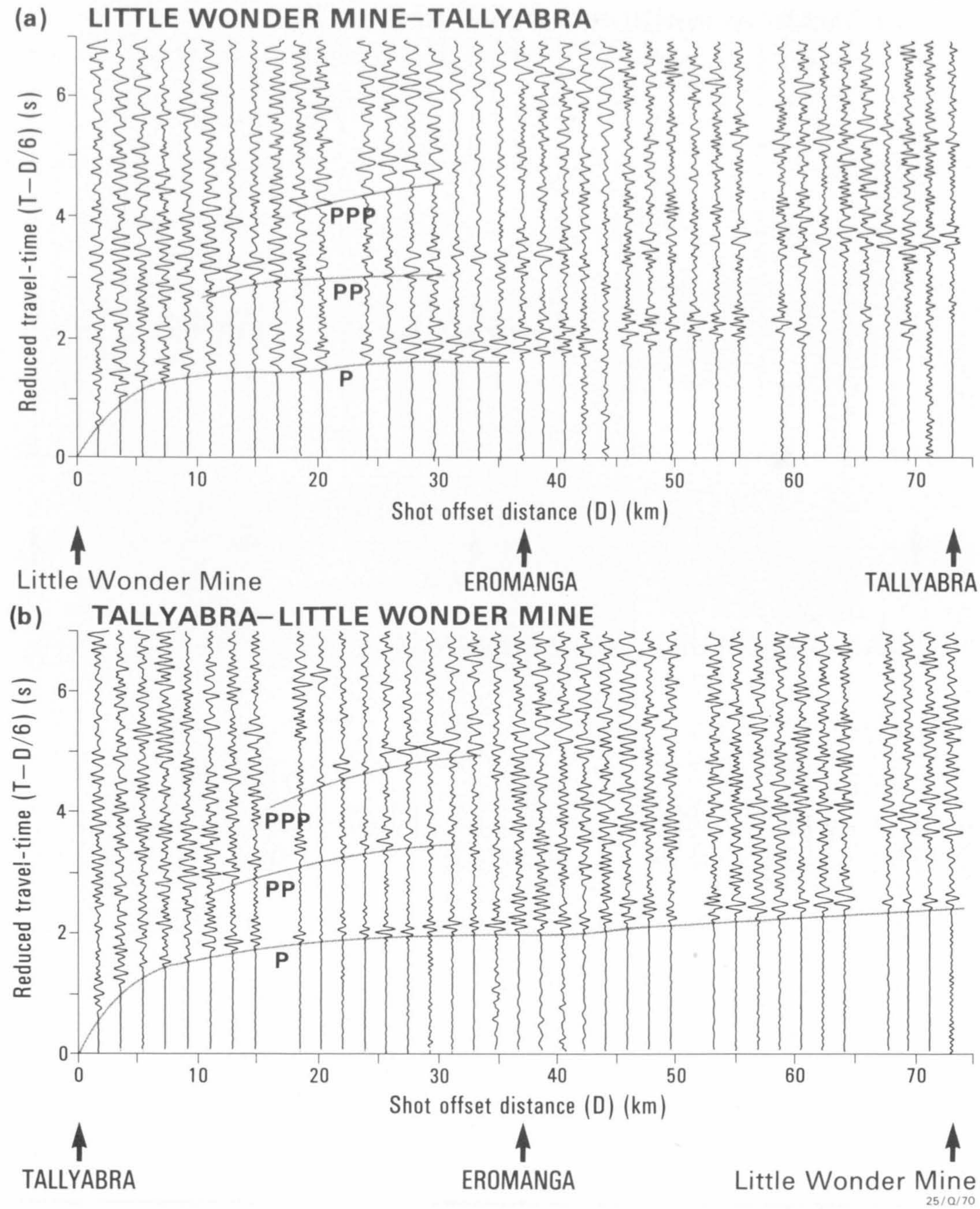


Fig. 12. Wide-angle reflection/refraction record section from a) shots at Little Wonder mine recorded towards Tallyabra, and b) shots at Tallyabra recorded towards Little Wonder mine.

The Devonian Warrabin and Quilpie Troughs are separated by a basement high, the Canaway Ridge. The Warrabin Trough sequence, which is bounded by high-angle faults, varies in thickness from 1.1 to 3.0 km; the Quilpie Trough, which is synclinal in form, has a Devonian sequence which varies in thickness from 0 to 3.8 km. The velocities in the troughs vary from about 4.3 km/s near the unconformity with the overlying Eromanga Basin, to between 5.0 and 5.5 km/s at the base of the Devonian sequence. The bottom of the troughs is not clearly defined, but reflections interpreted as coming from volcanics in the Gumbardo Formation are assumed to be from near basement.

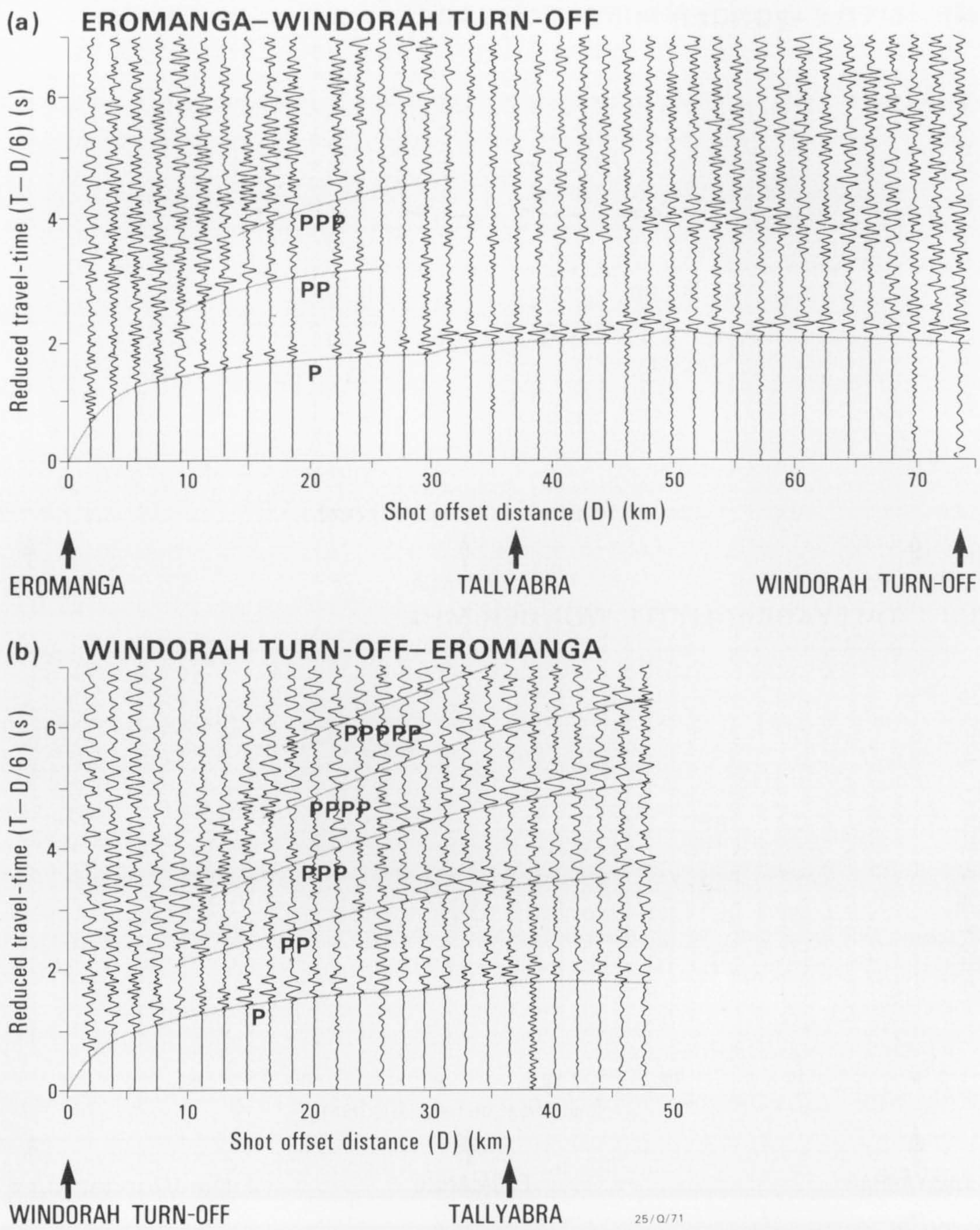


Fig. 13. Wide-angle reflection/refraction record section from a) shots at Eromanga recorded towards Windorah Road turn-off, and b) shots at Windorah Road turn-off recorded towards Eromanga.

Velocities within the top of basement vary from 4.8 km/s under the Canaway Ridge and Cheepie Shelf, to about 5.7 km/s beneath the troughs. The velocity increases with depth to 6.0 km/s at a depth of 4.0 km under the Cheepie Shelf, and at a depth of over 8.0 km elsewhere. Steep velocity gradients near the top of the basement may be caused by weathering when the basement surface was exposed before deposition of later sediments.

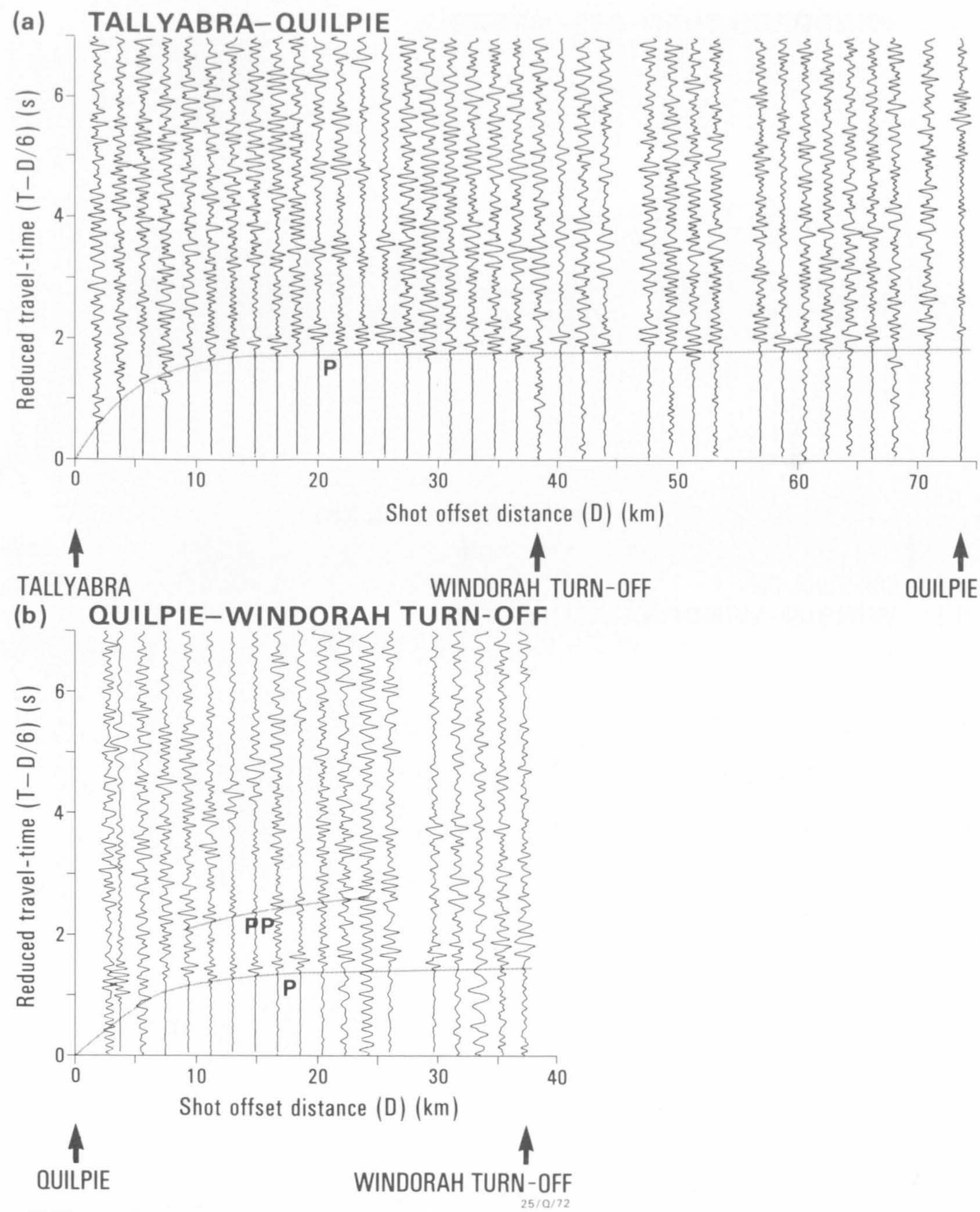


Fig. 14. Wide-angle reflection/refraction record section from a) shots at Tallyabra recorded towards Quilpie, and b) shots at Quilpie recorded towards Windorah Road turn-off.

Gravity modelling. To determine the gravitational effects of the seismic model, the P-wave velocities were converted to densities using the empirical relation of Dooley (1976) for continental sedimentary rocks. As the velocity within each layer is gradational, the average velocity within a layer was used to derive its mean density. The modelling was done using a computer program (B.J. Drummond, BMR, personal communication, 1982) adapted from Milsom & Worthington (1977). This computes the gravitational attraction of two-dimensional bodies of limited strike length. The model gravity values and the observed gravity values agree to within about 50 micrometres/second squared (Fig. 18).

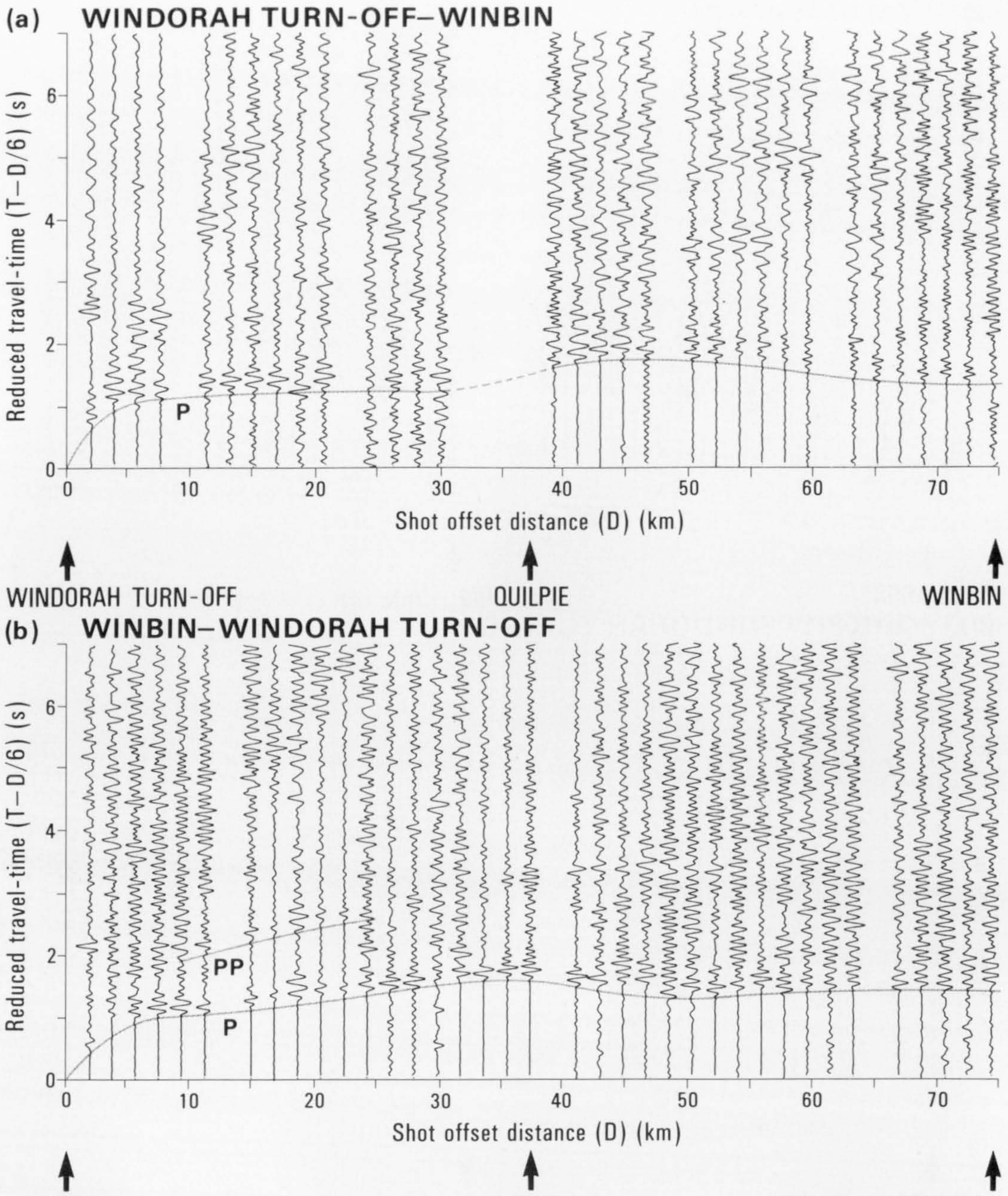


Fig. 15. Wide-angle reflection/refraction record section from a) shots at Windorah Road turn-off recorded towards Winbin, and b) shots at Winbin recorded towards Windorah Road turn-off.

The average crustal model between Mount Howitt and Cheepie for depths below 10 km (Finlayson & others, 1984) was included in the model to account for a regional effect observed after modelling the top 10 km. The regional gradient changes slope about half-way along the traverse, and it was found that this could be satisfactorily modelled by shallowing the crust-mantle boundary from 41 km in the east to 39 km in the west, over a distance of 25 km near the western margin of the Warrabin Trough. The refraction interpretation shows the crust-mantle boundary at about 36.4 km in the west, which is shallower than is required by the gravity. However, the gravity modelling assumes a two-dimensional model and a known velocity-density relationship for the whole crust.

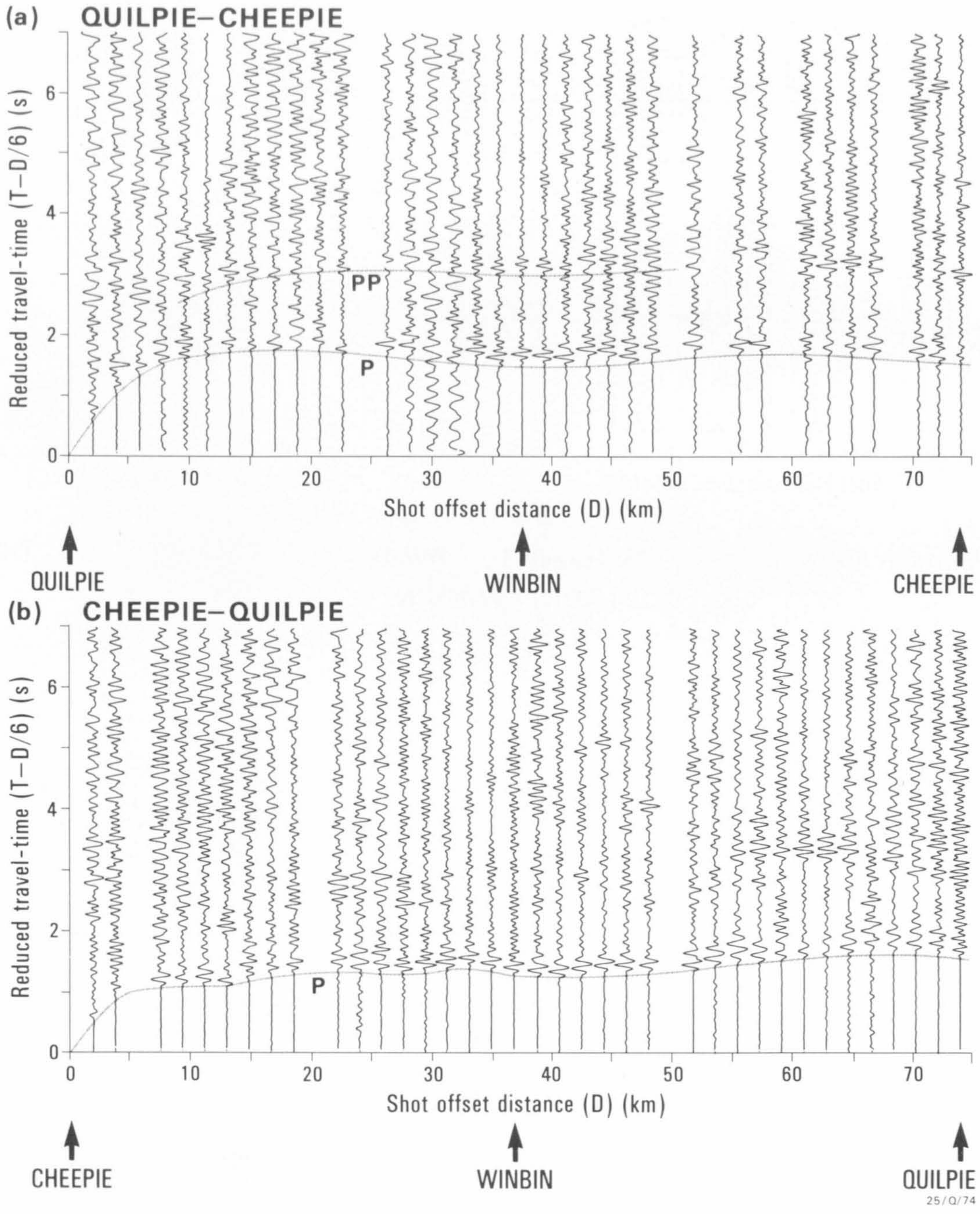


Fig. 16. Wide-angle reflection/refraction record section from a) shots at Quilpie recorded towards Cheepie, and b) shots at Cheepie recorded towards Quilpie.

Long-distance profiling

Interpretations of the data from the east-west traverse have been made by Finlayson (1983) and by Finlayson & others (1984). The prominent seismic phases annotated on the record sections (Figs. 19, 20, and 21) and used in the interpretations are as follows:

A-B - Pg phases; P-wave energy refracted within the upper crustal basement.

C-D - Pc and Pg' phases; P-wave energy reflected from and refracted through a velocity boundary (increase) at about 20-23 km depth.

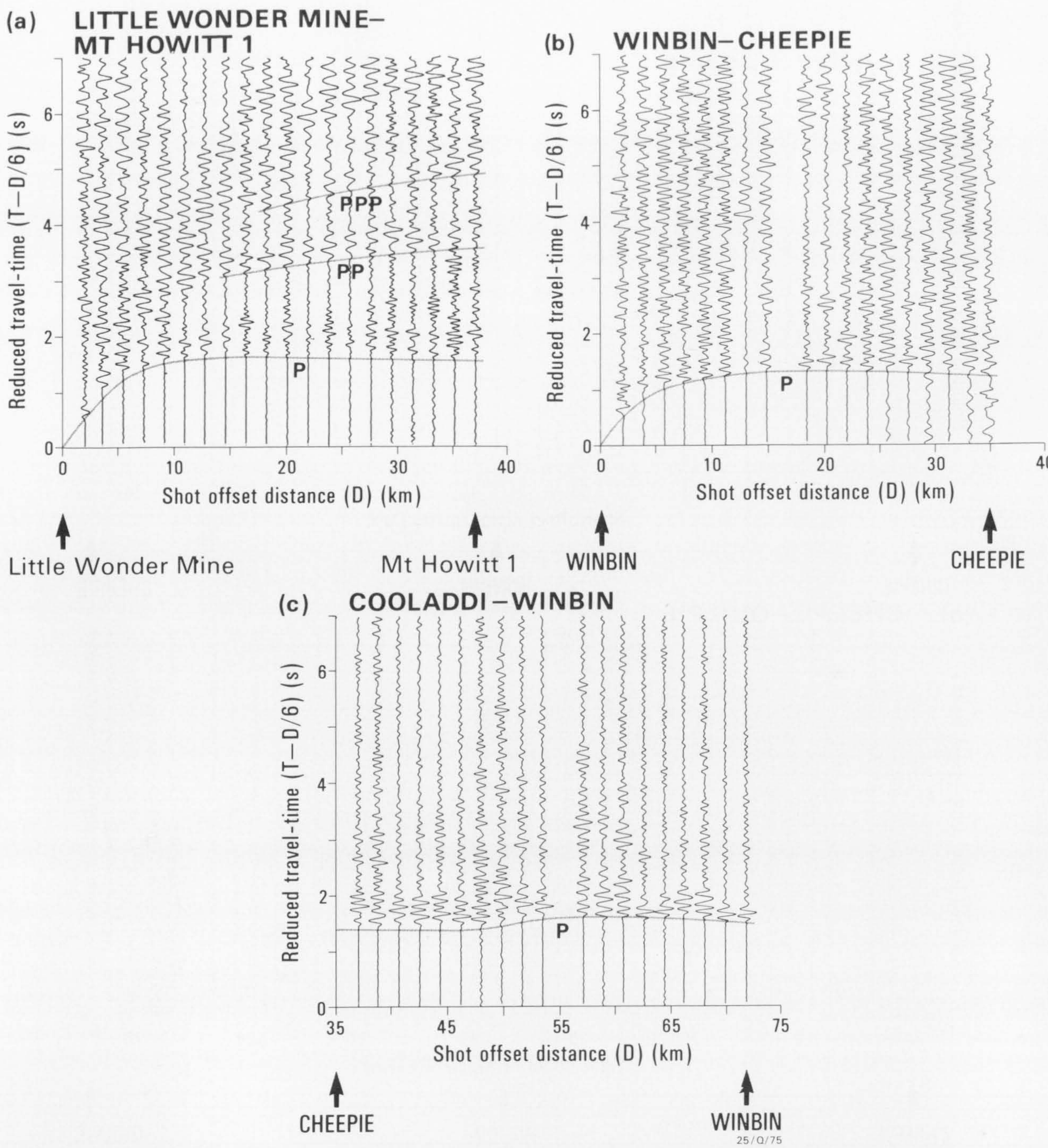


Fig. 17. Wide-angle reflection/refraction record section from a) shots at Little Wonder mine recorded towards Mount Howitt No. 1 well, b) shots at Winbin recorded towards Cheepie, and c) shots at Cheepie recorded towards Winbin.

E-F - PmP and Pn phases; P-wave energy reflected from and refracted through the crust/mantle boundary at a depth of 36-41 km.

G-H - Pn' phases; P-wave energy refracted from below a velocity increase within the upper mantle at a depth of about 56 km.

C-N - P-bar phases; P-wave energy multiply refracted in the upper crust and reflected from the near-surface; merges with Pc near C.

X-Y - P-bar phases; P-wave energy multiply refracted through the lower crust and reflected from the near-surface.

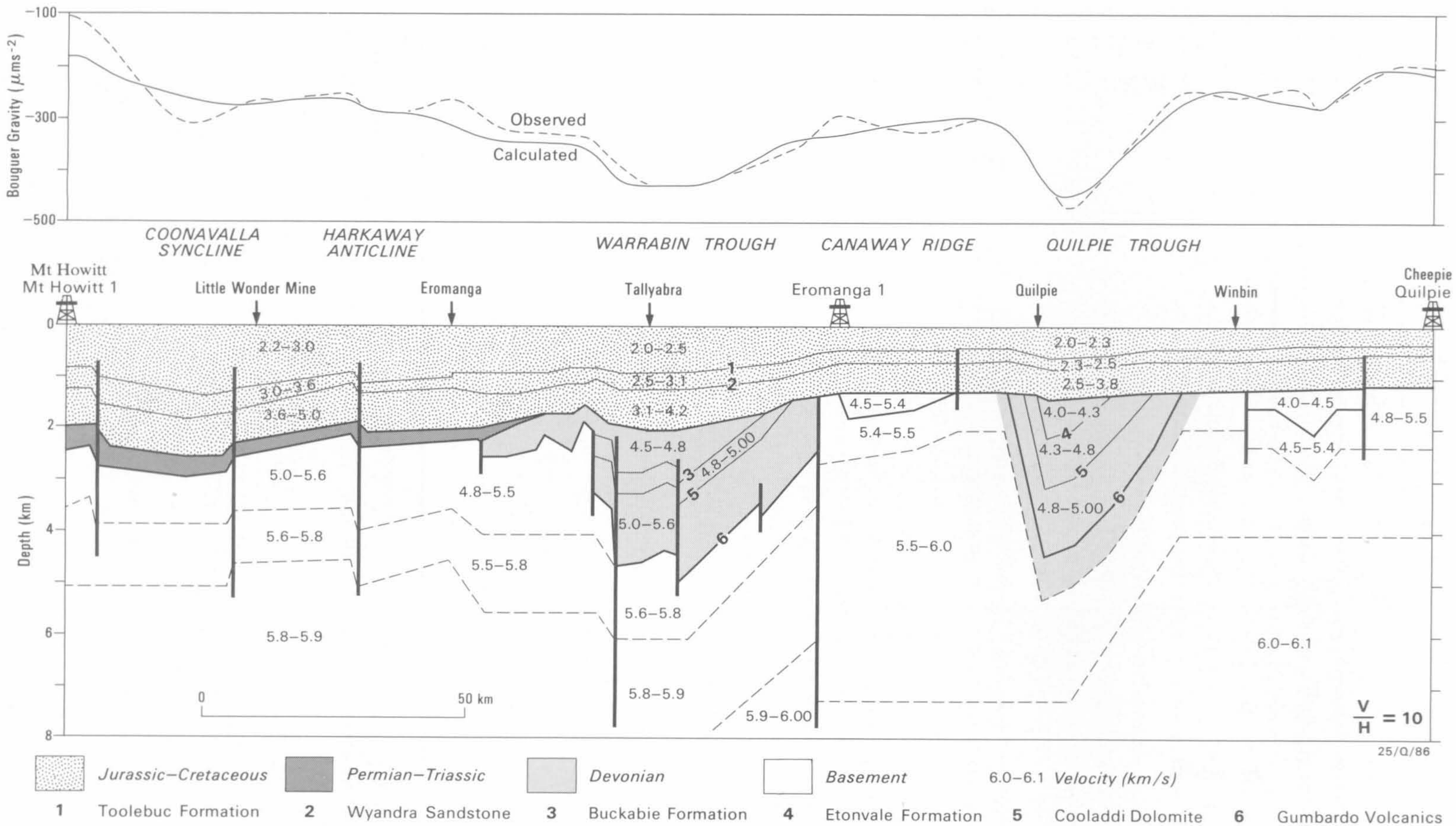


Fig. 18. Velocity structure of the upper crust along the BMR continuous reflection profiling traverses 1, 1X, and 9.

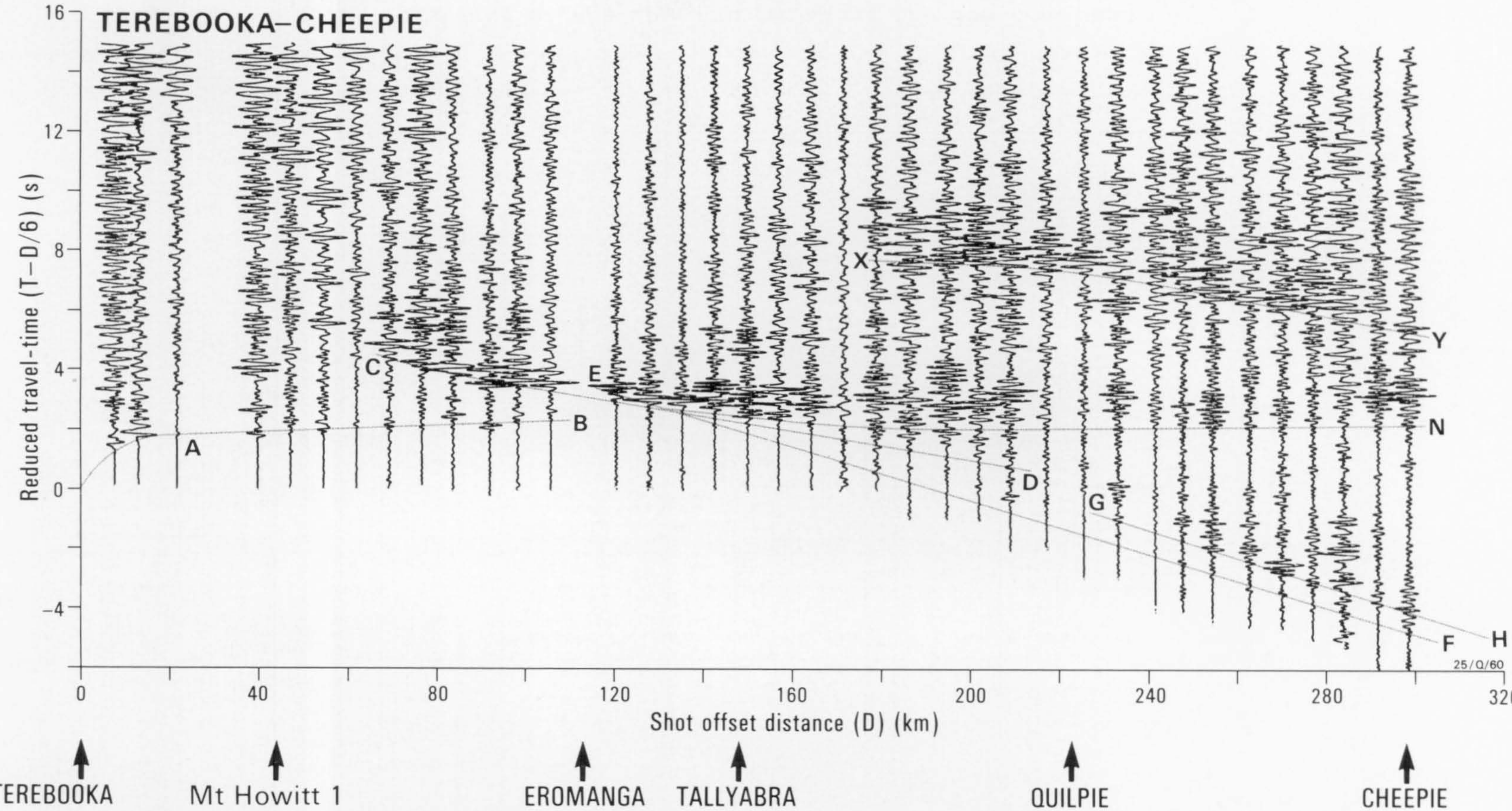


Fig. 19. Wide-angle reflection/refraction record section from shots fired at Terebooka recorded towards Cheepie. For traverse locations see Figure 3. Explanatory notes on the principal seismic phases indicated on the section are contained in the text.

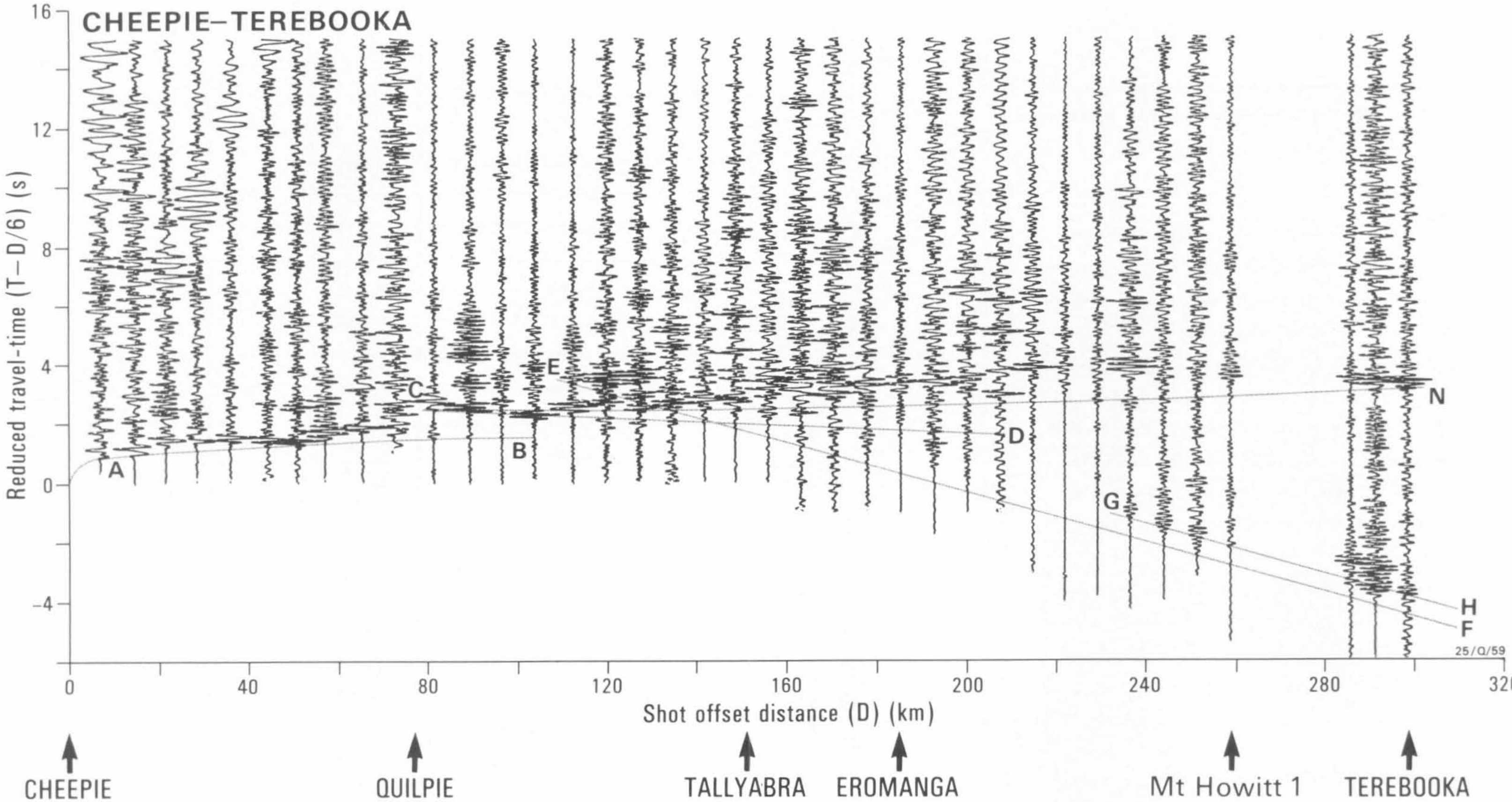


Fig. 20. Wide-angle reflection/refraction record section for shots fired at Cheepie recorded towards Terebooka.

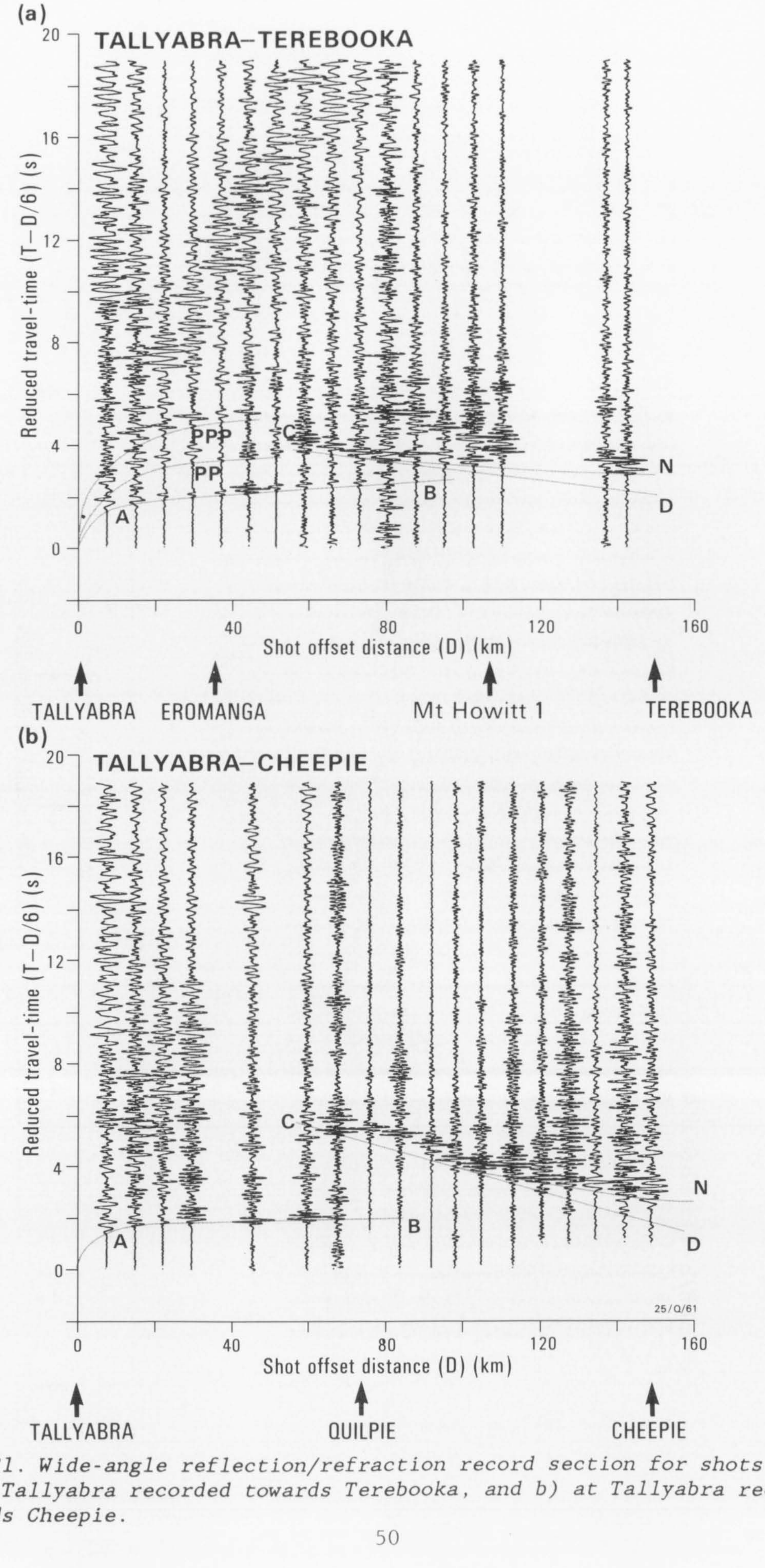


Fig. 21. Wide-angle reflection/refraction record section for shots fired a) at Tallyabra recorded towards Terebooka, and b) at Tallyabra recorded towards Cheepie.

PP - P-wave energy twice refracted in the upper crustal basement and reflected from the surface.

PPP - P-wave energy three times refracted through the upper crustal basement and reflected from the surface.

The interpretation of all these various seismic phases enables good controls to be placed on models of the velocity distribution within the crust and upper mantle for the region. The velocity/depth models derived by Finlayson & others (1984) from the data along the east-west traverse are shown in Figure 22. The most prominent feature of these models is the sharp increase in velocity at a depth of 21-24 km in three of them, and the apparent absence of this feature in the model applying under the Canaway Ridge. As will be discussed later, the velocity increase at mid-crustal depths correlates strongly with the upper boundary of reflection layers in the lower crust evident on deep reflection profiling record sections.

Another feature of the velocity/depth models is a decrease in velocity at depths of 8-10 km (Finlayson & others, 1984). Although this decrease in

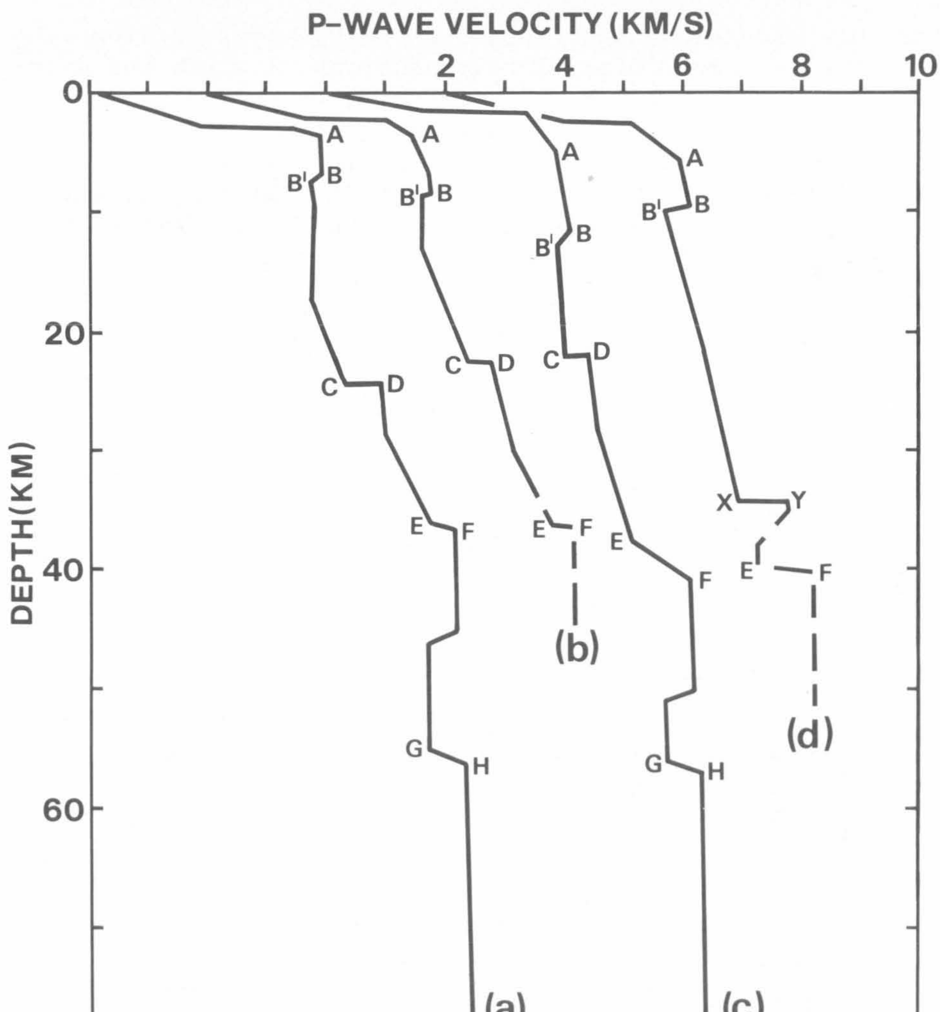


Fig. 22. Velocity/depth models throughout the crust and upper mantle derived from wide-angle reflection/refraction profiling along the BMR east-west traverse, Terebooka to Cheepie (Finlayson & others, 1984).

velocity appears to be quite sharp in Figure 22, its true nature cannot be interpreted uniquely from the data. A more gradual decrease in velocity could also be interpreted.

The crust/mantle boundary (Moho) determined from the east-west data indicates a transition to the upper mantle velocity of 8.15 km/s rather than a sharp increase. The depth of the Moho increases from 36-37 km in the west to 41 km in the east. Within the upper mantle, further velocity variations are interpreted from the data; for example, an increase in velocity to about 8.35 km/s is interpreted at a depth of 56-57 km. It is evident, therefore, that the crustal thickness decreases towards the western part of the region, and that the thickness of the lower crustal layer also decreases towards the west. Below the crust/mantle boundary, further indications of geochemical differentiation affecting velocities are apparent in the upper 20 km of the mantle.

The data recorded along the north-south traverses through the Adavale Basin have been interpreted by Finlayson & Collins (1986). The nomenclature annotated on the record sections (Figs. 23-26) to indicate the interpreted seismic phases is the same as that used for the east-west traverse.

Considerable lateral changes in the depth to basement along the traverse must be taken into account in any interpretation. As with the east-west traverse, the characteristics of all the identified seismic phases must be satisfied in order to achieve a reliable model of the velocity/depth distribution (Fig. 27). An example of the phases used in the interpretation north and south of Adavale is shown in Figure 28. Both the amplitudes and travel-times of the various phases can be modelled. An example of the integrated modelling of phases recorded beyond 100 km from the shot-point is shown in Figure 29.

A notable feature of the results is the continued identification of a mid-crustal velocity horizon at a depth of 24-25 km under the basin, but under the Canaway Ridge this feature is either not prominent or totally absent. A velocity decrease in the upper crustal basement has not been interpreted by Finlayson & Collins (1986). In the lower crust a velocity increase from 6.4 km/s at the mid-crustal velocity horizon to 6.6-6.7 km/s near the crust/mantle boundary correlates strongly with the zone of lower crustal reflections evident in continuous reflection profiling along BMR traverse 10. Between 35 km and 38-40 km depth, the velocity increases across a transition zone to an upper mantle velocity of 8.15 km/s. This upper mantle velocity is the same as that interpreted from the east-west traverse.

CONTINUOUS SIX-FOLD CMP REFLECTION PROFILING RESULTS

Mathur (1983) has commented on the reflection events which can be seen on records from the region (e.g., Fig. 30). He correlated the TWT interval 0-4 s with the structures of the Devonian and later sedimentary sequences. He described the interval 4-8 s TWT, coinciding with the basement rocks of the Thomson Fold Belt, as 'transparent' because it has very few reflectors. At TWTs of 8-14 s, the numerous discontinuous reflecting segments must be from the lower part of the crust. At TWTs greater than 14 s, only very few reflections are again apparent, and some of them may be diffractions or off-line reflections; primary reflections at these times must be from within the upper mantle.

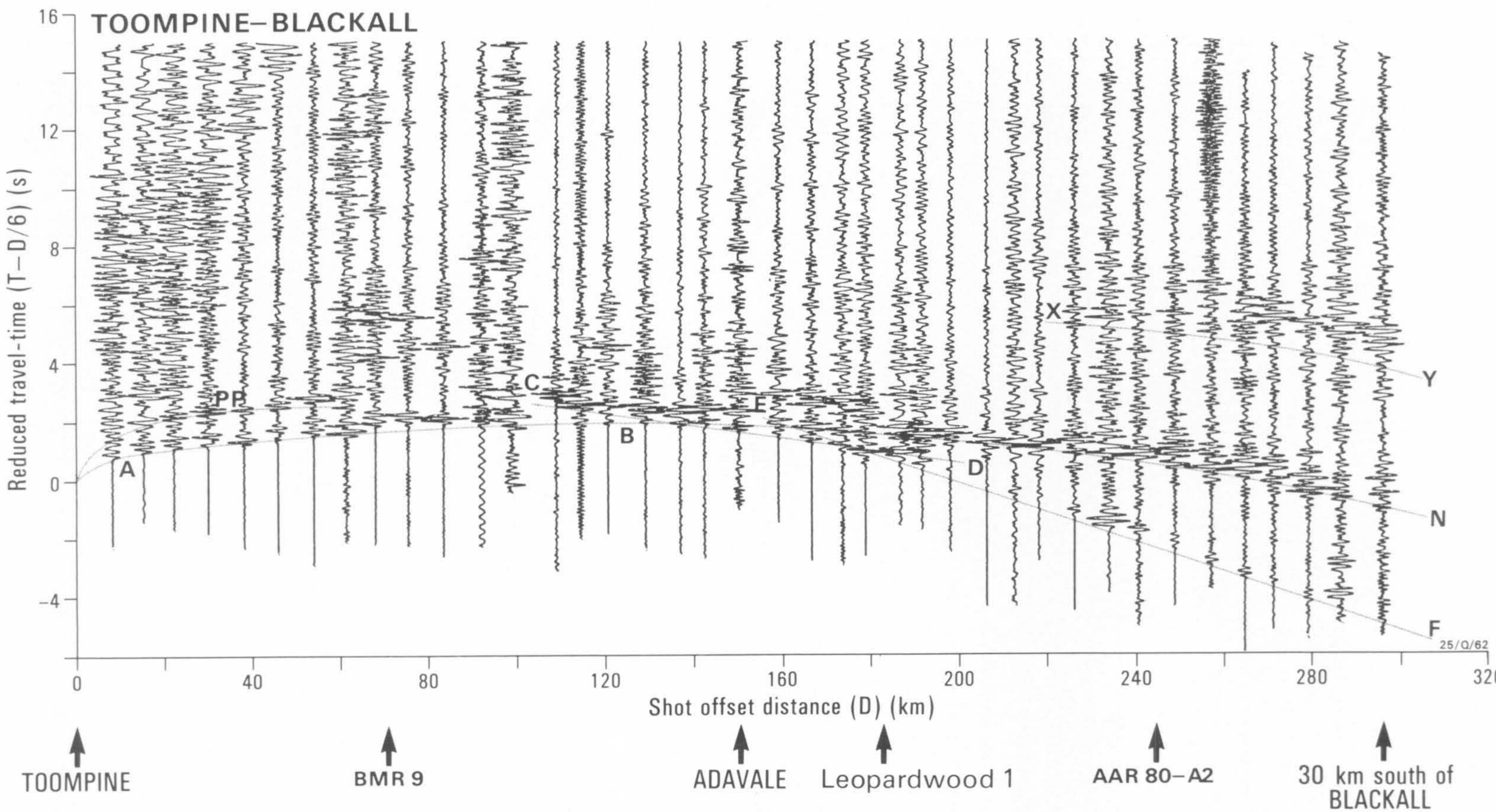


Fig. 23. Wide-angle reflection/refraction record section for shots fired at Toompine recorded towards Blackall.

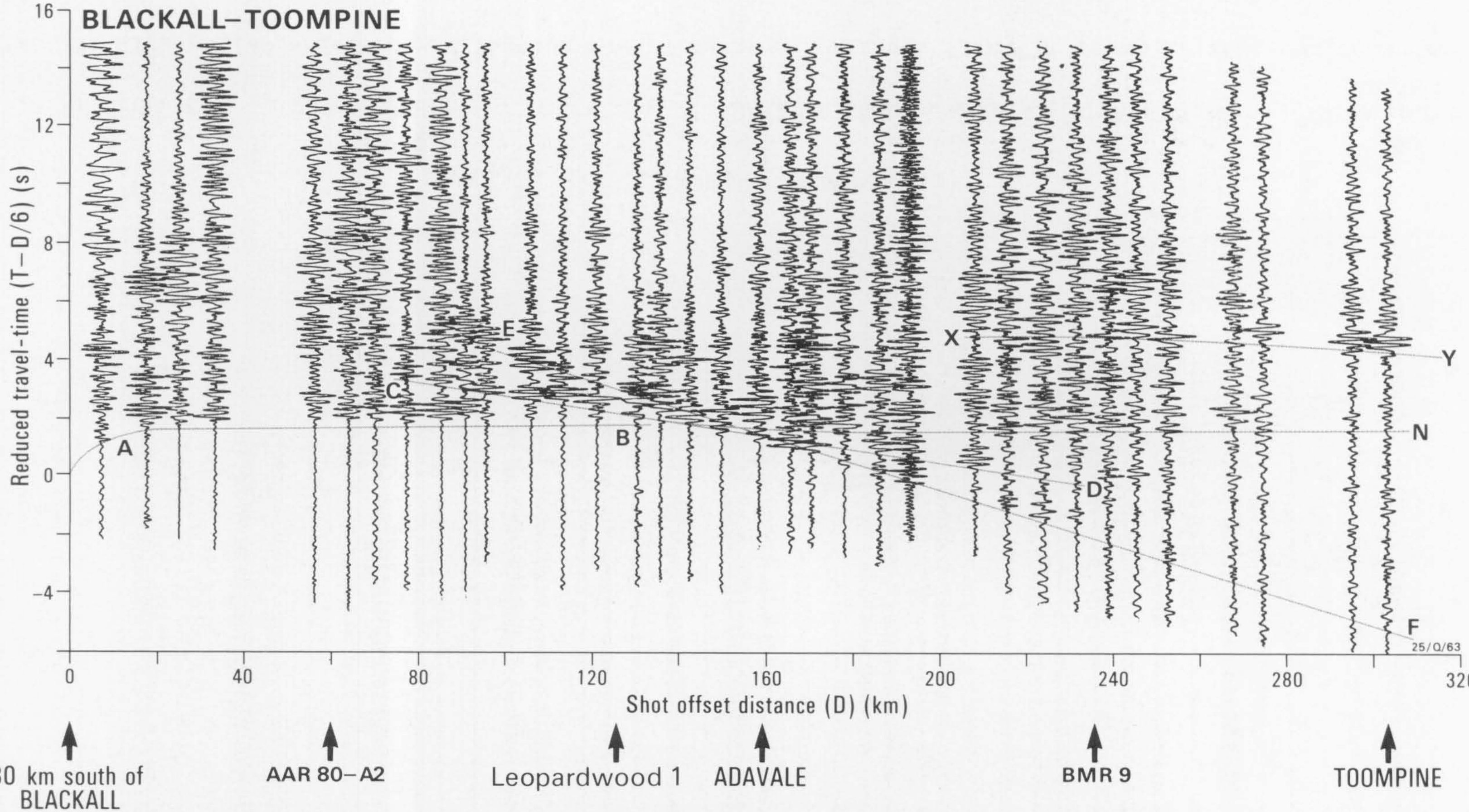


Fig. 24. Wide-angle reflection/refraction record section for shots fired at Blackall recorded towards Toompine.

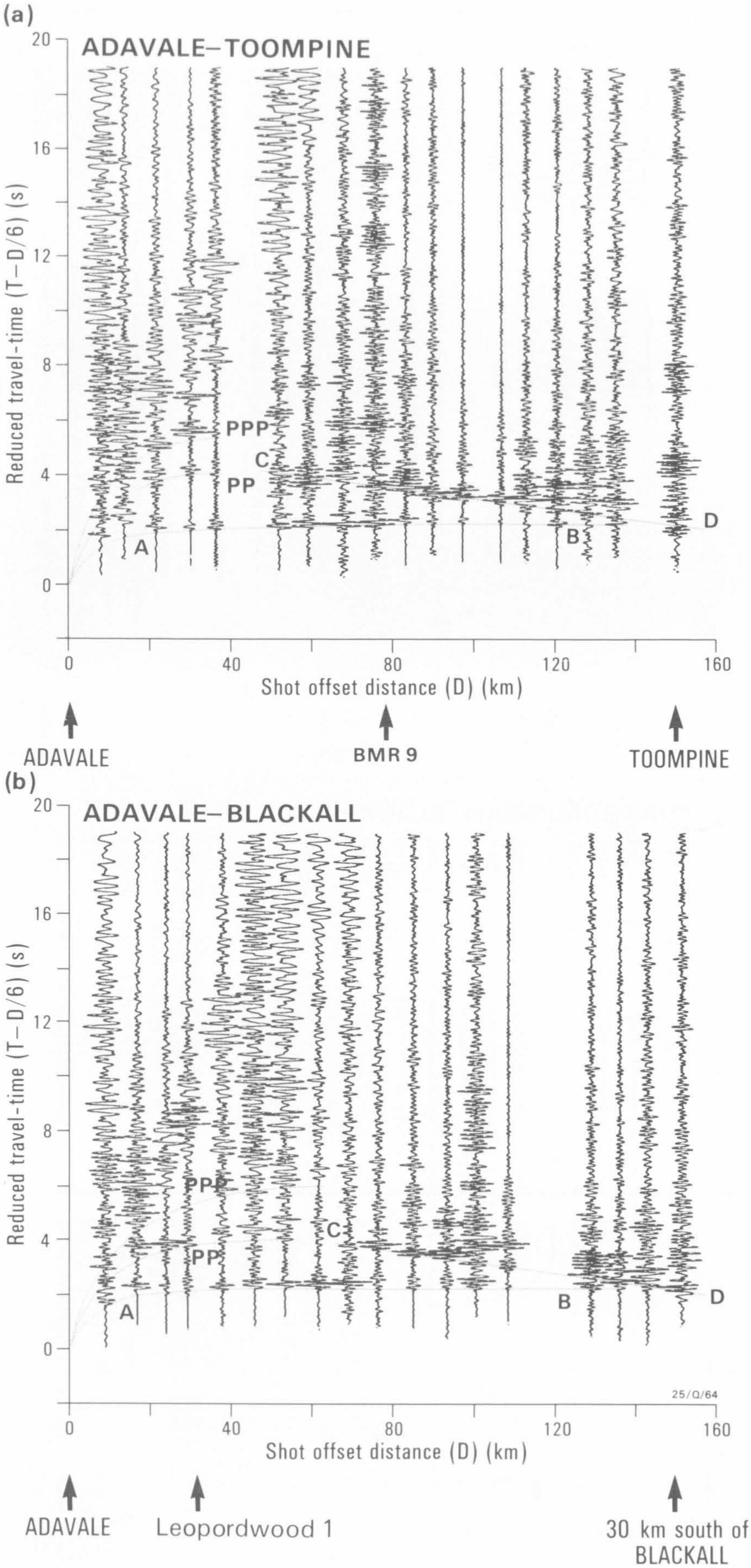


Fig. 25. Wide-angle reflection/refraction record sections for shots fired a) at Adavale towards Toompine, and b) at Adavale recorded towards Blackall.

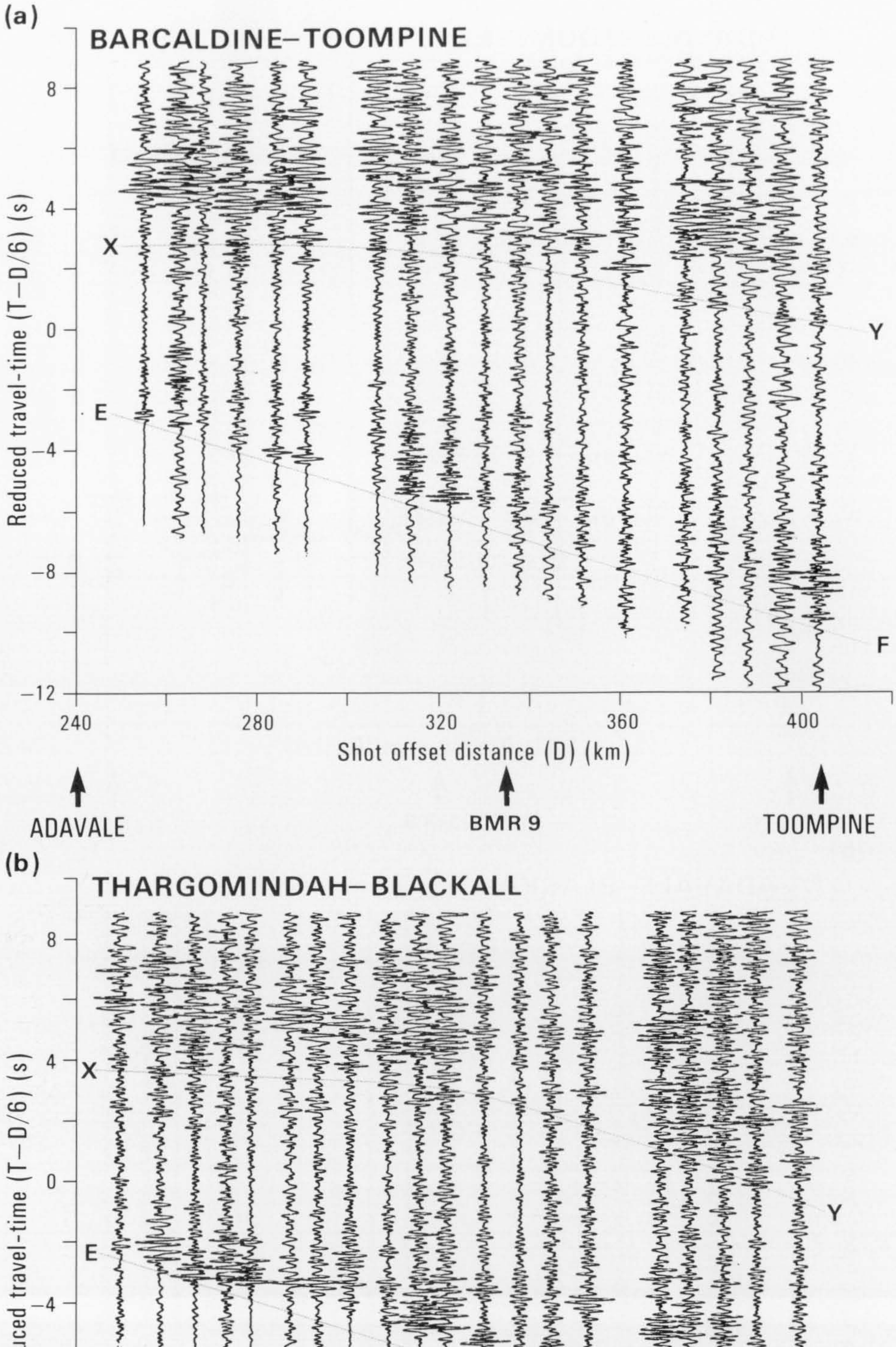


Fig. 26. Wide-angle reflection/refraction record section for shots fired a) at Barcaldine and recorded between Adavale and Toompine, and b) at Thargomindah and recorded between Adavale and Blackall.

The data from basin structures (0-4 s) and basement and deep lithospheric structures (4-20 s) are considered separately below.

Basin structures

The BMR six-fold CMP seismic reflection profiles for TWTs of up to 4 seconds were made available to the exploration industry as soon as possible after processing was completed (Wake-Dyster & Pinchin, 1981; Sexton & Taylor, 1983, in preparation). These data have been incorporated into a number of interpretations of structures and lithologies within the sedimentary sequences (Passmore & Sexton, 1984; Wake-Dyster & others, 1983; Finlayson & others, in press). In a large basin such as the Eromanga Basin it is important to have

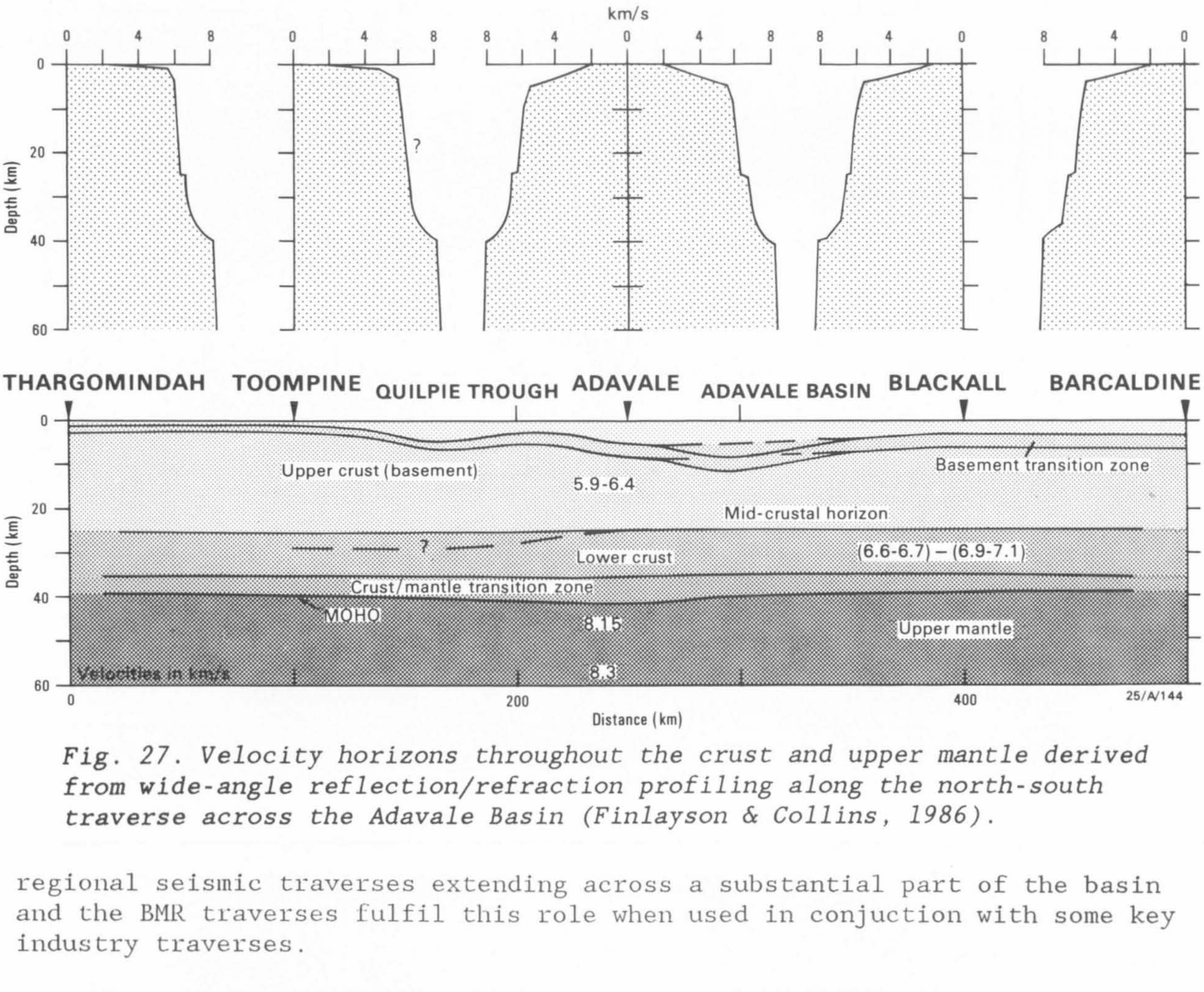


Fig. 27. Velocity horizons throughout the crust and upper mantle derived from wide-angle reflection/refraction profiling along the north-south traverse across the Adavale Basin (Finlayson & Collins, 1986).

regional seismic traverses extending across a substantial part of the basin and the BMR traverses fulfil this role when used in conjuction with some key industry traverses.

The seismic signatures of the various stratigraphic horizons (Table 1) have been determined using exploration drillhole data and synthetic records (Wake-Dyster & Pinchin, 1981; Sexton & Taylor, 1983, in preparation; Wake-Dyster & others, 1983; Passmore & Sexton, 1984). Figure 31 illustrates some of the well log information.

The key exploration company seismic profiles that supplement the BMR profiles have enabled us to develop an impression of the regional structures within the sedimentary sequences. Figures 32 and 33 illustrate the BMR data quality and show some of the structural features apparent within the Warrabin Trough (BMR traverse 1) and the Adavale Basin (BMR traverse 11). Plates 1 to

6 show reductions of the unmigrated BMR seismic profiling records to 4 s TWT. Line drawings of the features evident on a number of long regional traverses using combined company and BMR traverses are shown in Plates 7 to 12.

Finlayson & others (1986) have mapped regional fault structures based on 10 000 km of seismic profiling, and the principal elements of this mapping are shown in Figure 8. The majority of faults in the basin sedimentary rocks are interpreted as resulting from the reactivation of structures within the basement rocks of the Thomson Fold Belt. The most prominent of these reactivated faults are interpreted as reverse faults associated with

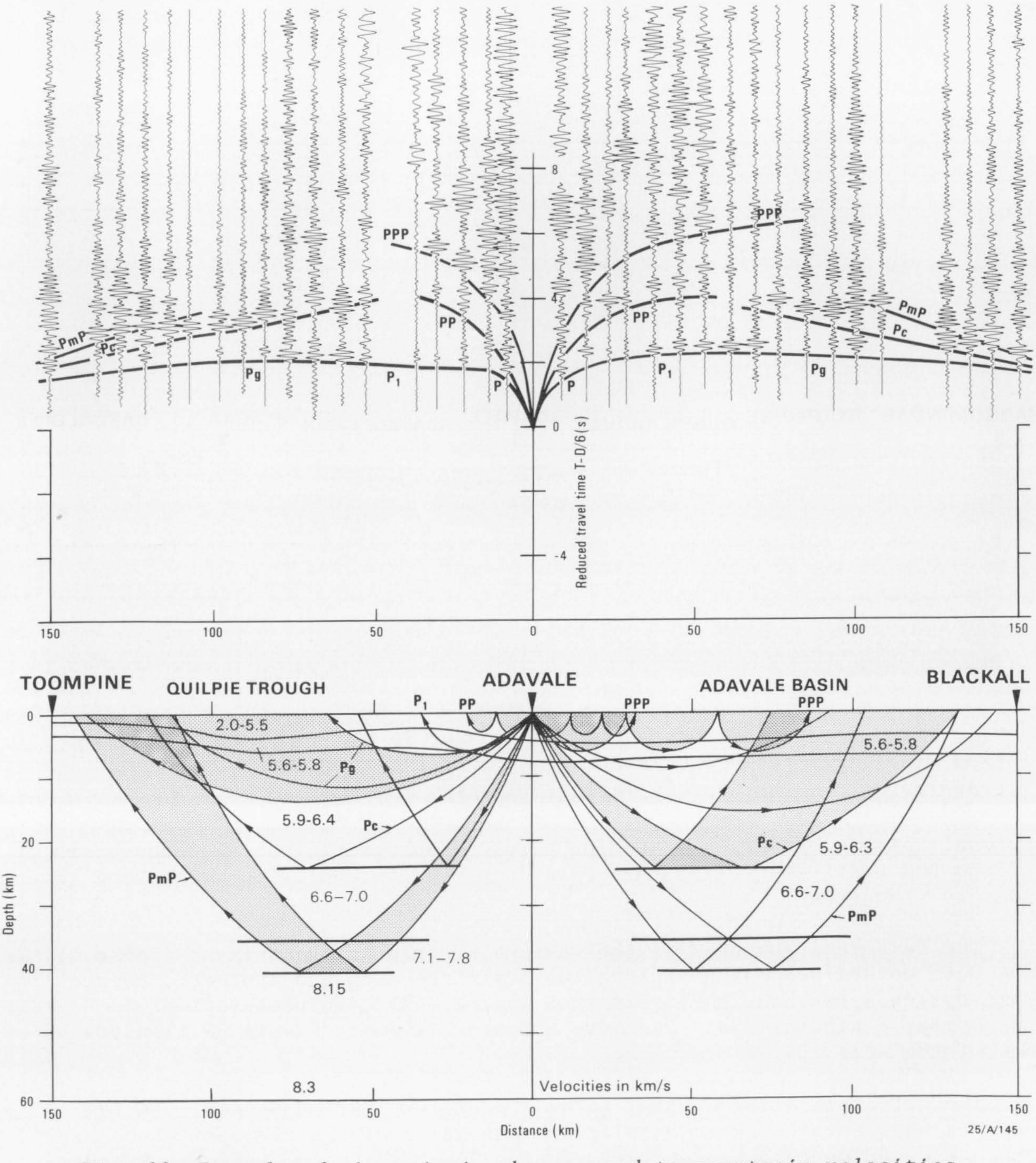


Fig. 28. Example of the seismic phases used to constrain velocities north and south of the shot-point at Adavale (Finlayson & Collins, 1986).

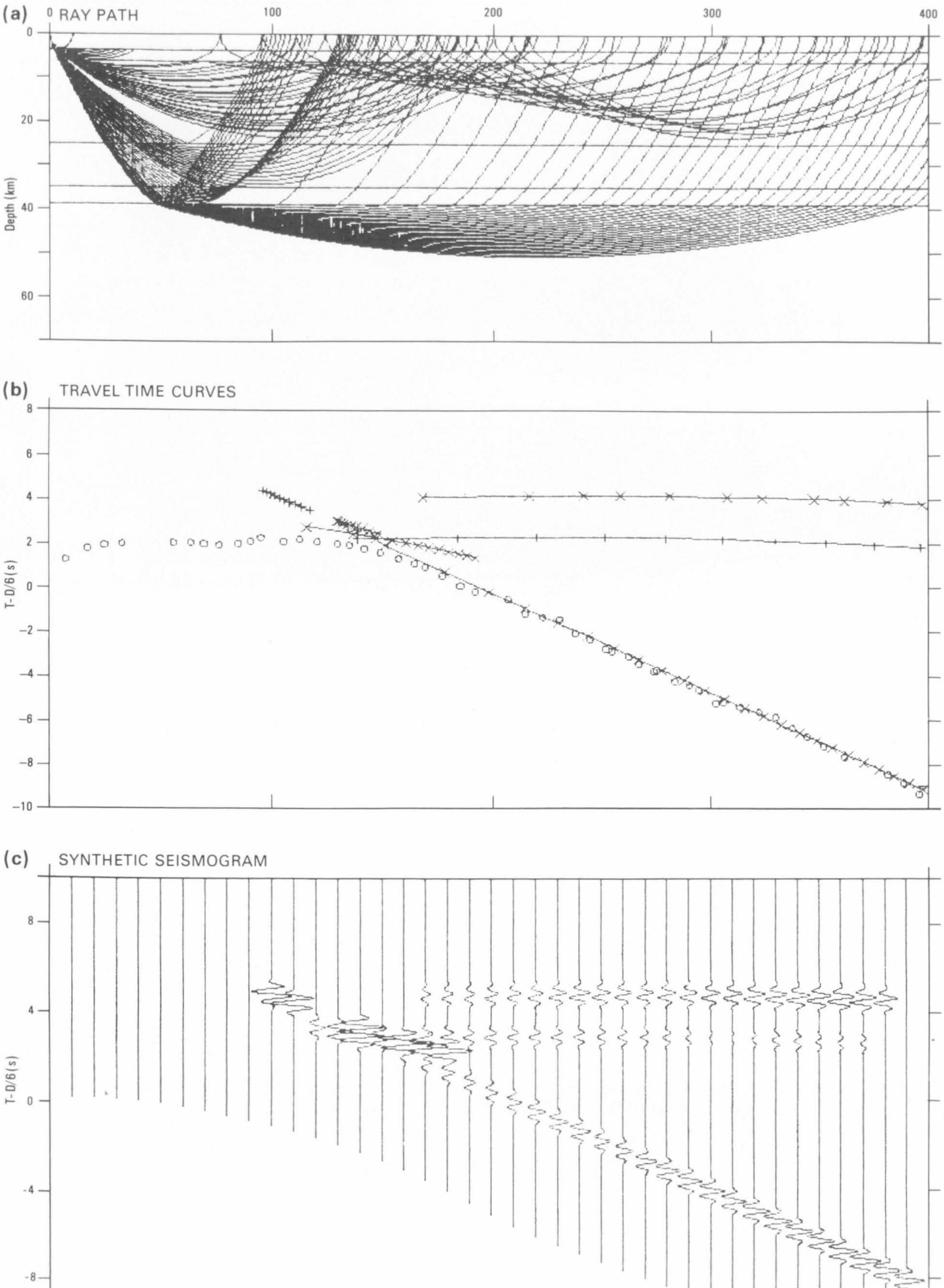


Fig. 29. Example of seismic modelling of upper and lower crustal phases, upper mantle phases, and multiply refracted phases using synthetic seismic records: a) ray diagram, b) travel-time plot, and c) synthetic records (Finlayson & Collins, 1986).

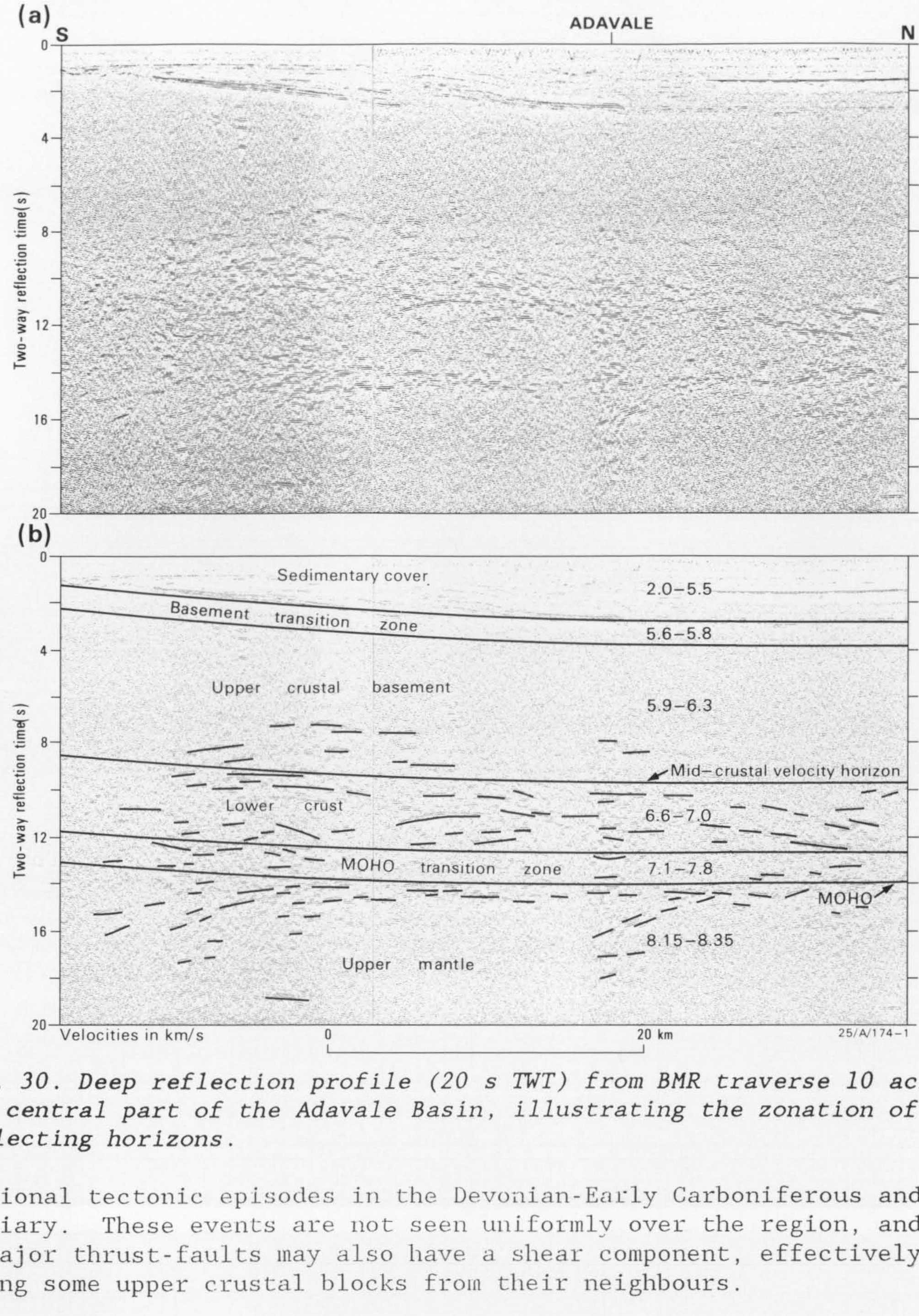


Fig. 30. Deep reflection profile (20 s TWT) from BMR traverse 10 across the central part of the Adavale Basin, illustrating the zonation of reflecting horizons.

compressional tectonic episodes in the Devonian-Early Carboniferous and mid-Tertiary. These events are not seen uniformly over the region, and some of the major thrust-faults may also have a shear component, effectively decoupling some upper crustal blocks from their neighbours.

Basement structural features and basin sediments form linked systems, and it is the recognition of the links which is essential for a tectonic reconstruction of the region. Faults which may be normal early in a region's history may be reactivated as thrust or wrench-faults in later orogenic episodes. In the central Eromanga Basin region, the Devonian-Early Carboniferous and mid-Tertiary compressional events have resulted in structures which are proving to be attractive petroleum prospects.

For the purpose of highlighting the depositional and structural features in this Report, six composite traverses have been chosen to be representative of the seismic profiling conducted in the central Eromanga Basin region. The data are shown in diagrammatic form, derived from reduced seismic record sections. The numbers attached to horizons correspond to those shown against the various sedimentary sequence horizons in Table 1. The interpreted fault structures give some indication of the style of deformation within the sedimentary sequences. However, within basement, there is little control on the dip angle of faulting. Only in a few places is there any evidence for the dip on thrust-faults decreasing with depth to sole at a horizon which can be identified (Leven & Finlayson, 1986). In most places, we have assumed that the dip angle within basement is steep, and therefore will not be evident on seismic profiling records. Where no recognised geological name is available, names attached to features such as faults are commonly taken from those used in the exploration industry or from local geographic place names.

BMR traverses 6 and 2, AAR traverse 82-A2, BMR traverse 13 (Plate 7). This composite traverse begins in the west at Galway No. 1 well on the Windorah Anticline, in the northern part of the region. It spans the Barcoo Trough, the Canaway Ridge, the northern Adavale Basin, the Warrego Fault, and the northern Pleasant Creek Arch, and is tied at its eastern extremity to Westbourne No. 1 well in the Galilee Basin.

Time depths to the top Devonian unconformity vary from a maximum of about 2.0 seconds in the Barcoo Trough, to a minimum of about 1.0 seconds across the Pleasant Creek Arch. Time thicknesses of the Devonian sequence vary from zero on the Canaway Ridge and Pleasant Creek Arch, to 0.7 seconds in the northern Adavale Basin. Some faults are restricted to the Devonian sequence, but mid-Tertiary reactivated faulting affected all basin sequences cut by the Thomson, Canaway, Grey Range, Etonvale and Warrego Faults.

The Permo-Triassic Cooper and Galilee Basin rocks are quite thin along this traverse (0-0.3 seconds). From exploration wells we can determine that the Permo-Triassic sequence is 338 m in Galway No. 1 well, 223 m in Etonvale No. 1, 627 m in Grey Range No. 1, 457 m in Lissoy No. 1, and 454 m in Stafford No. 1 (Table 2).

Table 2

Depths (in metres) to the tops of formations below the wellhead in exploration wells along composite traverse BMR 6, 2, AAR 82-A2, BMR 13

	Galway No.1	Grey Range No.1	Lissoy No.1	Etonvale No.1	Stafford No.1
Winton	11	4	5	4	4
Toolebuc	1259	991	951	748	471
Cadna-Owie	1503	1279	1256	1032	750
Hutton	1977	1718	1690	1458	1215
Permo-Triassic	2317	1943	1969	1684	1411
Top Dev. Unc.	n.p.	2570	2426	1907	1865
Etonvale	n.p.	3158	3493	2036	2060
Cooladdi	n.p.	n.p.	3744	2294	2750
Gumbardo	n.p.	3320	n.p.	3057	3030
Basement	2655	3360	3950	3325	--

n.p. = not present

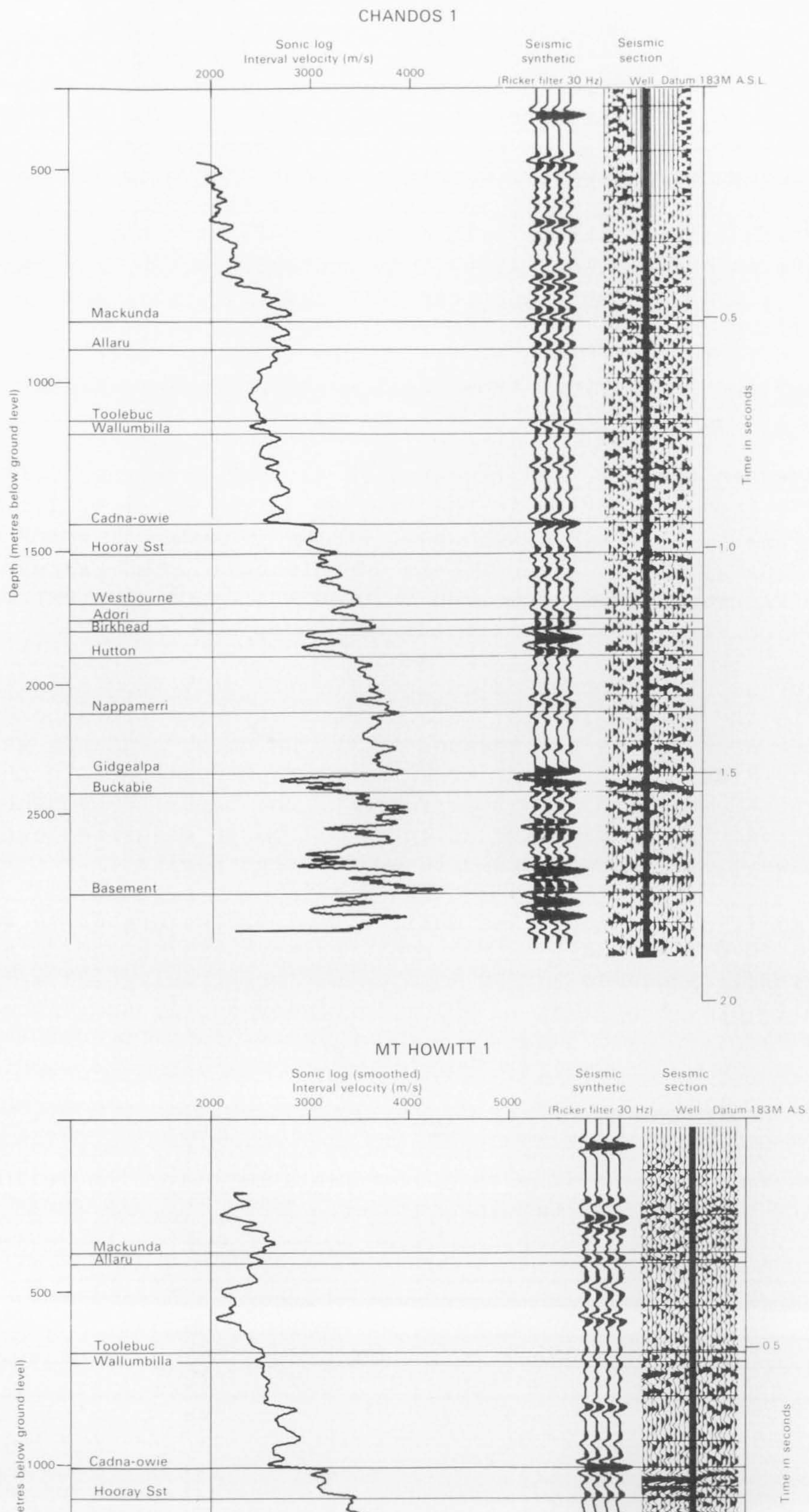
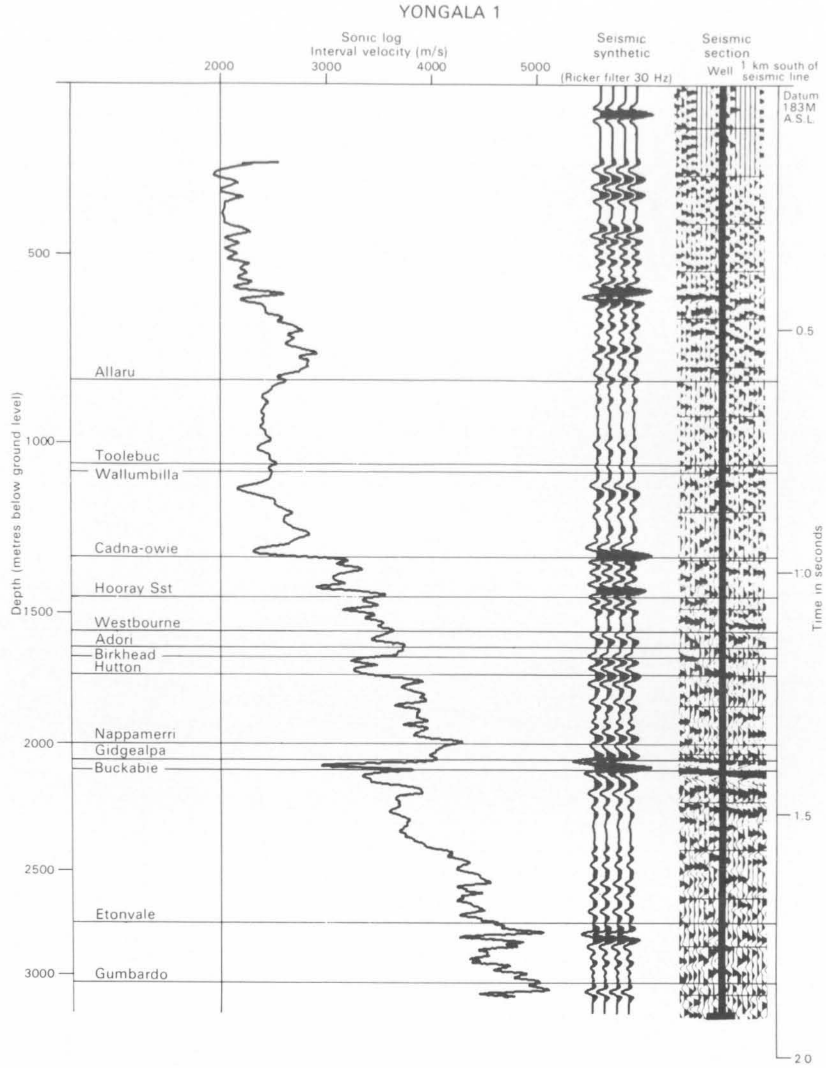


Fig. 31. Example of well log information and synthetic seismic reflection records for Mount Howitt No. 1, Chandos No. 1, Thunda No. 1, and Yongala No. 1 wells (Wake-Dyster & Pinchin, 1981).



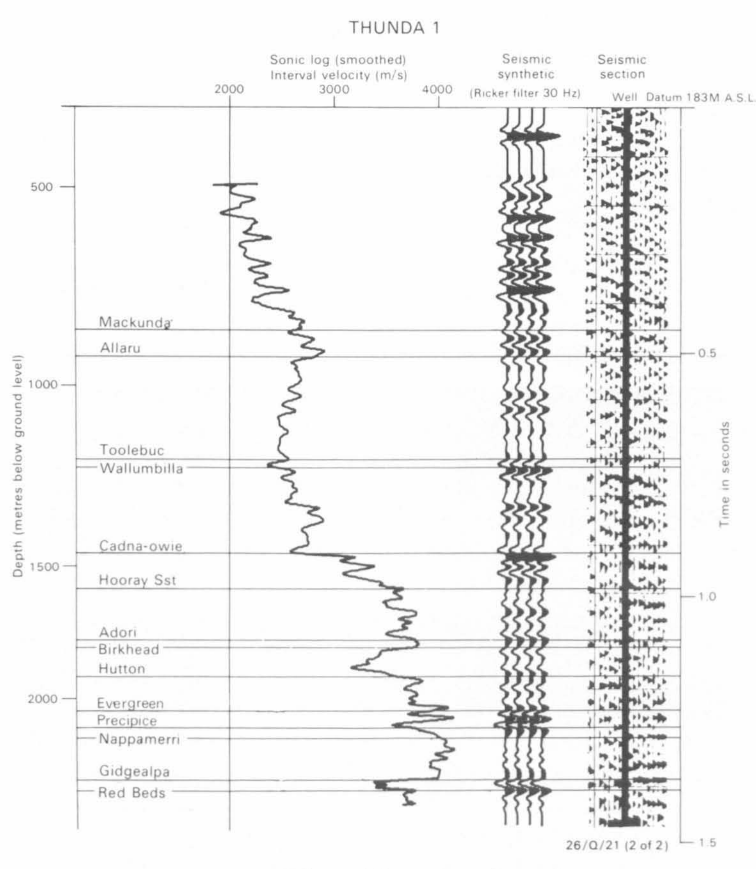


Fig. 31. continued.

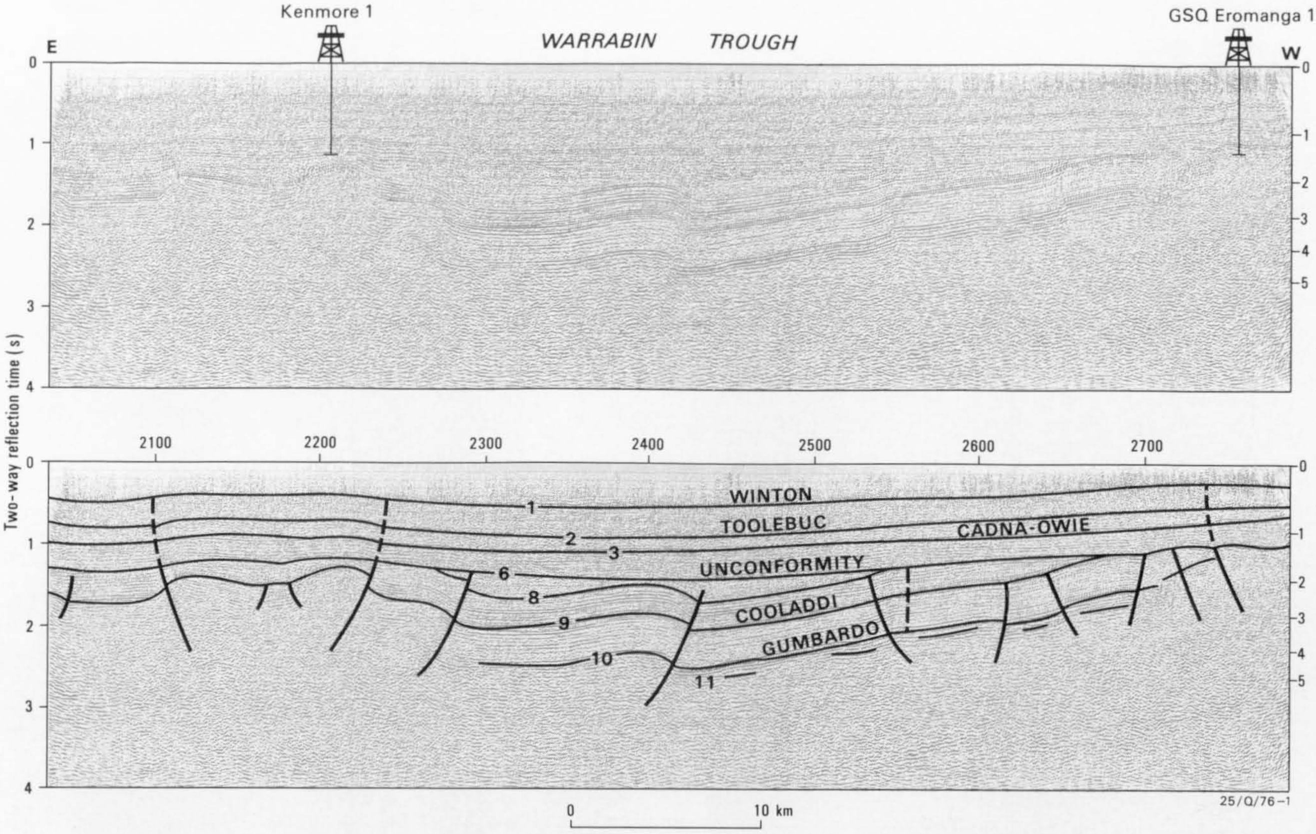


Fig. 32. Structural features evident on BMR traverse 1 across the Warrabin Trough.

BMR traverses 7 and 8, University of Sydney traverse AB, BMR traverses 8 and 11 (Plate 8). This composite traverse crosses the northern Cooper Basin, Barcoo Trough, Canaway Ridge, Adavale Basin, Cothalow Arch, Gumbardo structure, Grenfield Uplift, and Cooladdi Trough. It has poor well control at its western end, and a 25-km gap between the western and eastern parts of BMR traverse 7. However, in the eastern part of the composite traverse, well control is available at E. Windorah No. 1, Thunda No. 1, Yongala No. 1, Cothalow No. 1, and Gumbardo No. 1 wells.

Time depths to the top Devonian unconformity vary from about 2.1 s in the Barcoo Trough, to 1.0 s across the Grenfield Uplift. Along BMR traverse 7(west) the time depth to the Cooper Basin rocks exceeds 2.2 s towards the axis of the basin. The time thickness of the Devonian sequence along the composite traverse varies from zero over the Canaway Ridge, to 2.2 s adjacent to the Grenfield Fault in the southern Adavale Basin.

In the eastern part of the composite traverse the thickness of the Permo-Triassic sequence is small, being 210 m in Thunda No. 1 well, 101 m in Yongala No. 1, 58 m in Cothalow No. 1 (Permian), and zero in Gumbardo No. 1 (Table 3).

Along the western part of BMR traverse 7, the thickness of the Permo-Triassic sequence on the western side of the Cooper Basin appears to increase towards the centre of the basin. The eastern part of BMR traverse 7 crosses the Moothandella Fault, and the composite traverse continues across the main part of the Barcoo Trough and reveals little fault structure until it intersects the Thunda Fault farther east. The Canaway Ridge is evidently fault-controlled at the Bulgroo and Canaway Faults.

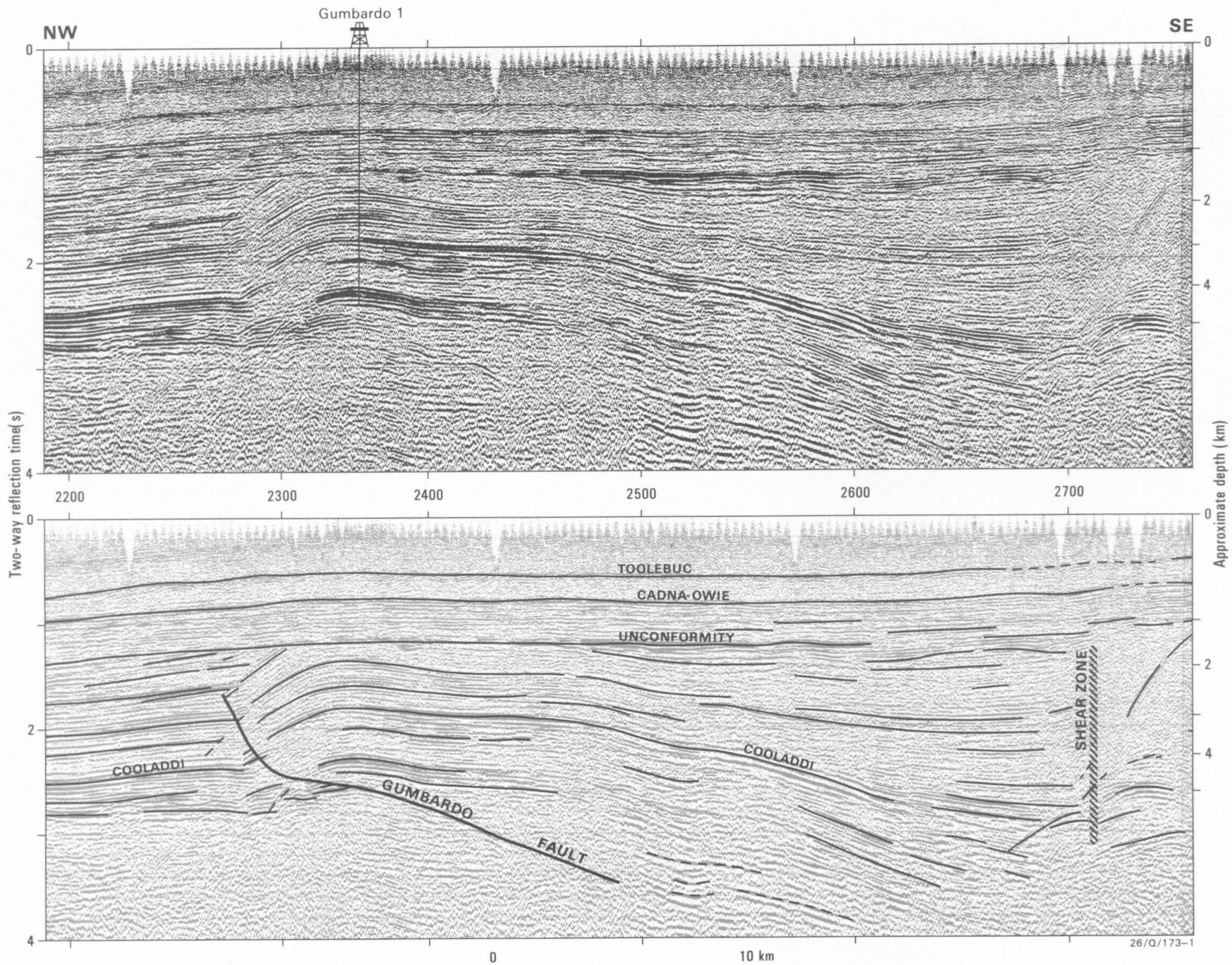


Fig. 33. Structural features evident on BMR traverse 11 through the Gumbardo No. 1 well in the southern Adavale Basin.

Within the Adavale Basin, the composite traverse crosses the Cothalow Arch, which has mid-Tertiary fault structures on its northwestern and southeastern margins. In the southern part of the Adavale Basin the deformation of the Devonian sequence penetrated by Gumbardo No. 1 well is apparent. Leven & Finlayson (1986) have discussed this deformation in some detail, and suggested that it is a thrust-fault with a listric fault plane which soles at a depth of less than 10 km and dips at a shallow angle towards the south. Southeast of the Gumbardo structure, major structural deformation is concentrated along the Grenfield Fault and across the Grenfield Uplift; this is interpreted as being caused by major crustal deformation with both

Table 3

Depths (in metres) to the tops of formations below the wellhead in exploration wells along composite traverse BMR 7, 8, University of Sydney AB, BMR 8, 11

	Thunda No.1	Yongala No.1	Cothalow No.1	Gumbardo No.1
Winton	0	5	18	29
Toolebuc	1201	1058	764	563
Cadna-Owie	1463	1301	1021	850
Hutton	1920	1721	1378	1277
Permo-Triassic	2149	1992	1542	n.p.
Top Dev. Unc.	2359	2093	1600	1441
Etonvale	--	2735	2036	2359
Cooladdi	--	3014	n.p.	2734
Gumbardo	--	3045	2285	3167
Basement	--	3071	2564	3913

n.p. = not present

compressional and shear components (Finlayson & Leven, in press b; Leven & Finlayson, 1986). The composite traverse ends in the Cooladdi Trough, where diffractions at 2.5 s TWT and greater indicate possible salt movement or other major structuring in the Lower Devonian rocks. Leven & Finlayson (1986) attribute the structure of the Cooladdi Trough to an east-west folding episode in the early Carboniferous which followed a north-south thrust-faulting episode in the Devonian.

Delhi traverse 81-QJS, BMR traverse 3, Lennard traverse 80-03 (Plate 9). This composite traverse crosses the northern part of the Cooper Basin, the Barcoo Trough and the Canaway Ridge, stopping just short of the Canaway Fault. The time thickness of the Eromanga Basin sequence varies from about 1.0 s over the Canaway Ridge to about 2.1 s towards the deeper part of the Cooper Basin. The thickness of Devonian rocks in the Barcoo Trough is not always clear, but more than 400 m of Middle-Upper Devonian section was intersected in Chandos No. 1 well (Table 4).

From west to east, structures encountered on the composite traverse are the Yamma Yamma, Gilpeppee, Tanbar, Cunnavalla, Harkaway, Monkey-Coolah, and Tallyabra Faults and the Chandos Anticline. Minor faulting is evident in the Devonian sequence in the Barcoo Trough, but any western boundary of the Canaway Ridge is not obvious in the Jurassic-Cretaceous sequences.

Table 4

Depths (in metres) to the tops of formations below the wellhead in exploration wells along the composite traverse Delhi 81-QJS, BMR 3, Lennard 80-03

	Tanbar No.1	Chandos No.1	Canaway No.1*
Winton	62	4	4
Toolebuc	1403	1113	677
Cadna-Owie	1718	1409	898
Hutton	2160	1891	1289
Permo-Triassic	2498	2124	n.p.
Top Dev. Unc.	3031	2436	n.p.
Etonvale	--	--	n.p.
Cooladdi	--	2807	n.p.
Gumbardo	--	--	n.p.
Basement	--	2842	1479

n.p. = not present
* Well offset 11 km south of traverse.

Delhi traverse 79-QAS, Aquitaine traverses B26C, B24C, B24D, W16D, and W14D, BMR traverses 1, 1X, 9 (Plate 10). This combination of traverses extends from the western side of the Cooper Basin to the Cheepie Shelf, and crosses the central Cooper Basin, the Warrabin Trough, the Canaway Ridge, and the Quilpie Trough. The TWT depth to the base of the Jurassic-Cretaceous sequence varies from about 2.1 s above the central Cooper Basin, to 0.8 s over the Cheepie Shelf. The TWT thickness of Devonian rocks varies from 1.5 s in the Quilpie Trough to zero over the Canaway Ridge and the Cheepie Shelf. The depths to the tops of formations in wells along the traverse are listed in Table 5.

From west to east, the structural features evident on the seismic record sections are the Yamma Yamma, Gilpeppee, Mount Howitt, Harkaway, Monkey-Coolah, and Tallyabra Faults, the Warrabin Trough, the Canaway Ridge, and the Quilpie Trough. The extension of the Canaway Fault southward is evident as a large monocline at the western boundary of the Quilpie Trough, and it is most likely fault-controlled within basement. A number of unnamed faults intersect the Warrabin Trough; it is likely that some of them are reverse faults at the eastern side of the trough adjoining the Canaway Ridge.

BMR traverse 10, Phillips-Sunray traverses 705 and 556 (Plate 11). BMR traverse 10 extends in a north-south direction from the northern Adavale Basin to the Quilpie Trough, and provides cross-ties between BMR traverses 2, 11, and 9. The thickness of Permian rocks on these traverses is small in Leopardwood No. 1 well (6 m), but increases in thickness to 198 m in Gilmore No. 1 well and to 457 m in Lissoy No. 1 well (Table 6).

The TWT depth to the top Devonian unconformity varies from 1.0 s in the Quilpie Trough to 1.7 s in the Adavale Basin northwest of Leopardwood No. 1 well. The TWT thickness of the Devonian sequence varies from zero just north of the Quilpie Trough to 1.6 s northwest of Leopardwood No. 1 well in the Powell Depression.

Table 5

Depths (in metres) to the tops of formations below the wellhead in exploration wells along the compsite traverse Delhi 79-QAS, Aquitaine B26C, B24C, B24D, W16D, W14D, BMR 1, 1X, 9

	Gilpeppee No.1	Mt.Howitt No.1	Kenmore No.1	GSQ Eromanga No.1	GSQ Quilpie No.1
Winton	125	0	0	0	0
Toolebuc	1379	668	732	464	316
Cadna-Owie	1711	1003	1000	714	612
Hutton	2164	1479	1390	1107	1025
Permo-Triassic	2370	1714	n.p.	n.p.	n.p.
Top Dev. Unc.	3191	2263	1533	n.p.	n.p.
Etonvale	--	n.p.	1533	n.p.	n.p.
Cooladdi	--	n.p.	1585	n.p.	n.p.
Gumbardo	--	n.p.	--	n.p.	n.p.
Basement	--	2263	--	1257	1115

n.p. = not present

The structures interpreted from these traverses have been described by Leven & Finlayson (1986). The Quilpie Trough is truncated at is northern boundary by the Como Fault and its associated Como splay, major southward-facing thrust-faults. Farther north, the Paradise Fault, another southward-facing thrust-fault, is associated along strike with the northward-facing Gumbardo Fault. Leopardwood No. 1 well is located on a basement high which has many of the characteristics of a flower structure, indicating transpressional deformation. On BMR traverse 10 north of the Leopardwood structure, Gilmore No. 1 well was drilled on a southwest-facing thrust-fault, the Grey Range Fault.

Table 6

Depths (in metres) to the tops of formations below the wellhead in exploration wells along traverse BMR 10

	Leopardwood No.1	Gilmore No.1	Lissoy No.1
Winton	30	58	5
Toolebuc	802	849	951
Cadna-Owie	1052	1120	1256
Hutton	1445	1514	1690
Permian	1675	1766	1969
Top Dev. Unc.	1681	1964	2426
Etonvale	3423	3213	3493
Cooladdi	3818	3629	3744
Gumbardo	4165	?	n.p.
Basement	4184?	4346?	3950

n.p. = not present

Phillips-Sunray traverses 705 and 556 cross the Powell Depression where a thickened Jurassic-Cretaceous sequence has no apparent fault structures. Over the Leopardwood structure, however, there is again evidence of flower structures at depth. This structure is along strike from the Cothalow Arch (Fig. 7), and the two features probably constitute a northeast-southwest transpressional zone trending northeasterly across the central Adavale Basin.

AAR traverse 164, Aquitaine traverses AD203 and ALX-101 (Plate 12). These traverses cross the Cooladdi Trough at right-angles to BMR traverse 11 and end, at their northeastern end, in the Galilee Basin. Leven & Finlayson (1986) have described some of the structures in the Cooladdi Trough, and indicated that the structuring of the Devonian rocks took place during an early Carboniferous east-west folding episode which followed a Devonian north-south thrust-faulting episode. They found evidence of thrust-faulting on the southwest margin of the Cooladdi Trough along the southwest part of AAR traverse 164, and suggested that this may have resulted in the formation of a small Carboniferous foreland basin, the Pingine Basin. The northern margin of the Cooladdi Trough has numerous unnamed faults in the Devonian sequence.

The maximum TWT thickness of the Devonian sequence is 1.5 s. Basement has not been positively identified in the trough, and a Lower Devonian sequence may be present. The TWT depth to the top Devonian unconformity varies from 1.0 s to 1.3 s along the composite traverse. The Permian sequence under the northeastern part of the traverses is only thin, being 167 m in Dartmouth No. 1 well and 20 m in Quilberry No. 1 (Table 7). There is no evidence of mid-Tertiary faulting in the Jurassic-Cretaceous sequence.

Basement and deep lithospheric structures

Within the zone between 4 and 8 seconds TWT, which corresponds to the seismically transparent zone (Mathur, 1983), coherent reflections are generally lacking. The signal is of relatively low amplitude (Fig.30) and has a characteristic frequency in the range 20 to 30 Hz. Geologically, the upper

Table 7

Depths (in metres) to the tops of formations below the wellhead in exploration well Dartmouth No.1 on traverse Aquitaine 203, and in Quilberry No.1

	Dartmouth No.1	Quilberry No.1*
Winton	5	0
Toolebuc	433	207
Cadna-Owie	764	509
Hutton	1231	896
Permian	1387	1037
Top Dev. Unc	1554	1057
Etonvale	1554	1057
Cooladdi	1829	1647
Log Creek	?	1710
Basement	3051	3052(Log Creek?)

* Well offset 35 km southeast of Aquitaine Traverse 203.

portion of this zone corresponds to the Thomson Fold Belt (Murray & Kirkegaard, 1978). The uniform seismic character over the 4-second range in reflection time suggests that there is no significant change in the geological composition or structure in the basement beneath the sedimentary basins down to a depth of about 22 km. However, core samples from petroleum drillholes which have sampled basement indicate a wide diversity of rock types, ranging from steeply dipping metamorphics to granitic intrusives and volcanics. This range in rock types would be expected to produce geological interfaces with significant velocity contrasts, which ought to be apparent on the seimic records.

The most probable explanation for the lack of any coherent seismic reflections from within this zone is the presence of a steeply dipping metamorphic fabric which has effectively overprinted the geological boundaries, but which dips too steeply to be imaged using the conventional CMP reflection technique. Detailed velocity models for the basement constructed from shallow refraction data (Collins & Lock, 1983; Lock & Collins, 1983) indicate a slight positive velocity gradient of 0.055 km/s per km within the basement, which persists to a depth of around 8 km. Finlayson & others (1984) have modelled a low-velocity zone (LVZ) below 8 km, which commences with a sharp negative velocity jump. However, there is no corresponding reflection event on the CMP stacked section to corroborate this sharp transition, suggesting that the velocity decrease may be a more gradual phenomenon.

Below 8 km depth the reflection profiling sections show little structure. Only some multiple events from the stronger reflections in the overlying basins are seen. The lack of any substantial reflections in this zone precludes an analysis of velocities using normal moveout, and therefore refraction studies provide the only control on the upper crustal velocities in the region. The deeper refraction data interpreted by Finlayson & others (1984) indicate a general velocity increase from 6.1 to 6.4 km/s over the depth range of this transparent zone.

Within this upper crustal zone, there are a number of low-amplitude events interpreted by Leven & Finlayson (1986) to be reflections from the decollement zone of thrust-faults which have affected the overlying sedimentary sequences. Thrust-faults such as the Gumbardo Fault display a relatively high dip (greater than 70 degrees) in the sedimentary section, but sole out into a comparatively low dip (less than 20 degrees) on the decollement, and possess a characteristic listric form.

The mid-crustal ('Conrad') velocity increase observed in the central Eromanga Basin region (Finlayson & others, 1984) corresponds to a significant change in the reflection character around 8 seconds TWT. Between the two-way reflection times of 8 to 12 seconds, the reflection events have greater relative amplitude, and typically form packets which remain coherent over a distance range of 0.5 to 2.0 km, and a time range of 0.25 to 0.5 seconds. The dominant frequency within this zone lies in the range from 30 to 40 Hz, and is significantly higher than in the overlying 'transparent' zone.

An enigma of the reflections from this zone is the distance over which they remain coherent relative to the Fresnel zone radius. For example, taking the values of the root-mean-square velocity (Vrms) of 6.0 km/s at a depth of 22 km and a frequency of 40 Hz, the Fresnel zone radius is about 2 km, and yet some reflection packets are only coherent over distances of less than 0.5 km, and do not decay to their edges in the manner to be expected of diffraction tails. This suggests that either the focusing and defocusing effects of a corrugated interface, or the interference effects from layering with laterally varying thickness, may be responsible for the generation of these reflection packets. At a depth of 22 km, little normal moveout control of the velocities can be obtained from a 4-km split-spread, and additional expanded-spread experiments have been conducted to provide this control. The velocity increase associated with the top of this zone in the refraction velocity models is greater than 0.2 km/s, and Finlayson & others (1984) have suggested that either a change to a higher metamorphic grade or an increase in the mafic content of the crust could be responsible for this prominent increase in P-wave velocity.

Two models for the evolution of this lower part of the crust have been proposed to explain this velocity increase, and the form of the observed reflections. Underplating of a partial melt fraction from the mantle together with the injection of sill structures has been suggested as one hypothesis (Finlayson, 1983; Drummond & Collins, 1986). The second hypothesis for the formation of this zone is that the reflectors represent the remnants of Proterozoic oceanic crust which was not subducted, and upon which the accretionary wedge and back-arc sedimentary sequences accumulated (Roy-Chowdhury & others, 1984). However, oceanic layer 3, with a velocity of 6.9-7.0 km/s, would have to be considerably thickened over a large area from its thickness of 5-6 km under the oceans to 14-20 km, the thickness of the lower crust under the central Eromanga Basin.

The structure of the upper surface of the reflective mid-crustal zone, although not well resolved, can be related to the tectonic activity in the overlying sedimentary basins. On BMR traverses 1, 1X, and 9, the upper surface of this zone is seen to shallow from west to east beneath the Quilpie Trough; below the Canaway Ridge to the west it is around 9 s TWT, while below the Cheepie Shelf to the east it is around 7 s TWT. Thrust-faults which can be traced through the upper crustal zone are seen to disrupt this mid-crustal zone, indicating that it was formed before the activation of the thrusting in the Late Devonian or Carboniferous (Leven & Finlayson, 1986).

The 20-s reflection profiling records from the central Eromanga Basin are shown in Plates 13 to 24. Comments on the deep reflections on each traverse are made below. These comments are made with due recognition of the limitations which have to be put on the interpretation of any reflection horizons which cannot be followed up to shallow levels. We are also well aware of the possibility that near-surface conditions can influence the amplitude of recordings. Additionally, there is no way of knowing with certainty that reflections are from the line of the traverse; side reflections are quite possible and must be expected.

BMR traverses 6 and 2 (Plates 13-15). These traverses cross the Barcoo Trough, Canaway Ridge, and northern Adavale Basin and the shallow basin structure is shown in Plates 2 and 7.

Below the sedimentary sequences at two-way-times of less than 5 s along the western part of BMR traverse 6, isolated reflectors are interpeted as multiples. The upper crustal basement has very few reflectors. At about 9 s TWT, however, westward-dipping reflections are evident between survey stations 6350 and 6550, and at 10-13 s TWT a quite prominent reflection zone is apparent. The lower boundary of this zone tends to dip eastwards towards the centre of the Barcoo Trough. Individual reflection segments within the zone have continuity over a distance of 1-3 km, and some have higher dips to the east than the zone as a whole. At greater than 13 s TWT a few isolated reflections have quite high eastward dips; their number and prominence generally decrease at large two-way-times.

The most prominent middle/lower crustal reflections along the eastern part of BMR traverse 6 occur under the Barcoo Trough; deep reflections decrease markedly under the the Canaway Ridge. At 11-13 s TWT, the zone of prominent reflections on the western part of traverse 6 continues eastward, and is deepest at about survey station 6800. Under survey station 7100, reflectors between 8 and 14 s are very prominent. Between 8 and 8.5 s a strong eastward-dipping reflector may be associated with isolated reflectors at 7-8 s farther west, and could connect up with the westward-dipping reflectors under survey stations 6350-6550 in Plate 13; these reflectors would enclose a lenticle or 'pod' of lower crustal material 50-60 km long. At greater than 13 s TWT only isolated reflectors are apparent under the Barcoo Trough.

Under the Canaway Ridge, prominent reflections are lacking at greater than 12 s TWT; indeed, the strong semicontinuous zone of reflections at 11-13 s TWT under the Barcoo Trough is not apparent under the Canaway Ridge. Isolated reflections occur at shallower depths, but apart from two or three reflectors under survey station 7550 the continuity and strength of reflections is much less than that under the Barcoo Trough. To the east of the Canaway Fault, reflections occupy a diffuse zone between 7 and 11 s TWT, but they do not have lateral continuity to the east or west.

Along BMR traverse 2, only a few reflections originate from within the upper crustal basement at two-way times of 2 to 7 s. Between the western end of BMR traverse 2 and survey station 3700, Devonian rocks are missing from the section (Plate 7); also in this part of the traverse, there are few deep reflections, highlighting the observation that uplifted regions with no Devonian rocks differ in their crustal structure from the areas of significant Devonian deposition.

Between survey station 3700 and the eastern end of the traverse near Etonvale No. 1 well, deep crustal reflections occupy a prominent zone. The depth to the upper boundary of this zone is about 8 s TWT, but is deeper in the west (about 9 s TWT) and shallower under Etonvale No. 1 (about 7 s TWT). The lower boundary, however, is consistently at 12.5-13.0 s and is a prominent feature in this part of the traverse. Only isolated reflectors occur at greater depths; these tend to be under the eastern half of BMR traverse 2.

Eastward of survey station 3300, a semicontinuous reflector at 8.5 s TWT dips westward under survey point 3300. This reflector, taken together with the reflectors at 12.5-13.0 s, bounds a lenticle at lower crustal depths. As with the similar feature under the Barcoo Trough (Plates 13-14), the upper part of the lenticle has few reflectors, but the strength and continuity of reflectors tend to increase towards the lower boundary. In their interpretation of deep seismic refraction data along a north-south line about 20 km east of Etonvale No. 1 well, Finlayson & Collins (1986) indicated that a mid-crustal velocity increase is evident at 24 km depth, and that the crust/mantle boundary was at 39 km depth. The reflectors at 8.5 s TWT and 12.5-13.0 s TWT under the eastern half of BMR traverse 2 may well correspond to these velocity horizons under the main depression of the Adavale Basin, where the P-wave velocity in the lower crust is 6.6-7.0 km/s (Finlayson & Collins, 1986). The prominent reflectors near 13 s TWT are probably within the Moho transition zone, where the velocity increases quite rapidly from 7.1 to 8.15 km/s over a 4-km depth interval above the upper mantle.

<u>BMR traverse 13 (Plate 16).</u> There is a gap in deep reflection data between Etonvale No. 1 well and Stafford No. 1 well. East of the latter well, however, BMR traverse 13 provides some valuable information on processes in

the deep crust. At its western end the Warrego Fault truncates the Adavale Basin sedimentary rocks. Few reflection events are apparent at 2 to 8 s TWT. Under the Galilee Basin, events at 2.0-2.5 s TWT are interpreted as multiples.

East of the Warrego Fault, the pattern of deep crustal reflections contrasts with that under the Adavale Basin and Barcoo Trough: the reflections are not nearly as strong or continuous, pointing to major differences in the deep structure east of the Warrego Fault.

Under Stafford No. 1 well in the eastern Adavale Basin, deep reflections in the interval 8.5 to 13.5 s TWT diminish east of the Warrego Fault, where weak reflections apparent at 9-10 s are certainly not as prominent as under the Adavale Basin and Barcoo Trough. Neither the continuity nor amplitude of reflections increases in the zone near 13 s TWT as they do under the Devonian sedimentary sequence.

What is evident, however, is a series of eastward-dipping reflectors between survey stations 1350 and 1750 at 9-12 s TWT. Without other adjacent deep data we cannot determine with any certainty whether these dipping events represent dipping layered geology. However, we have some evidence for similar deep dipping horizons on the southern side of the Grenfield Fault on BMR traverse 11 (Plate 20). We therefore tentatively interpret such events as real events dipping southeast under the Pleasant Creek Arch on the southeastern side of the Warrego Fault. We also speculate that the Warrego Fault-Pleasant Creek Arch is a major thrust feature evident in the seismic data obtained from considerable depth in the crust.

<u>BMR traverse 5 (Plate 17).</u> Deep reflections on this traverse at its point of intersection with BMR traverse 6 correlate well with those on BMR traverse 6: the upper crustal basement in the range 3 to 8 s TWT is largely devoid of primary reflections.

At 8 s TWT under the intersection with BMR traverse 6, reflections are quite prominent and have continuity towards the north and south. The upper boundary of these reflections has a northward dip; the shallowest is at 7.5 s TWT at the southern end of BMR traverse 5, and they tend to merge with deeper reflections at 9-10 s TWT under Barcoo Junction No. 1 well. North of this well the deep reflection zone is not apparent until 10 s TWT.

Along the length of BMR traverse 5, an increase in strength and continuity of reflectors in the range 10-12 s TWT is consistent with the deepest reflections on the BMR east-west traverse 6. In the range 12-13 s TWT the reflections become less consistent, and at greater depths have a cross-cutting appearance, indicative of structural complications which make interpretation difficult. The lower boundary of the deep crustal reflection zone is taken to be at 12.0-12.5 s TWT.

South of Barcoo Junction No. 1 well the lower crustal reflections again appear to form a lenticle in the range 7.5 to 12.5 s TWT. Within the lenticle the reflections are not particularly strong or continuous, and the upper boundary closes on the lower boundary under Barcoo Junction No. 1 well. If the upper boundary of this lenticle represents the mid-crustal velocity horizon of Finlayson & others (1984), then this horizon becomes deeper under the northern part of BMR traverse 5 (about 30 km).

<u>BMR traverses 7 (Plate 18).</u> The western extremity of BMR traverse 7 is near the western margin of the Cooper Basin. At 2 to 10 s TWT, no coherent primary reflections are evident. The upper boundary of lower crustal

reflections occurs at about 11 s TWT, and shallows towards the east, being about 9.5 s TWT between survey stations 6350 and 6500. East of survey station 6500, reflectors are evident at shallower depth (8 s TWT) under the deepest part of the Cooper Basin.

The deepest reflectors along BMR traverse 7 (west) occur at about 13 s TWT. A few isolated reflections are evident at greater depths, but they cannot be regarded as having the same consistent pattern as those at shallower depths in the range 9-13 s TWT. The zone of reflections in the lower crust is, therefore, interpreted as thickening from the western margin of the Cooper Basin towards the deepest point of the basin; this thickening occurs by a shallowing of the upper boundary of the reflection zone. The upper boundary decreases in depth even further under the central part of the Cooper Basin from about 9.5 s to about 8.0 s TWT. If this lower crustal zone corresponds to the high-velocity lower-crustal material interpreted by Finlayson & others (1984), then the volume of high-velocity material seems to increase from the margin of the Cooper Basin towards its centre.

BMR traverse 7 (east) is separated from BMR traverse 7 (west) by a 55-km gap in seismic coverage, in which a major structural feature - the Windorah Anticline - is located. Therefore it is difficult to extrapolate features from BMR 7(west) to BMR 7(east). Plate 18 shows the deep reflections along BMR traverse 7(east) as it enters the Barcoo Trough.

The outstanding feature of the deep reflections is the repetition of features seen about 32 km farther north on BMR traverse 6 (Plate 13). A strong reflector shallowing from west to east at mid-crustal depths is at 9.5-10.0 s TWT in the west and at 8.0 s TWT in the east. The lower boundary of deep crustal reflections is at a depth of 12.5 to 13.0 s TWT. The interval between these horizons takes the form of a lower crustal lenticle, as it does on BMR traverse 6. The shape of the lenticle is almost identical with the feature apparent on BMR traverse 6 to the east of survey station 6300.

BMR north-south traverse 5, in part, gives some idea of the three-dimensional shape of the Barcoo lower crustal lenticle or 'pod', since the southern end of the traverse is only about 18 km from traverse 7(east). The northern part of the lenticle pinches out under Barcoo Junction No.1 well. Hence, the northern, western, and eastern extents of the lenticle are well defined from the BMR deep seismic profiling.

<u>BMR traverses 8 and 11 (Plates 19-20).</u> In the upper crust along traverse 8, reflections at less than 5 s TWT are interpreted as multiples. The upper crustal basement has very few primary reflections at less than 8.5 s TWT on traverse 8. Between 8.5 and 13 s TWT, a series of reflectors is apparent, but displays a different pattern from that seen under the Barcoo Trough farther west. Those under the Canaway Ridge tend to be dipping (steeply in places), possibly indicating structural features at a depth which cannot be defined without adjacent deep seismic traverses. These deep reflectors cannot be correlated with a lower crustal lenticle as they can under traverses 5, 6, and 7.

BMR traverse 11 crosses the deepest part of the Adavale Basin, and evinces many structures in the lower crust at 7-16 s TWT. At the northwestern end of traverse 11, where it joins traverse 8, the upper boundary of deep reflectors is at 9 s TWT between Yongala No. 1 and Cothalow No. 1 wells. Of the numerous reflectors in the depth range 9-16 s between these wells, the most prominent is a series occupying a zone between 13 and 16 s TWT dipping towards the northwest. These reflectors seem to outline a lenticle structure in the lower crust, but are interspersed with other dipping reflectors, so the features cannot be readily interpreted without other deep seismic cross-traverses. Deep reflectors dipping to the southeast are also evident between the Yongala and Cothalow wells, and farther southeast towards the intersection of traverse 11 and traverse 10 (Plate 24). The lenticle structure under the Barcoo Trough is not clearly defined along the northwest part of traverse 11, perhaps because the greater deformation in the Adavale Basin has diminished our ability to determine the deep structure clearly.

Between Cothalow No. 1 well and the Grenfield Uplift, numerous reflections are apparent in the lower crust; some of them can be defined more precisely with the aid of data from the intersecting traverse 10 (Plate 24). Southeast of the Cothalow well the deepest consistent reflectors are at about 15.0 s, interpreted as being the crust/mantle boundary based on the wide-angle reflection and refraction work of Finlayson & Collins (1986). Above this level, however, a prominent series of reflectors at 11-12 s TWT under survey station 2060 arches to shallower levels at 8 s TWT between Gumbardo No. 1 well and the Grenfield Uplift. This forms the upper boundary of a lenticle in the lower crust similar to that in the Barcoo Trough.

The shape of this lenticle or 'pod' in the lower crust of the Adavale Basin is better defined along BMR traverse 10 (Plates 23-24), where the lenticle south of survey station 1600 can be quite clearly seen between 9 and 14.5 s TWT - i.e., the lenticle is thinner by about 1.5 s TWT under traverse 10 than it is under traverse 11, but the reflections correlate quite accurately at the cross-over point. At this cross-over point, weak reflectors at 8.0-8.5 s TWT correlate between traverses 10 and 11, but their lateral extent is not great.

At survey station 2700 on BMR traverse 11 the Grenfield Fault is evident on shallow profiling records (Plate 6). On the deep reflection profiling record (Plate 20) there is a very obvious change in the character of the lower crustal reflectors northwest and southeast of this fault; to the northwest, the many deep crustal reflectors terminate at the fault, and to the southeast the few reflectors have a greatly diminished strength and continuity compared with those under the Adavale Basin.

Between survey stations 2760 and 2880 at 6.5-7.0 s TWT, reflectors seem to image the deformation in the upper crustal Devonian rocks. Leven & Finlayson (1986) have indicated that these reflectors may indicate deformation of the whole upper crust during regional tectonic processes. Also under the Grenfield Uplift at greater than 7 s TWT s a weak reflector dips from northwest to southeast, reaching at least 12 s TWT. This reflector may in some way be a significant feature of the lower crust, but without further data this suggestion is difficult to demonstrate.

At the southeastern end of traverse 11 under the Cooladdi Trough, a few isolated strong reflectors are evident at 14 s TWT, but the strong pattern of reflectors seen under the Adavale Basin is not evident.

<u>BMR traverses 1, 1X and 9 (Plates 21-22).</u> Deep crustal reflectors are prominent at times greater than 7 s TWT along the length of traverse 1. The deepest consistent reflectors are at 13.5 s TWT, but other dipping reflectors are deeper, in particular near survey station 2300 under the Warrabin Trough.

Between Mount Howitt No. 1 well and survey station 1300, a prominent reflector dips westward, at 9.5 s TWT at its shallowest and 11.5 s TWT at its deepest under Mount Howitt No. 1 well. This reflector may be similar to those evident under the Barcoo Trough on traverse 6, which define a lenticle of lower crustal material; without data from cross-lines, this analogy cannot be substantiated.

East of survey station 1300 the lower crustal reflectors take on the appearance of a lower crustal lenticle with an upper boundary at 8.5 s TWT and a lower boundary at 13.5 s TWT; the most prominent of these reflectors are near the two boundaries. This style of reflecting horizons persists between survey stations 1300 and 2200. Several gaps in the deep signals are attributed to near-surface conditions of recording.

Between survey stations 1400 and 1500 the upper boundary of deep crustal reflectors shallows to 7.5 s; this could be an indication of deep structure, but without other deep data this suggestion cannot be proved.

To the east of survey station 2200 under the Warrabin Trough the pattern of an upper and lower boundary to the deep reflectors is distorted. The upper boundary converges on the lower boundary under survey station 2700, the western boundary of the Canaway Ridge. Between survey stations 2300 and 2400 the deep reflectors are distorted by what is assumed to be structure in the lower crust. The upper boundary shallows in an arc-like fashion to 6.5 s, and it is tempting to associate the deep structure with the deformation of the Devonian rocks of the Warrabin Trough. Similar deformation may have taken place at the lower boundary of deep crustal reflections where westward-dipping reflectors penetrate to 16 s TWT; however, these are not structures which can be resolved with a single deep seismic traverse.

Between survey stations 2700 and 8900 (Plate 22) across the Canaway Ridge, the deep reflectors are extremely diffuse, and do not have the characteristics of those under the basin to the west. The deep reflectors under this large basement feature display marked differences from those under the neighbouring basins. The characteristics under the ridge are similar to those under the Canaway Ridge on BMR traverse 6 (Plate 14), namely very weak and diffuse reflecting horizons. Some cross-cutting reflectors are apparent under the Canaway Ridge on traverse 1X and 9 between 12 and 14 s TWT, but generally the lower boundary of any reflectors is about 12 s TWT. The upper boundary of any reflectors is difficult to define because of their diffuse nature, but few of them are shallower than 9.5 s under the Canaway Ridge. Finlayson & Collins (1986) and Finlayson & Leven (in press b) have drawn attention to the different velocity structure of the crust under the Canaway Ridge, and the different characteristics of the deep reflectors under the ridge which highlight the importance of the ridge as a regional tectonic feature.

Under the Quilpie Trough, to the east of the Canaway Ridge, the deep reflections exhibit more strength and continuity. The upper boundary of reflectors is at about 7 s TWT farther east, under the Cheepie Shelf, but dips westward quite markedly to over 8 s TWT under the Quilpie Trough. The boundary at mid-crustal level appears to parallel the dip on the lower boundary of the Devonian rocks, suggesting that the two may be related.

The deepest reflectors east of the Canaway Ridge do not form an obvious horizon as they do to the west of the ridge. There is certainly no strengthening of the amplitude and continuity of reflections as there is under, say, BMR traverse 6 across the Barcoo Trough (Plate 13). Weak reflecting segments are apparent between 12 and 13 s TWT, below which the continuity of any reflectors is doubtful; rather, the reflectors seem to appear as isolated events - some with apparent dips, some without.

At the cross-over between BMR traverses 9 and 10 (Plate 23), the depth at which the upper boundary of lower crustal reflectors lies, at 8 s TWT, corresponds for both traverses. On traverse 10 these reflectors also have a diffuse lower boundary at about 13 s TWT; the strength and continuity of the reflectors is weak, as on traverse 9. What is apparent, however, is that deep, dipping events at 15-18 s TWT correlate reasonably well on both traverses 9 and 10. These events dip steeply to the west under traverse 9, and more gently to the south on traverse 10, giving rise to speculation that a structure within the upper mantle may be imaged. Finlayson & Collins (1986) define the crust/mantle boundary at 39 km depth (about 13 s TWT) under the Quilpie Trough; thus at 15-18 s TWT we are certainly considering upper mantle features.

The deep refraction data of Finlayson & others (1984) indicate that the depth to the crust/mantle boundary is probably shallower under the Canaway Ridge (34 km) than under the neighbouring basins. This is in broad agreement with the lower boundary of deep reflectors being at 12 s TWT under the ridge and at 13-14 s TWT under the basins. Under the Cheepie Shelf, Finlayson & others (1984) determined a mid-crustal velocity horizon at 21.6 km depth and a crust/mantle boundary at 41 km depth, which correlate with the upper and lower (diffuse) boundaries of the lower crustal reflectors.

BMR traverse 10 (Plates 23-24). The deep crustal reflections under the Quilpie Trough at the southern end of traverse 10, where it crosses BMR traverse 9, are discussed in the preceding description of BMR traverse 1, 1X, and 9. The diffuse nature of the lower boundary of deep crustal reflections continues towards the north as far as the Adavale Basin north of survey station 800. The upper boundary of deep reflections south of this station is at 8.0-8.5 s TWT and quite well defined.

North of survey station 800, the deep reflectors are apparent over a greater time range, from 7 s TWT to 14.5 s TWT. The reflectors at the lower boundary have a greater strength and continuity than those to the south of survey point 800. As described in the section commenting on BMR traverse 11 where it crosses traverse 10, a lower crustal lenticle under this part of the Adavale Basin has an upper boundary rising to 8-9 s TWT and converging on the lower boundary near survey station 1600. The arc-like upper boundary reflections correlate well with those along traverse 11.

North of survey station 1600 (Plate 24) the lower boundary of deep reflections shallows to 14 s, and the upper boundary becomes less distinct. Under Leopardwood No. 1 well, deep upwardly-convex reflectors at 8.5-10.0 s TWT tend to dip both north and south to deeper levels. Tenuous reflectors at 8.0-8.5 s TWT farther north to the limit of the traverse become clearer under Lissoy No. 1 well, where they are apparent on the intersecting BMR traverse 2 (Plate 15) at the same depth. On traverse 2 the upper and lower boundaries of deep reflectors are seen to form a lower crustal lenticle.

Between Gilmore No. 1 and Lissoy No. 1 wells on traverse 10, cross-cutting reflectors at greater than 13 s TWT indicate complex structures in the lower crust. The strongest reflectors dip towards the north, and are at the same depth as westward-dipping reflectors at 13-15 s TWT under Lissoy No. 1 well along traverse 2. As with similar dipping features described under the intersection of BMR traverses 9 and 10, it is difficult to comment further on such structures, which must be within the upper mantle if they arise from on-line primary reflectors.

BMR traverse 10 provides a very useful function in tying together the features on traverses 2, 9, and 11. The correspondence of the deep reflecting events at the cross-over points confirms that such deep events do provide a guide to the features in the lower crust. Few surveys around the world have traced deep events across separate traverses and therefore the deep profiling data from the central Eromanga Basin provide a useful contribution towards a basic understanding of the deep structure under basins.

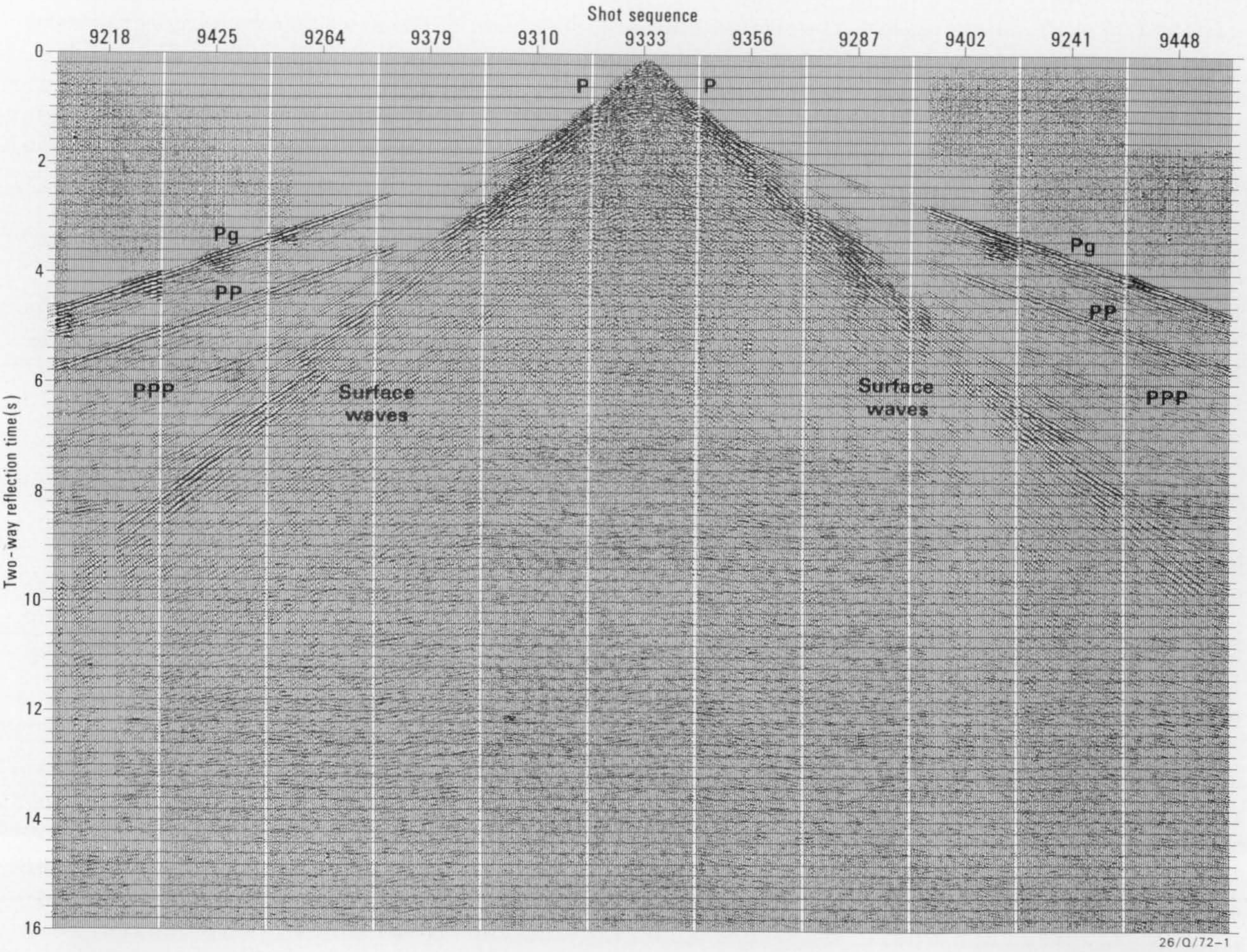


Fig. 34. Expanded-spread seismic record section from BMR traverse 9 centred on shot-point 9333.

EXPANDED-SPREAD RECORDING RESULTS

The recordings of the expanded-spread deployments on traverses 9 and 10 are shown in Figures 34 and 35 respectively. At both sites, clear vertical-incidence events are recorded from the basin sedimentary rocks and the upper crustal basement at less than 3 s TWT. As in the short-distance refraction records described earlier, clear refracted (Pg) phases are recorded from the upper crustal basement, and up to three multiply-refracted phases (PP, PPP and PPPP) are reflected from the surface (e.g., Fig. 28). These multiply refracted phases put tight constraints on the velocity structure in the upper part of the crust to depths of about 8 km.

The main purpose of expanded-spread recording is to help provide a better understanding of moveout velocities and average velocities at moderate offsets, and to facilitate more precise processing of deep reflection events. Reflections from a common mid-point should be displayed as an upwardly convex surface on expanded-spread records. Such surfaces are seen from the reflectors within the sedimentary section in Figures 34 and 35, and from basement at less than 3 s TWT, but evidence for such clear horizons deep within basement is not good.

On BMR traverse 9 (Fig.34) deep reflections are apparent under shot-point 9333 at 7-8 s and 12-13 s TWT. These are in agreement with the results from the continuous reflection profiling (Plate 22). However, these deep events tend to be in the form of reflection bands rather than single reflectors. Under these circumstances a good estimate of the average velocity to these deep events may not be possible. The distortion of the seismic ray-paths through the upper crust may be breaking up seismic reflection events even at comparatively small offsets.

On BMR traverse 10 (Fig. 35), deep reflections are evident under shot-point 1384 at 10-11 s and at 14 s TWT. These events are in agreement with the reflection profiling data (Plates 23-24). However, as with the recordings from traverse 9, the deep reflections on the expanded-spread record sections are broken up and do not form a single reflection horizon which can be analysed in detail. As mentioned above, the distortion of ray-paths in the upper crust is probably a major factor in breaking up these deep horizons.

CONCLUSIONS

The seismic research by BMR in the central Eromanga Basin during 1980-82 was a major contribution to the understanding of the basin structures in one of Australia's most prospective basins, and made a major advance in the understanding of the deep structure and composition of intra-continental basins. For the first time, a concerted program of multi-mode seismic techniques was applied to (1) determining the tectonic framework of a large intra-continental basin to significant depths within the lithosphere, and (2) making a contribution to the reconciliation of models of basin development with observational data. Not all goals were achieved, but, certainly, geoscientists now have a more realistic picture of the structures to be expected under basins and how they relate to the processes of basin formation.

The detailed results from the 1980-82 BMR survey are contained in the many publications listed in the References at the end of this Report. Some aspects of the interpretation of data from the central Eromanga Basin region

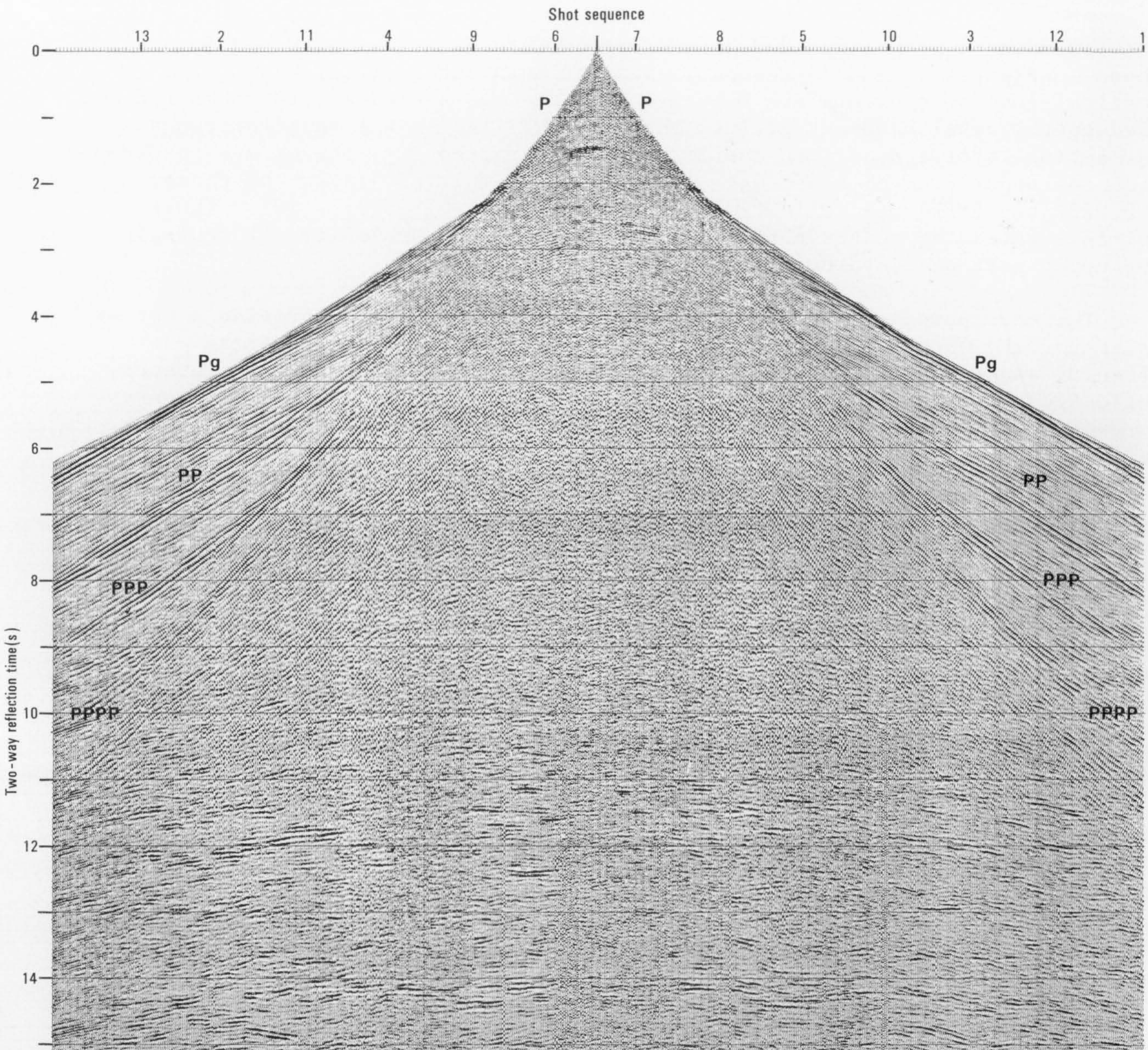


Fig. 35. Expanded-spread seismic record section from BMR traverse 10 centred on shot-point 1384.

will continue because of their importance in developing a further understanding of the processes by which basins are formed. In this respect the network of seismic reflection and refraction traverses is particularly valuable in providing an integrated data set.

The BMR regional seismic reflection profiles which traversed large parts of the central Eromanga Basin region provided valuable tie-lines across many exploration lease boundaries, and thus facilitated an integrated interpretation of BMR and company data. This has led to a more precise analysis of the structural pattern in the region. The major structural features are a series of northeast and northwest-trending high-angle reverse faults to the east and west of the Canaway Ridge, the major north-south trending basement high in the centre of the region. These faults are interpreted as being the result of crustal shortening events caused by processes deep within the lithosphere. Significantly, it is the basement highs associated with these faults that are seen by the exploration industry as being the most prospective drilling targets for oil and gas.

The upper crustal basement, into which many of the identified high-angle reverse faults must extend, proved to be largely transparent to the techniques employed in continuous vertical-incidence reflection profiling. At 4-8 s TWT, only a few reflections were apparent, and only some of these could be interpreted as primary reflections from structures in the upper crustal basement. The implications of this interpretation are that this part of the basement must contain rocks which are steeply dipping and strongly folded, thus providing a poor target for reflection profiling techniques. Drilling into basement has shown that metamorphic, volcanic, and plutonic rocks make up the upper crust, but their contacts must preclude prominent velocity contrasts for good reflections, or their dips are very steep.

The velocities determined from the detailed seismic refraction studies in the upper crustal basement indicate that significant lateral and vertical variations occur in the upper 8 km. Steep velocity gradients immediately below the Devonian and later sedimentary rocks are interpreted as being the result of deep weathering when this surface was exposed. The maximum velocity in the upper crustal basement is 6.0-6.1 km/s, generally at about 8 km depth - i.e., about 6 km below the top of basement. However, below the Cheepie Shelf the depth to 6.0-6.1 km/s is at 4 km depth - i.e., about 2.5 km below the top of basement. Therefore there are certainly broad subdivisions within the basement which can be defined from the velocity data, emphasising the probable differences in the tectonic histories of the various geological provinces in the region.

At depths between about 10 and 20 km in some places, there are indications of velocity decreases to a value below 6.0 km/s. However, the geological significance of this is still unclear because of the conflicting effects of increasing temperature and pressure on the velocities at depth. The exact nature of the velocity decrease may also be much more gradual than has been modelled; the data do not permit the negative velocity gradient to be determined uniquely. The subtle changes in the velocities of the rocks in the upper crust at depths of 10-20 km may therefore be a reflection of the physical conditions at these depths rather than any significant compositional or metamorphic changes.

The most significant feature of both the reflection profiling data and the velocity data is the change which occurs at 20-25 km depth. At this depth, a marked increase in velocity in many parts of the region and an obvious change in the character of reflections coincide with the top of a zone of discontinuous reflecting horizons in the lower crust. Under areas of thick Devonian rocks in particular, the top boundary can be traced across the network of BMR reflection profiling traverses, and is shown to dip under major basement highs. This leads to an interpretation of these lower crustal reflection zones as lenticles or 'pods' of high-velocity material at depths of 20-40 km.

The lenticles tend to disappear under the basement highs such as the Windorah Anticline and the Canaway Ridge. The composition of the material in these lenticles is inferred from velocity information to be more basic than upper crustal rocks. The limiting of these lenticles to the regions under Devonian rocks suggests that they are a major component in the basin-forming process. Some models of basin-forming processes include the stretching and shallowing of high-velocity upper mantle material, and the intrusion of basic material into the lower crust (DeRito & others, 1983). The indications are that, in the central Eromanga Basin, we are observing the three-dimensional form of this basic lower-crustal material, and measuring its velocity.

Not all velocity measurements in the lower crust indicate the prominent velocity increase at 20-25 km depth. Under the Canaway Ridge, no such velocity increase is evident, and the form of the crustal velocity models under the ridge strongly suggests that its tectonic evolution differs considerably from that of the adjacent Devonian basins. The lack of a lenticle or 'pod' in the deep reflection profiling data substantiates this interpretation. The Canaway Ridge is interpreted as a major north-south-trending crustal feature that separates basins which have somewhat different structural styles.

The crust/mantle boundary is identified in the wide-angle reflection/refraction seismic data at 36-40 km depth, being shallower in the west of the region. The boundary appears on the deep reflection profiling data as a rather diffuse region in which lower crustal reflections tend to decrease markedly in their amplitude and continuity. This diffuse region forms the deeper boundary of the lower crustal lenticles. When converted to depths, the two-way times to the crust/mantle boundary correspond with the depths determined by the wide-angle reflection/refraction method. The depth to the crust/mantle boundary does not seem to change sharply anywhere in the region, although it may be shallower under the Canaway Ridge.

The lower crustal reflections are not featureless. As mentioned above, the shape of the edges of the lower crustal lenticles can be defined in places. In some areas, such as under the Warrego Fault, marked changes in the character of reflections suggest that such faults are major lithospheric features separating areas which have undergone significantly different geological evolutionary histories.

Within the upper mantle, the velocity of 8.15 km/s appears to be evident everywhere, and on the longest east-west seismic traverse a higher velocity is apparent at a depth of about 56 km. The upper mantle has a significant vertical zonation, if not lateral variations. It has not been demonstrated convincingly that the structures causing deep reflection events penetrate the crust/mantle boundary, but the possibility cannot be ruled out based on the data available. In places, dipping reflectors - if they have sources in the plane of the traverse - must be from upper mantle features; however, the possibility of such reflections being from sources out of the plane of the traverse at shallower depths must be seriously considered, and further work is required to demonstrate this.

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REFERENCES

ARMSTRONG, J.D., & BARR, T.M., 1982 - The Eromanga Basin. In Moore, P.S., & Mount, T.J. (Editors) - EROMANGA BASIN SYMPOSIUM, SUMMARY PAPERS. Petroleum Exploration Society of Australia, and Geological Society of Australia (South Australian Branches), Adelaide, 20-42.

AUCHINCLOSS, G., 1976 - Adavale Basin. In LESLIE, R.B., EVANS, H.J., & KNIGHT, C.L. (Editors) - ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA, 3: PETROLEUM. Australasian Institute of Mining and Metallurgy, Melbourne, Monograph Series, 7, 309-315.

BATTERSBY, D.G., 1976 - Cooper Basin gas and oil fields. In LESLIE, R.B., EVANS, H.J., & KNIGHT, C.L. (Editors) - ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA, 3: PETROLEUM. Australasian Institute of Mining and Metallurgy, Melbourne, Monograph Series, 7, 321-368.

BOWERING, O.J.W., 1982 - Hydrodynamics and hydrocarbon migration - a model for the Eromanga Basin. Australian Petroleum Exploration Association Journal, 22, 227-236.

COLLINS, C.D.N., & LOCK, J., 1983 - A seismic refraction study of the Quilpie Trough and adjacent basement highs, Eromanga Basin, Queensland, Australia. Tectonophysics, 100, 185-198.

COLLINS, C.D.N., & LOCK, J., in preparation - Detailed seismic refraction studies in the central Eromanga Basin, Queensland. To be submitted to BMR Journal of Australian Geology & Geophysics.

DeRITO, R.F., COZZORELLI, F.A., & HODGE, D.S., 1983 - Mechanism of subsidence of ancient cratonic rift basins. Tectonophysics, 94, 141-168.

DOOLEY, J.C., 1976 - Variations of crustal mass over the Australian region. BMR Journal of Australian Geology & Geophysics, 1, 291-296.

DOUTCH, H.F., & NICHOLAS, E., 1978 - The Phanerozoic sedimentary basins of Australia and their tectonic implications. Tectonophysics, 48, 365-388.

DRUMMOND, B.J., & COLLINS, C.D.N., 1986 - Seismic evidence for underplating of the lower continental crust of Australia. Earth and Planetary Science Letters, 79, 361-372.

EMBLETON, B.J.J., 1984 - Past global settings, continental palaeomagnetism. In VEEVERS, J.J. (Editor) - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford, 11-16.

EXON, N.F., & SENIOR, B.R., 1976 - The Cretaceous of the Eromanga and Surat Basins. BMR Journal of Australian Geology & Geophysics, 1, 33-50.

FINLAYSON, D.M., 1983 - The mid-crustal horizon under the Eromanga Basin, eastern Australia. Tectonophysics, 100, 199-214.

FINLAYSON, D.M., & COLLINS, C.D.N., 1980 - A brief description of BMR portable seismic tape recording equipment. Australian Society of Exploration Geophysicists, Bulletin. 11, 75-77.

FINLAYSON, D.M., & COLLINS, C.D.N., 1986 - Lithospheric velocity beneath the Adavale Basin, Queensland, and the character of deep crustal reflections. BMR Journal of Australian Geology & Geophysics, 10, 23-37.

FINLAYSON, D.M., & COLLINS, C.D.N., in press - Crustal differences between the Nebine Ridge and the central Eromanga Basin from seismic data. Australian Journal of Earth Sciences, 34.

FINLAYSON, D.M., COLLINS, C.D.N., & LOCK, J., 1984 - P-wave velocity features of the lithosphere under the Eromanga Basin, eastern Australia, including a prominent mid-crustal (Conrad?) discontinuity. Tectonophysics, 101, 267-291.

FINLAYSON, D.M., & LEVEN, J.H., in press a - 3-Dimensional image of the lower crust under an intra-continental basin in eastern Australia. Exploration Geophysics, 18.

FINLAYSON, D.M., & LEVEN, J.H., in press b - Lithospheric structures and possible processes in Phanerozoic Australia from deep seismic investigations. Tectonophysics, 133.

FINLAYSON, D.M., LEVEN, J.H., & ETHERIDGE, M.A., in press - Structural styles and basin evolution in the Eromanga region, eastern Australia. American Association of Petroleum Geologists, Bulletin.

FINLAYSON, D.M., & MATHUR, S.P., 1984 - Seismic refraction and reflection features of the lithosphere in northern and eastern Australia, and continental growth. Annales Geophysicae, 2(6), 711-722.

GRAVESTOCK, D.I., & MORTON, J.G.G., 1984 - Geology of the Della Field, a perspective on the history of the Cooper Basin. Australian Petroleum Exploration Association Journal, 24, 266-277.

GRAY, R.J., & ROBERTS, D.C., 1984 - A seismic model of faults in the Cooper Basin. Australian Petroleum Exploration Association Journal, 24, 421-428.

HARRINGTON, H.J., 1974 - The Tasman Geosyncline in Australia. In DENMEAD, A.K., TWEEDALE, G.W., & WILSON, A.F. (Editors) - THE TASMAN GEOSYNCLINE, A SYMPOSIUM. Geological Society of Australia (Queensland Division), 383-407.

HARRISON, P.L., MATHUR, S.P., MOSS, F.J., PINCHIN, J., & SENIOR, B.R., 1980 - Central Eromanga Basin Project proposals, 1980-82. Bureau of Mineral Resources, Australia, Record 1980/32.

HEGARTY, R.A., 1983, - Downhole velocity survey: GSQ Quilpie 1. Geological Survey of Queensland, Record 1983/73.

JOHNSON, B.D., & VEEVERS, J.J., 1984 - Past global settings, oceanic palaeomagnetism. In VEEVERS, J.J. (Editor) - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford, 17-38.

KINGSTON, D.R., DISHROON, C.P., & WILLIAMS, P.A., 1983 - Global basin classification system. American Association of Petroleum Geologists, Bulletin 67, 2175-2193.

KIRKEGAARD, A.G., 1974 - A review of major Palaeozoic tectonometallogenic events, northern part of the Tasman Orogenic Zone. In DENMEAD, A.K., TWEEDALE, G.W., & WILSON, A.F. (Editors) - THE TASMAN GEOSYNCLINE: A SYMPOSIUM. Geological Society of Australia (Queensland Division), 99-128.

KUANG, K.S., 1985 - History and style of Cooper-Eromanga Basin structures. Bulletin of the Australian Society of Exploration Geophysicists, 16, 245-248.

LEVEN, J.H., & FINLAYSON, D.M., 1986 - Basement thrusts in the southern Adavale Basin. In 8th Australian Geological Convention abstracts. Geological Society of Australia, Abstracts 15, 123-124.

LEVEN, J.H., & FINLAYSON, D.M., in press - Lower crustal involvement in upper crustal thrusting. Geophysical Journal of the Royal Astronomical Society.

LEVEN, J.H., FINLAYSON, D.M., & ETHERIDGE, M.A., in preparation - Basement involved compression and the tectonic evolution of the southern Adavale Basin. Submitted to Tectonics.

LIU, Y.S.B., & SEERS, K.J., 1982 - A playback system for portable seismic recorders. Bulletin of the Australian Society of Exploration Geophysicists, 13, 77-81.

LOCK, J., 1983 - Central Eromanga Basin seismic refraction surveys, 1980, 1981, operational report. Bureau of Mineral Resources, Australia, Record 1983/29.

LOCK, J., & COLLINS, C.D.N., 1983 - Velocity/depth modelling using reflection and refraction data recorded in the central Eromanga Basin, Queensland, Australia. Tectonophysics, 100, 175-184.

LOCK, J., COLLINS, C.D.N., & FINLAYSON, D.M., 1986 - Basement structure and velocities under the Eromanga Basin from seismic refraction studies. Geological Society of Australia, Special Publication 12, 155-162.

MARSDEN, M.A., 1972 - The Devonian history of northeastern Australia. Journal of the Geological Society of Australia, 19, 125-162.

MATHUR, S.P., 1983a - Deep crustal reflection results from the central Eromanga Basin, Australia. Tectonophysics, 100, 163-173.

MATHUR, S.P., 1983b - Deep reflection probes in eastern Australia reveal differences in the nature of the crust. First Break, 1(7), 9-16.

MATHUR, S.P., 1984 - Improvements in seismic reflection techniques for studying the lithosphere in Australia. Tectonophysics, 105, 373-381.

MATHUR, S.P., & SEXTON, M.J., 1981 - Central Eromanga Basin seismic survey, Queensland, 1981, preview report. Bureau of Mineral Resources, Australia, Record 1981/33.

McMECHAN, G.A., & MOONEY, W.D., 1980 - Asymptotic ray theory and synthetic seismograms for laterally varying structures: theory and application to Imperial Valley, California. Bulletin of the Seismological Society of America, 70, 2021-2035.

MEISSNER, R., 1965 - Multiple events in refraction shooting. Geophysical Prospecting, 13, 617-658.

MILSOM, J., & WORTHINGTON, G.A., 1977 - Computer programs for rapid computation of gravity effects of two-dimensional and three-dimensional bodies. Computers and Geosciences, 3, 269-281.

MOORE, P.S., & MOUNT, T.J., (Editors), 1982 - EROMANGA BASIN SYMPOSIUM, SUMMARY PAPERS. Petroleum Exploration Society of Australia, and Geological Society of Australia, (South Australian Divisions), Adelaide.

MOSS, F.J., & WAKE-DYSTER, K.D., 1983 - The Australian central Eromanga Basin project: an introduction. Tectonophysics, 100, 131-145.

MURRAY, C.G., & KIRKEGAARD, A.G., 1978 - The Thomson Orogen of the Tasman Orogenic Zone. Tectonophysics, 48, 299-326.

MUSGRAVE, A.W., 1962 - Applications of the expanding reflection spread. Geophysics, 27, 981-993.

O'DRISCOLL, E.S.T., 1983 - Deep tectonic foundations of the Eromanga Basin. Australian Petroleum Exploration Association Journal, 23, 5-17.

PASSMORE, V.L., & SEXTON, M.J., 1984 - The structural development and hydrocarbon potential of Palaeozoic source rocks in the Adavale Basin region. Australian Petroleum Exploration Association Journal, 24(1), 393-411.

PATEN, R.J., 1977 - The Adavale Basin, Queensland. In PETROLEUM IN QUEENSLAND - A STOCKTAKE FOR THE FUTURE. Petroleum Exploration Society of Australia (Queensland Division), Brisbane.

PINCHIN, J., 1980 - Central Eromanga Basin seismic survey, Queensland, 1980, preview report. Bureau of Mineral Resources, Australia, Record 1980/77.

PINCHIN, J., & ANFILOFF, V., 1986 - The Canaway Fault and its effect on the Eromanga Basin. Geological Society of Australia, Special Publication 12, 163-173.

PINCHIN, J., & SENIOR, B.R., 1982 - The Warrabin Trough, western Adavale Basin, Queensland. Journal of the Geological Society of Australia, 29, 413-424.

POWELL, C.McA., 1984 - Terminal fold-belt deformation: relationship of mid-Carboniferous megakinks in the Tasman fold belt to coeval thrusts in cratonic Australia. Geology, 12, 546-549.

QUILTY, P.G., 1984 - Phanerozoic climates and environments of Australia. In VEEVERS, J.J. (Editor) - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford, 48-56.

ROY-CHOWDHURY, K., LEVEN, J.H., & PHINNEY, R.A., 1984 - Accretionary structure of the lithosphere beneath Australia. EOS Transactions, American Geophysical Union, 65(45), 1017.

SENIOR, B.R., & HABERMEHL, M.A., 1980 - Structure, hydrodynamics and hydrocarbon potential, central Eromanga Basin, Queensland, Australia. BMR Journal of Australian Geology & Geophysics, 5, 47-55.

SENIOR, B.R., MOND, A., & HARRISON, P.L., 1978 - Geology of the Eromanga Basin. Bureau of Mineral Resources, Australia, Bulletin 167.

SEXTON, M.J., & TAYLOR, F.J., 1983 - Central Eromanga Basin seismic survey, Queensland, 1981, operational report. Bureau of Mineral Resources, Australia, Record 1983/13.

SEXTON, M.J., & TAYLOR, F.J., in preparation - Eromanga Basin seismic survey, operations report, 1982. Bureau of Mineral Resources, Australia, Record.

SLANIS, A.A., & NETZEL, R.K., 1967 - Geological review of Authorities to Prospect 109P and 125P Queensland, Australia. Phillips Oil Company; open-file report, Queensland Department of Mines, Brisbane (unpublished).

SPENCE, A.G., & FINLAYSON, D.M., 1983 - The resistivity structure of the crust and upper mantle in the central Eromanga Basin, Queensland, using magnetotelluric techniques. Journal of the Geological Society of Australia, 30, 1-16.

SPRIGG, R.C., 1982 - The long lead-up to commercial oil discovery in the Mesozoic Eromanga Basin. In MOORE, R.S., & MOUNT, T.J. (Editors) - EROMANGA BASIN SYMPOSIUM, SUMMARY PAPERS. Petroleum Exploration Society of Australia, and Geological Society of Australia (South Australian Branches), 2-19.

VEEVERS, J.J., (Editor), 1984 - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford.

VEEVERS, J.J., JONES, J.G., & POWELL, C.McA., 1982 - Tectonic framework of Australia's sedimentary basins. Australian Petroleum Exploration Association Journal, 22, 283-300.

VEEVERS, J.J., JONES, J.G., POWELL, C.McA., & TALENT, J.A., 1984 - Synopsis. In VEEVERS, J.J. (Editor) - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford, 351-364.

VEEVERS, J.J., & POWELL, C.McA, 1984 - Uluru and Adelaidean regimes. In VEEVERS, J.J. (Editor) - PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford, 270-350.

VELOCITY DATA PTY LTD, 1982 - Well velocity survey, GSQ Eromanga No.1, ATP 298P, Queensland, for GSQ/Magnet Petroleum Pty. Ltd. Geological Survey of Queensland, Company Report 10725 (unpublished).

WAKE-DYSTER, K.D., MOSS, F.J., & SEXTON, M.J., 1983 - New seismic reflection results in the central Eromanga Basin, Queensland, Australia: the key to understanding its tectonic evolution. Tectonophysics, 100, 147-162.

WAKE-DYSTER, K.D., & PINCHIN, J., 1981 - Central Eromanga Basin seismic survey, Queensland, 1980, operational report. Bureau of Mineral Resources, Australia, Record 1981/22.

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PLATE 1

BMR TRAVERSE 1

BMR TRAVERSE 1X and 9

Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverses 1, 1X, and 9.

PLATE 2

BMR TRAVERSE 6

WEST | EAST

BMR TRAVERSE 2

WEST | EAST

Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverses 2 and 6.

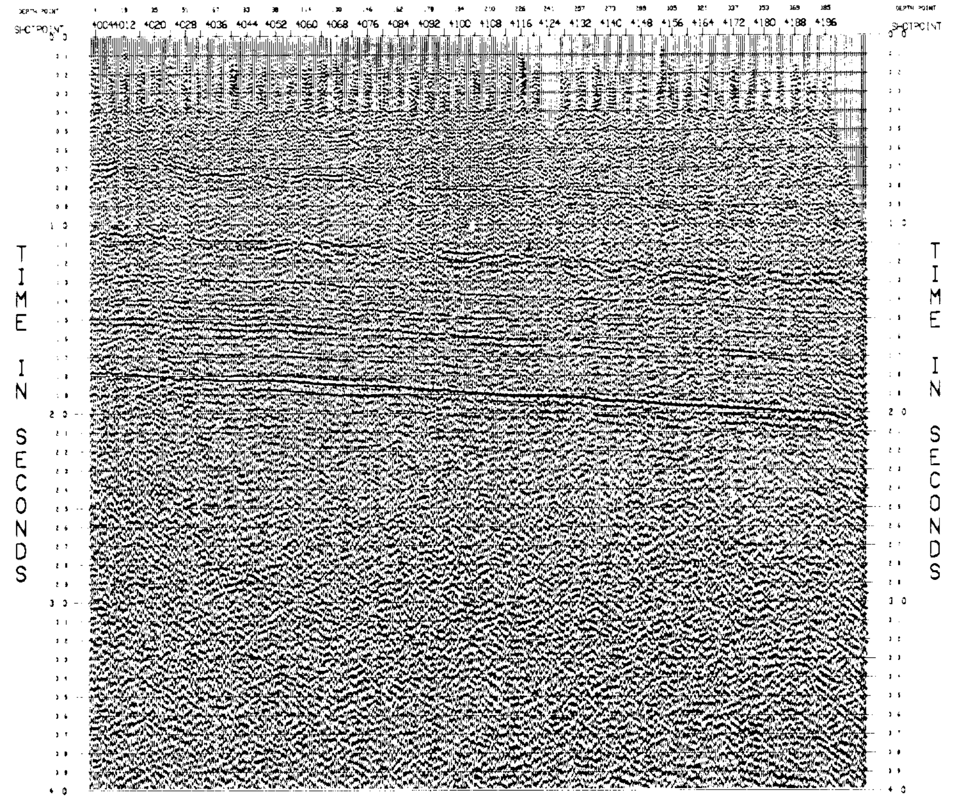
PLATE 3

BMR TRAVERSE 3

WEST EAST

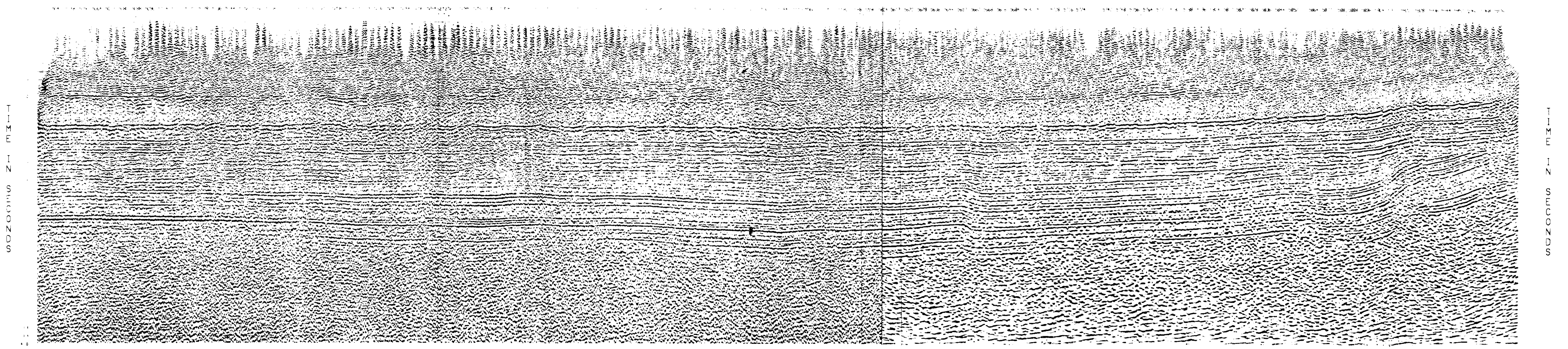
BMR TRAVERSE 4

SOUTH NORTH



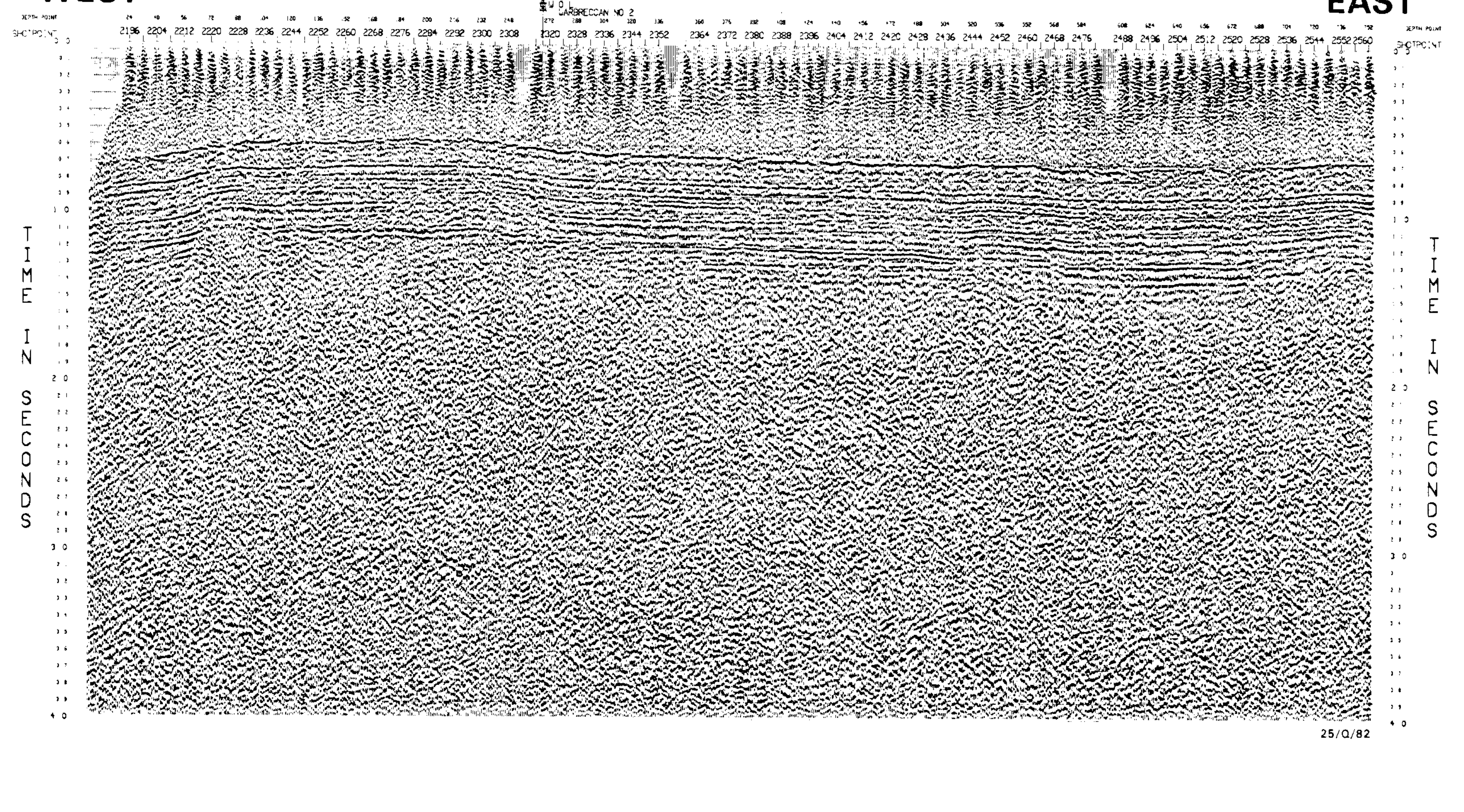
BMR TRAVERSE 5

SOUTH NORTH



BMR TRAVERSE 12

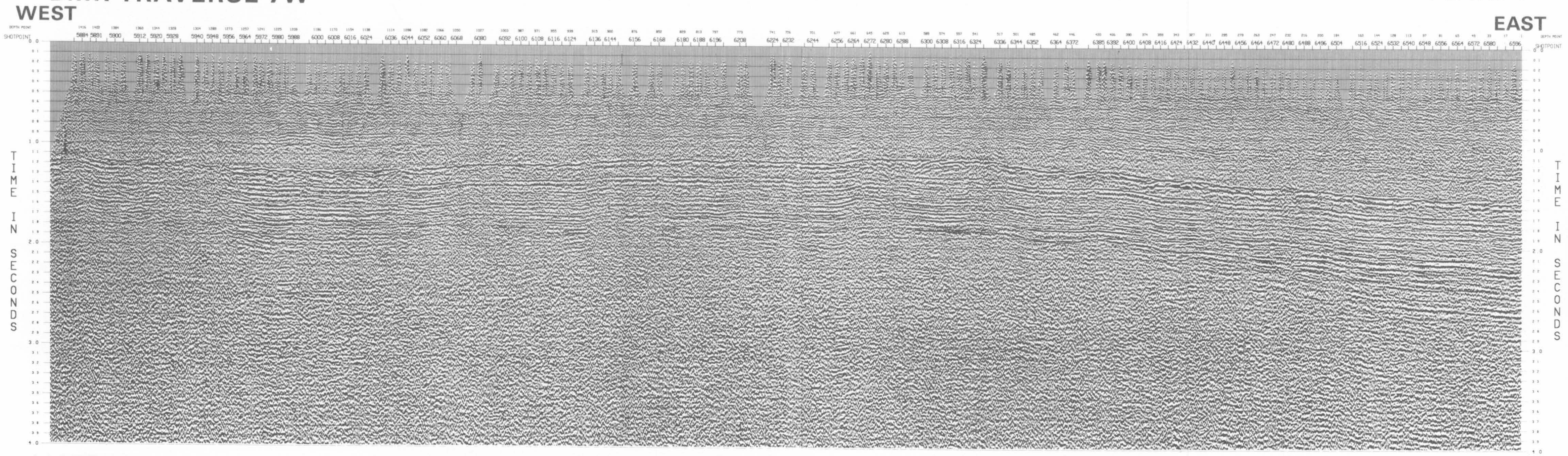
WEST EAST



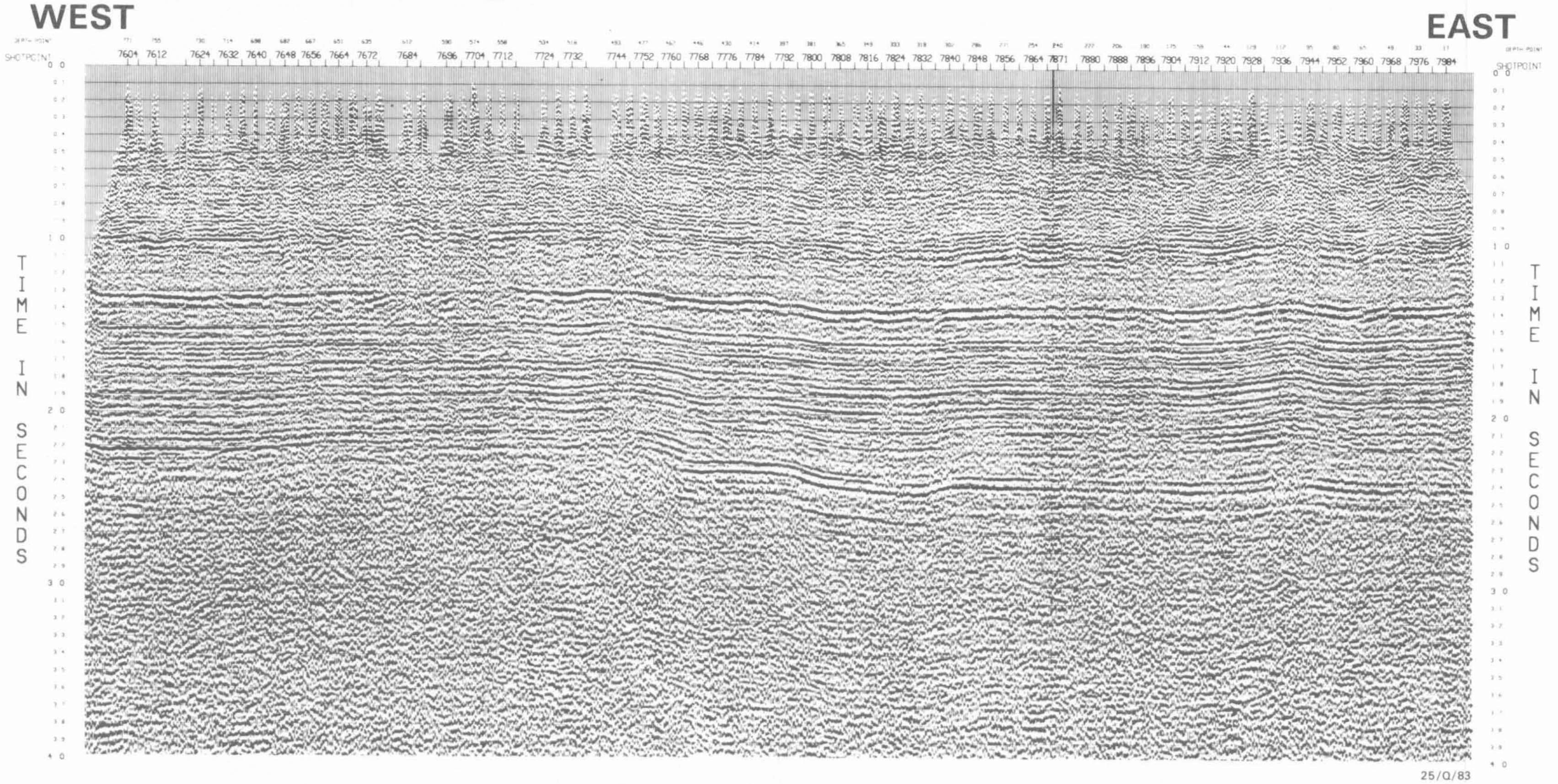
Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverses 3, 4, 5, and 12.

PLATE 4

BMR TRAVERSE 7W



BMR TRAVERSE 7E

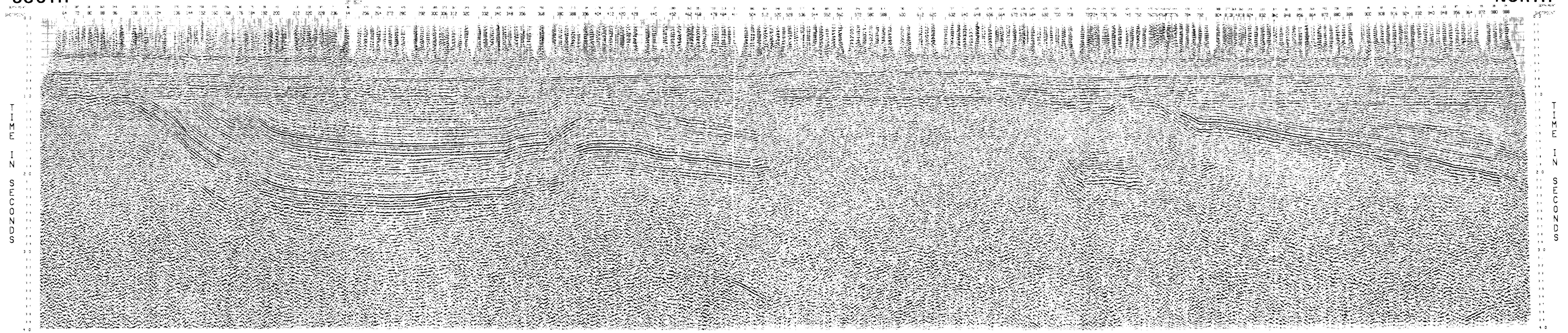


Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverse 7.

PLATE 5

BMR TRAVERSE 10S

SOUTH NORTH



BMR TRAVERSE 10N

SOUTH NORTH

Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverse 10.

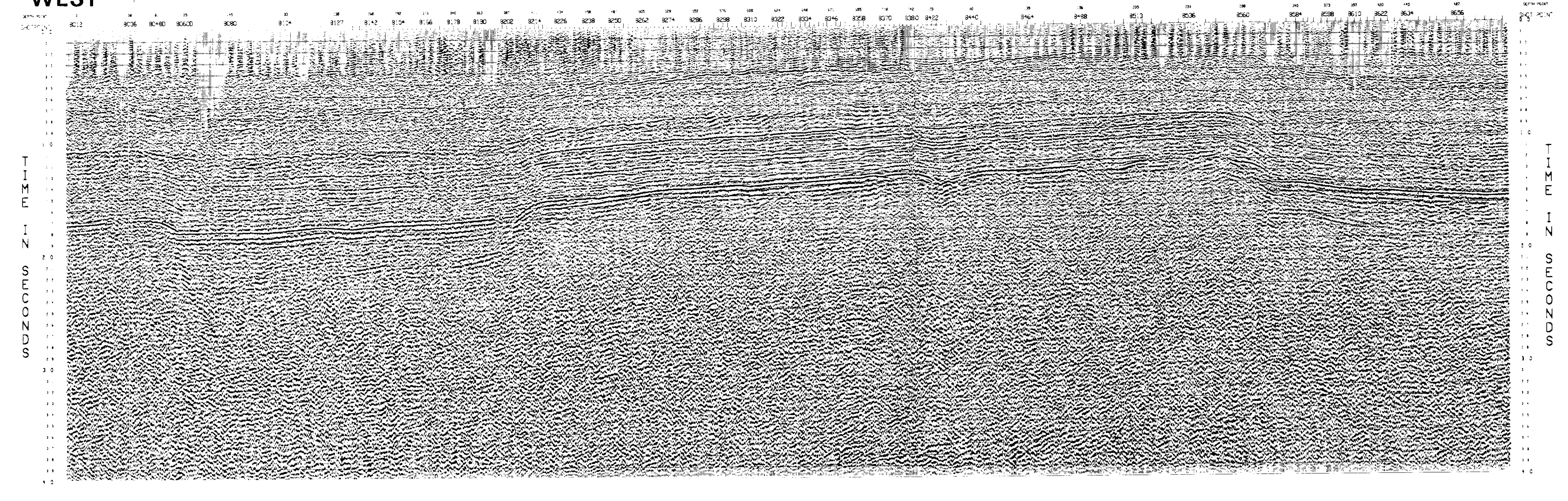
PLATE 6

BMR TRAVERSE 11

NORTHWEST — SOUTHEAST

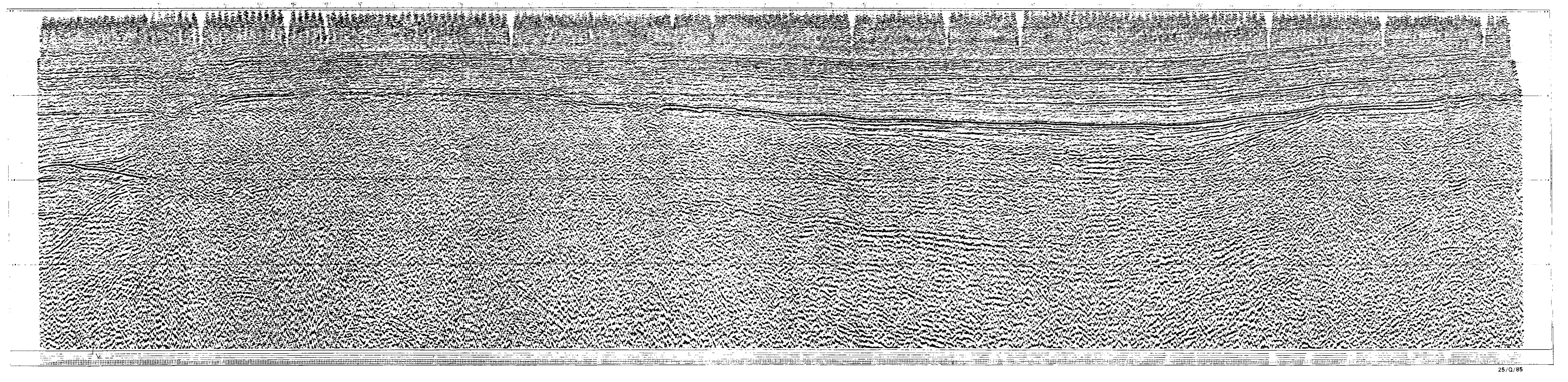
BMR TRAVERSE 8

WEST — EAST



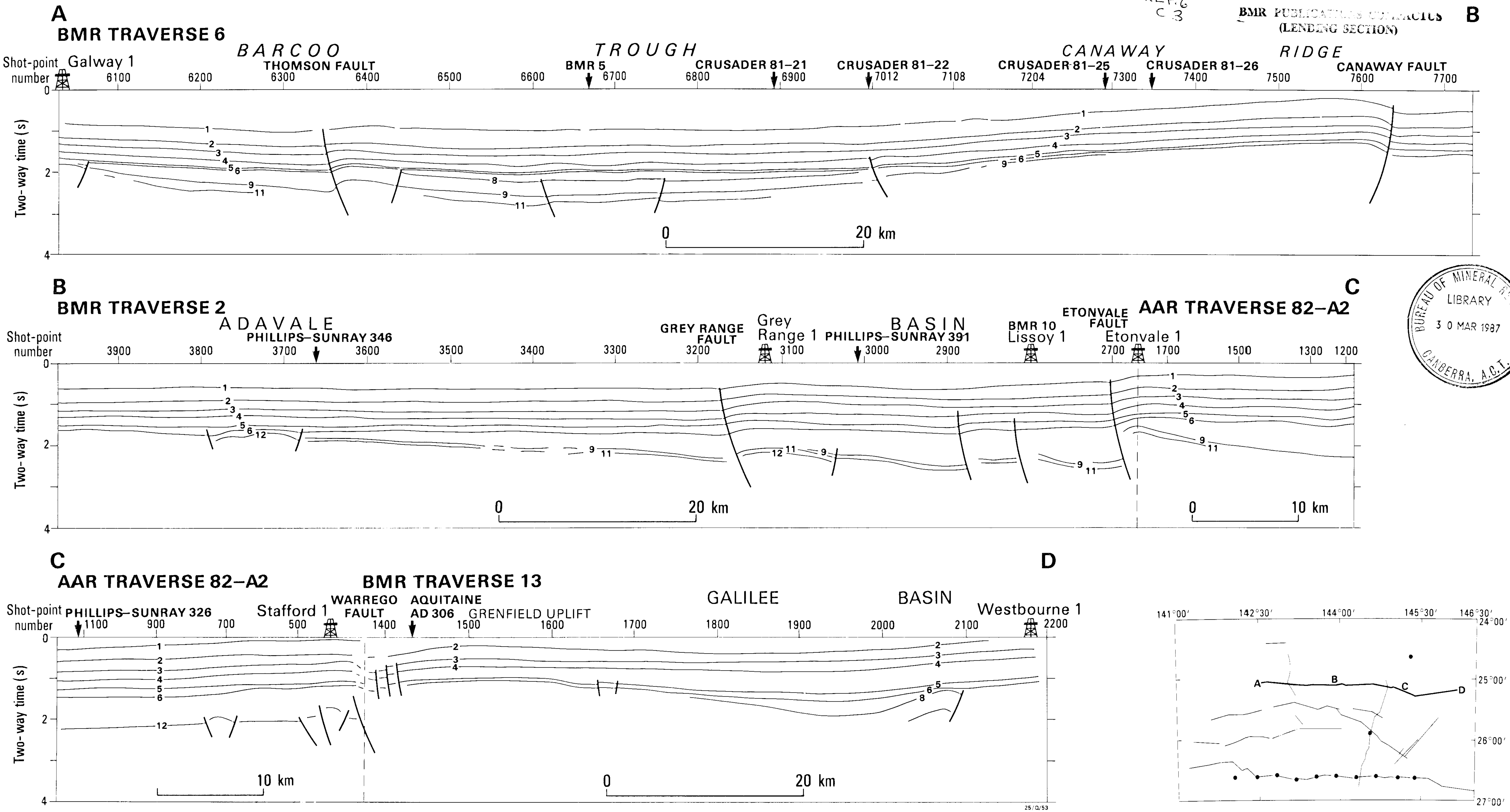
BMR TRAVERSE 13

WEST — EAST



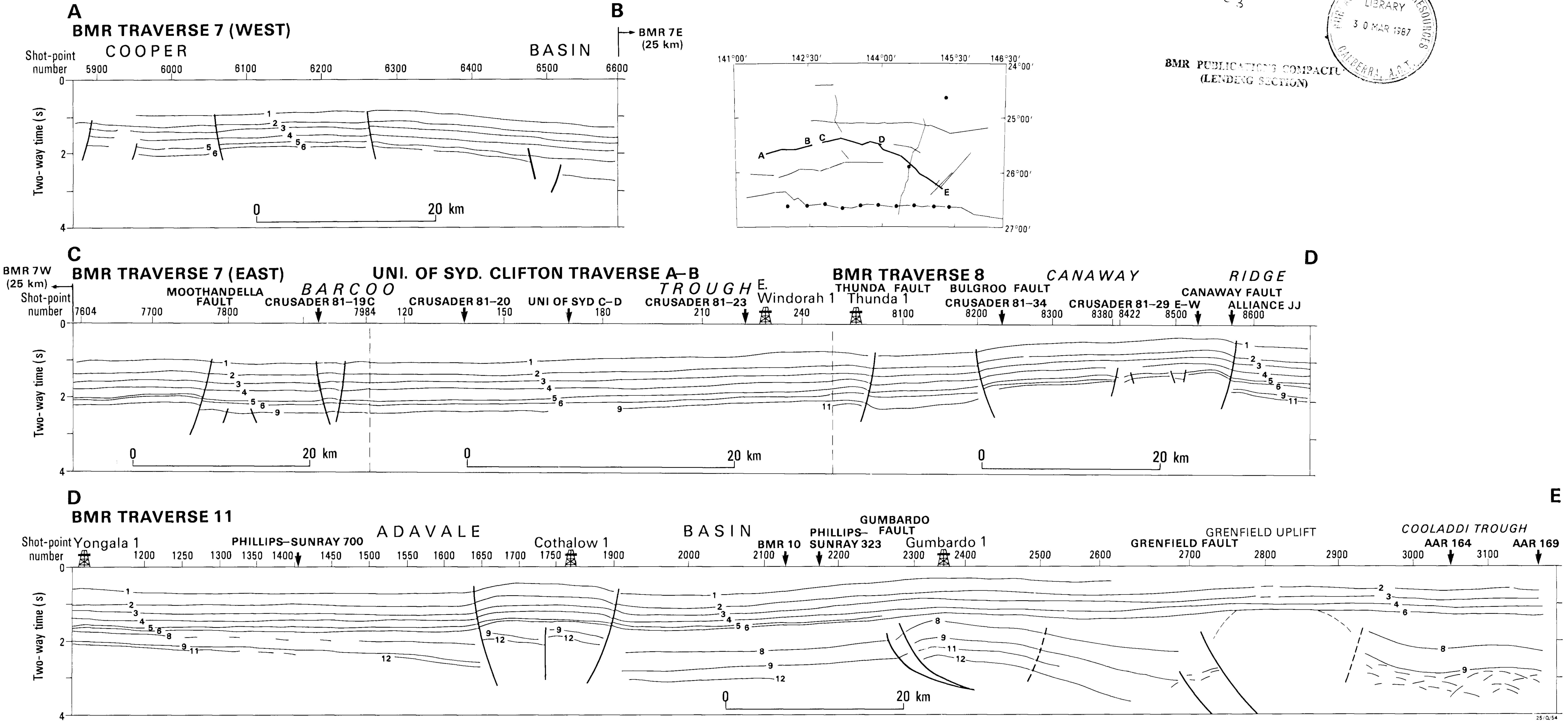
Unmigrated six-fold CMP seismic record sections to 4 s two-way-time along BMR traverses 8, 11, and 13.

PLATE 7



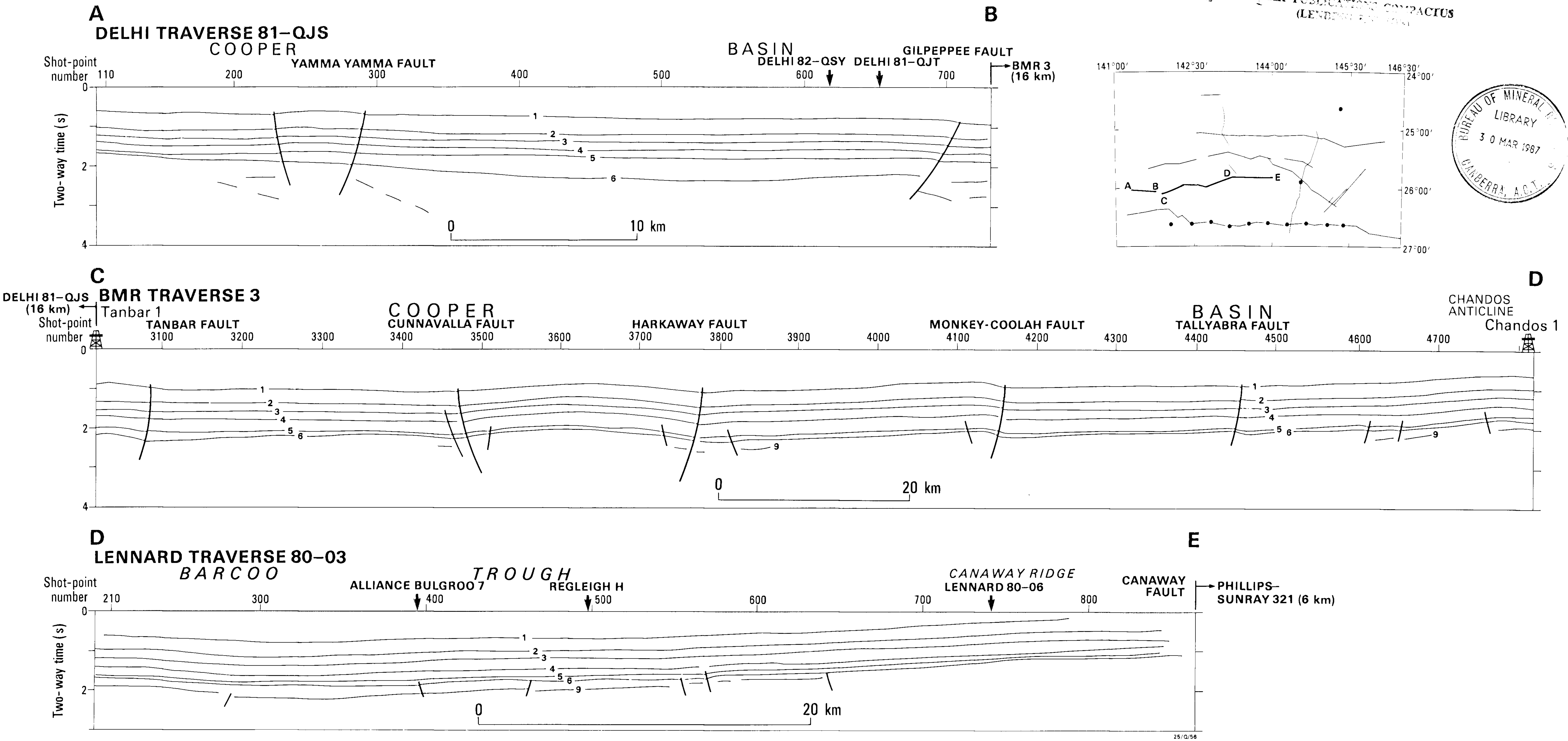
Line drawing of structural features in the upper crust along BMR traverses 6 and 2, AAR traverse 82-A2, and BMR traverse 13.

PLATE 8



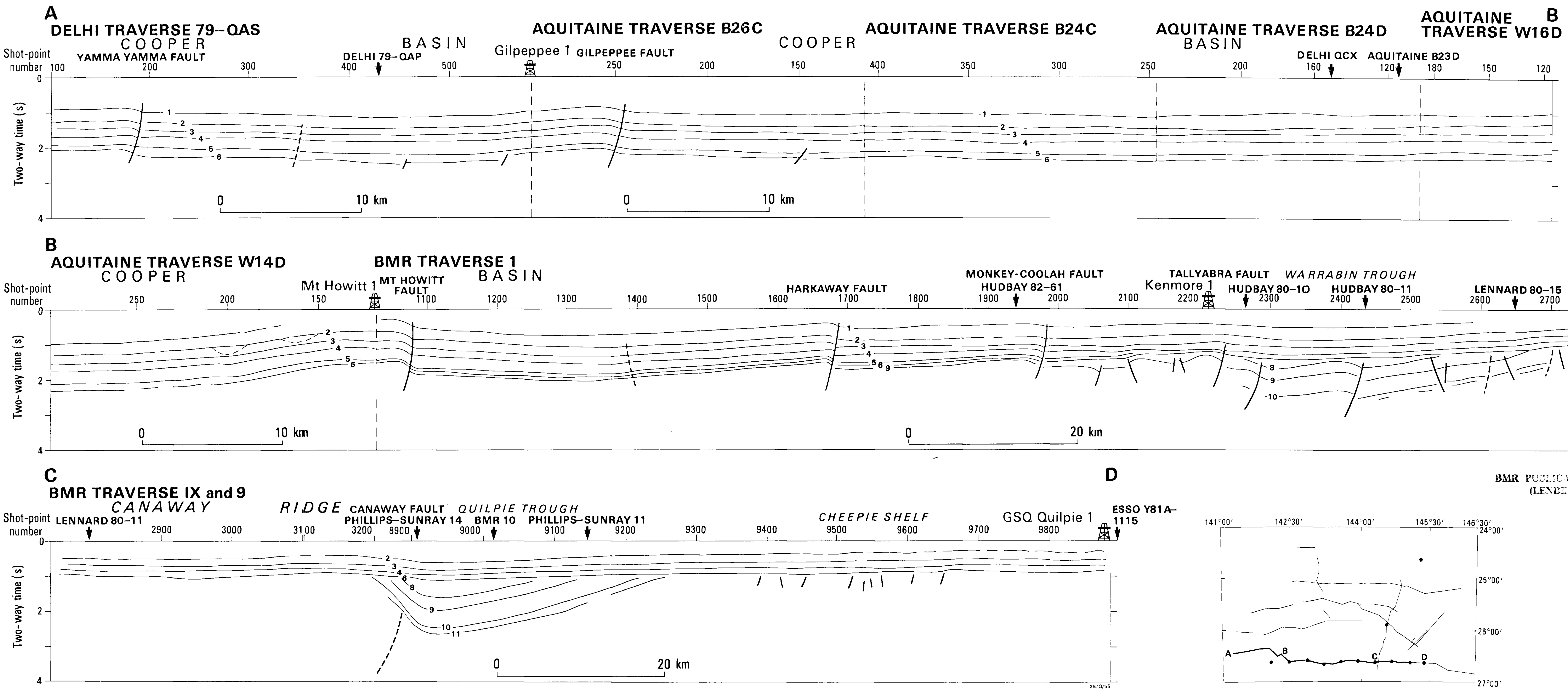
Line drawing of structural features in the upper crust along BMR traverses 7W and 7E, Sydney University traverse AB, and BMR traverses 8 and 11.

PLATE 9



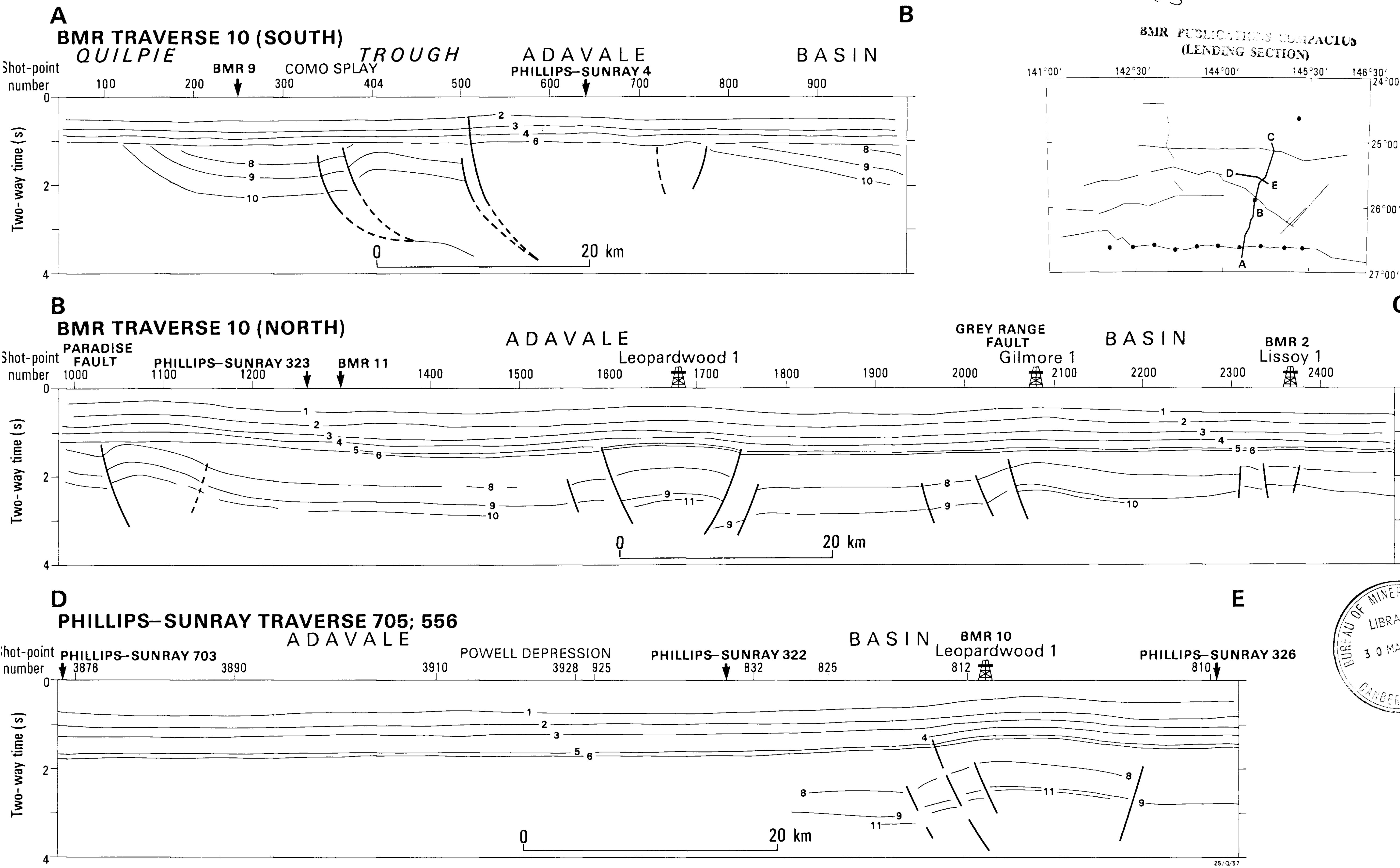
Line drawing of structural features in the upper crust along Delhi traverse 81-QJS, BMR traverse 3, and Lennard Oil traverse 80-03.

PLATE 10



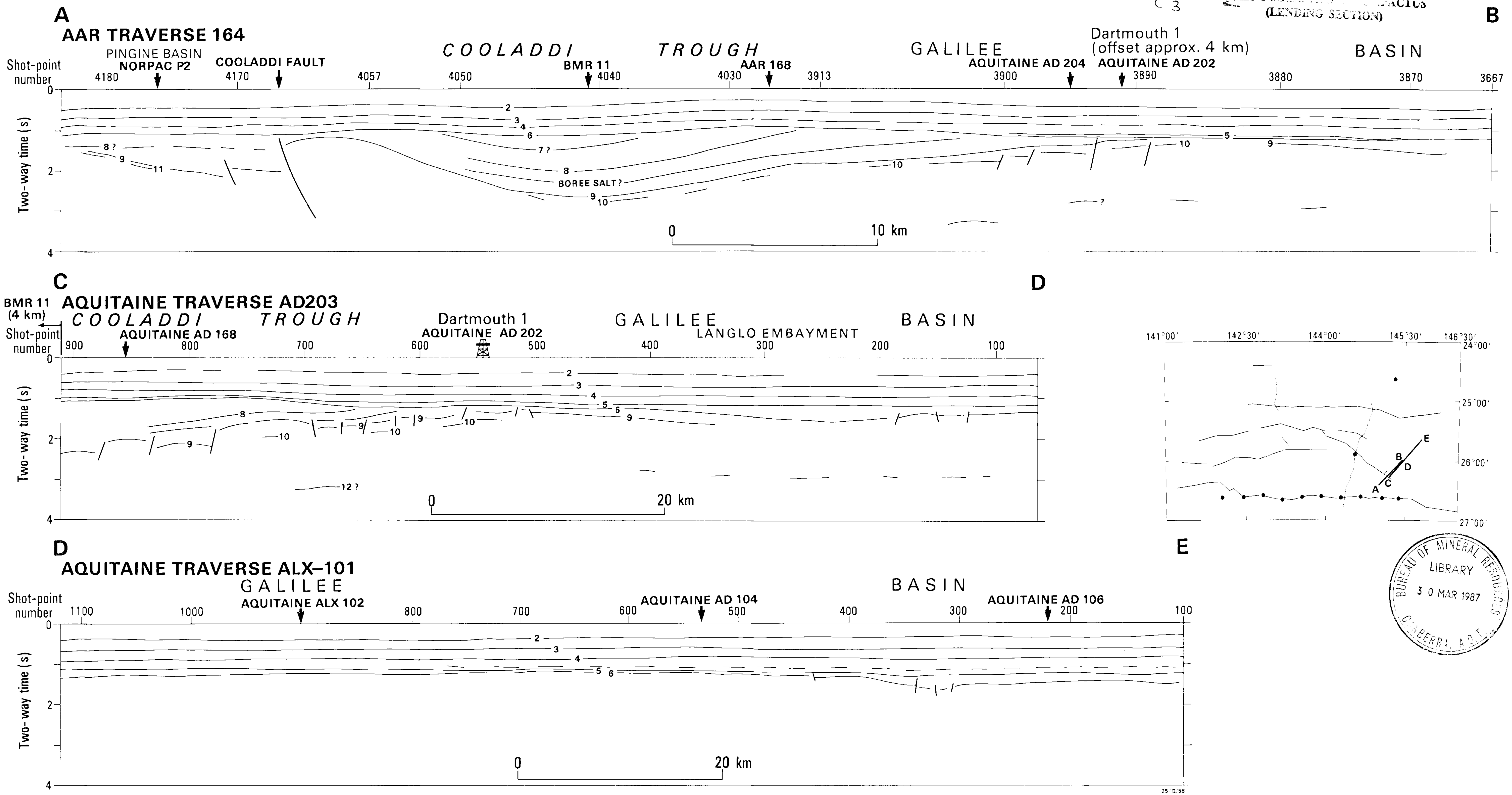
Line drawing of structural features in the upper crust along Delhi traverse 79-QAS, Aquitaine traverses B26C, B24C, B24D, W16D, and W14D, and BMR traverses 1, 1X, and 9.

PLATE 11



Line drawing of structural features in the upper crust along BMR traverse 10 and Phillips-Sunray traverses 705 and 556.

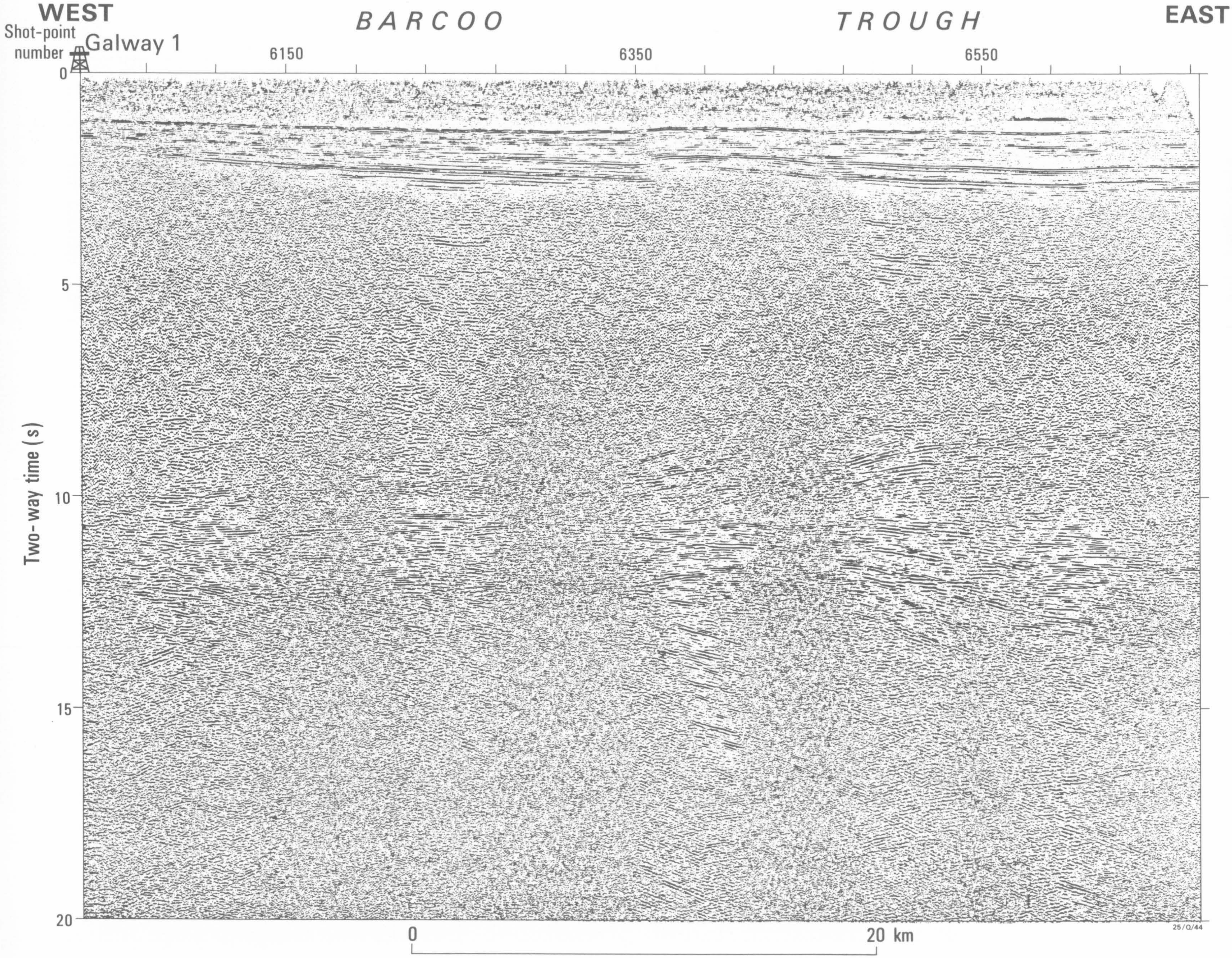
PLATE 12



Line drawing of structural features in the upper crust along AAR traverse 164 and Aquitaine traverses AD-203 and ALX-101.

PLATE 13

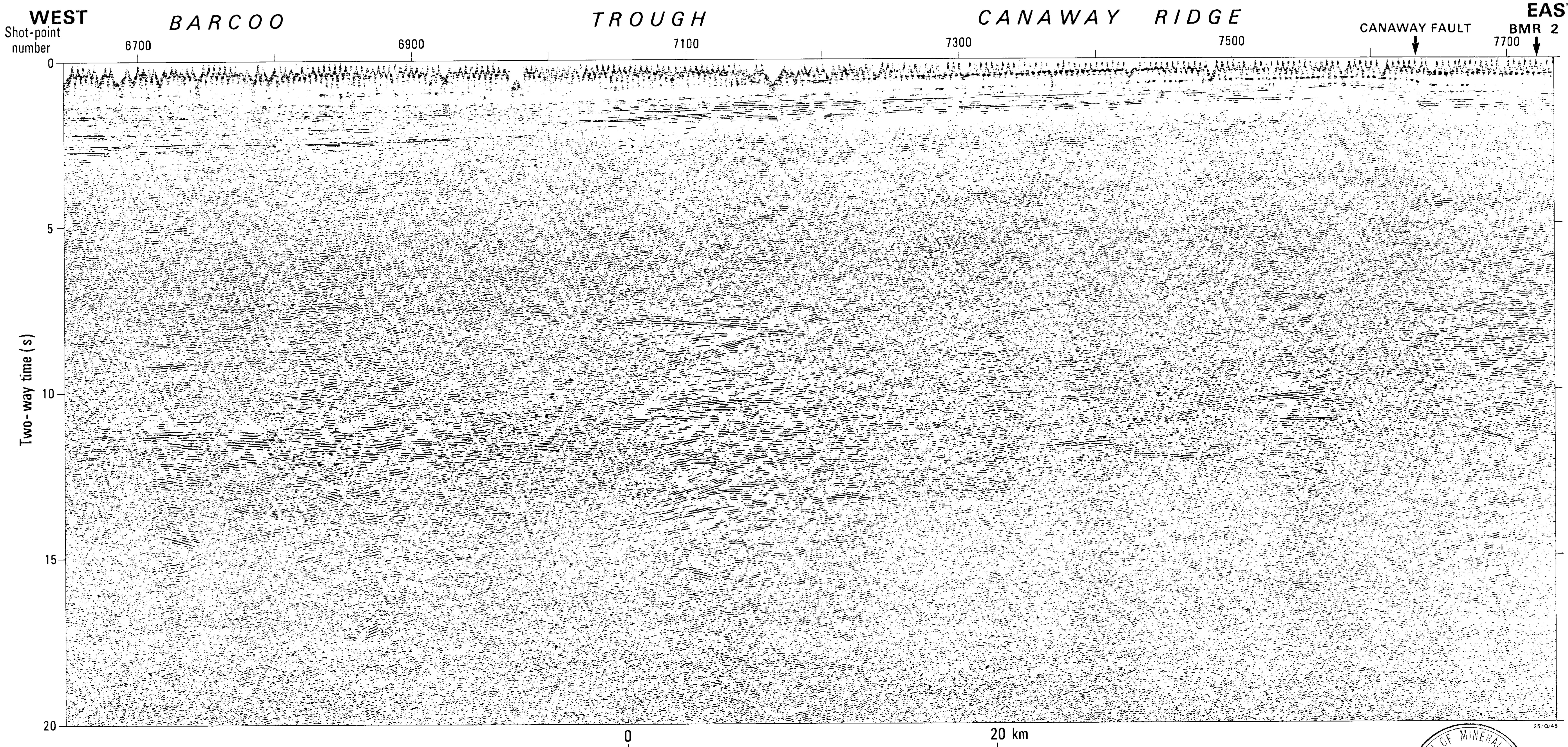
BMR TRAVERSE 6 (WEST), CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 6(west).

PLATE 14

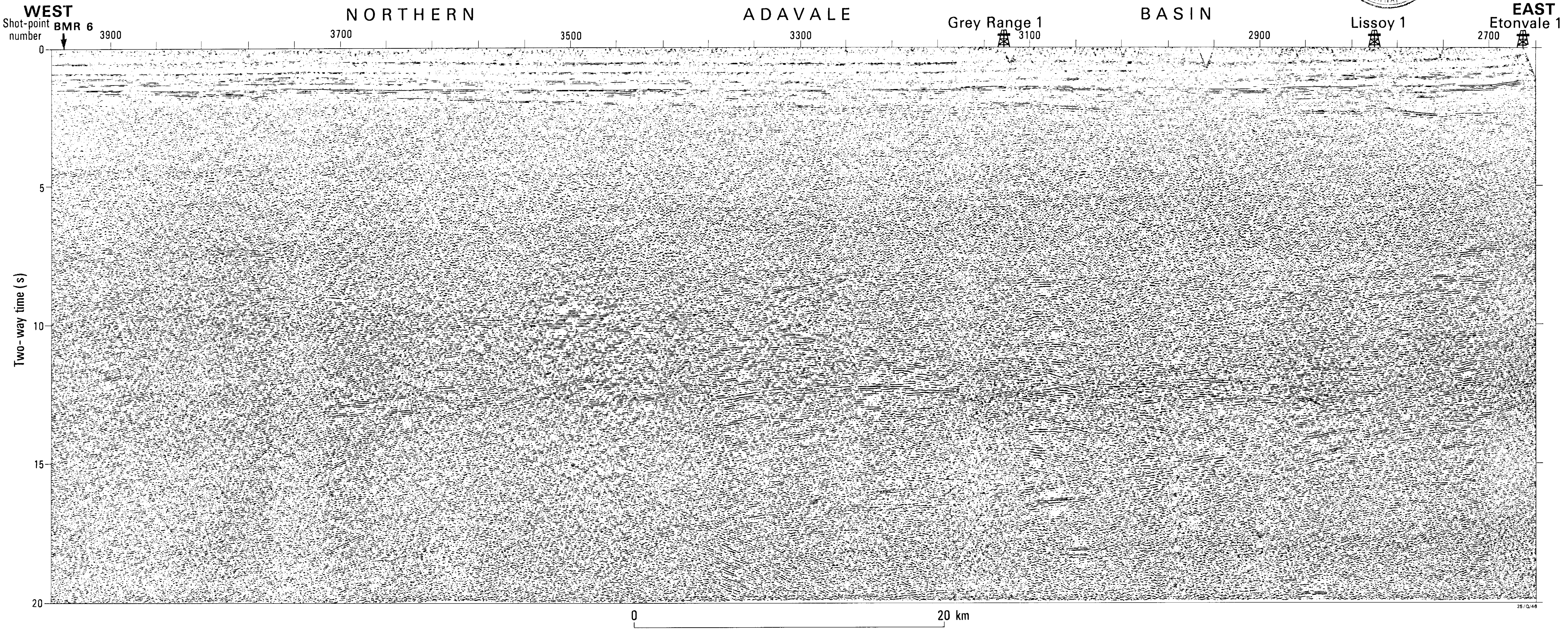
BMR TRAVERSE 6 (EAST), CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 6(east).

PLATE 15

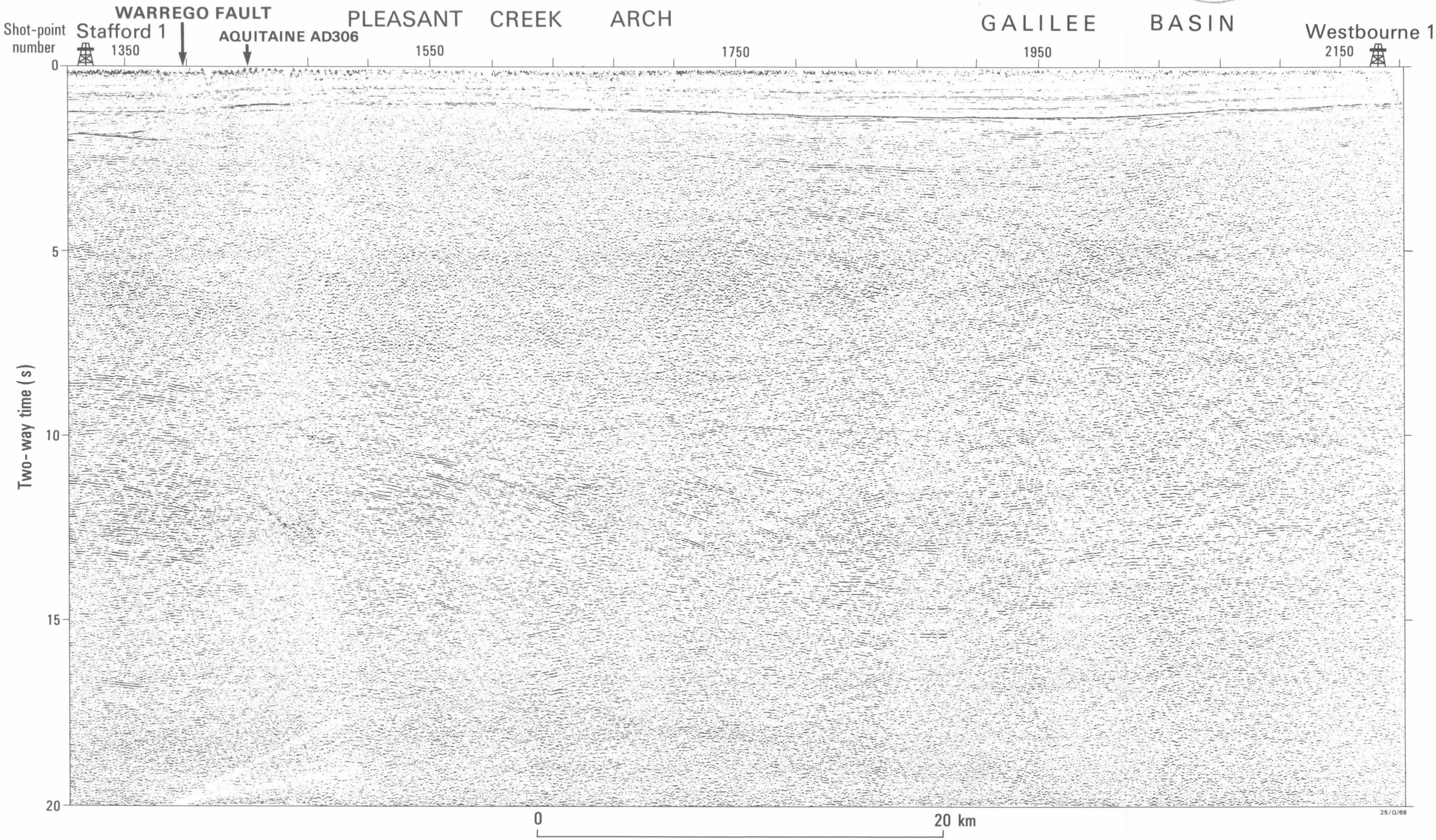
BMR TRAVERSE 2, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 2.

PLATE 16

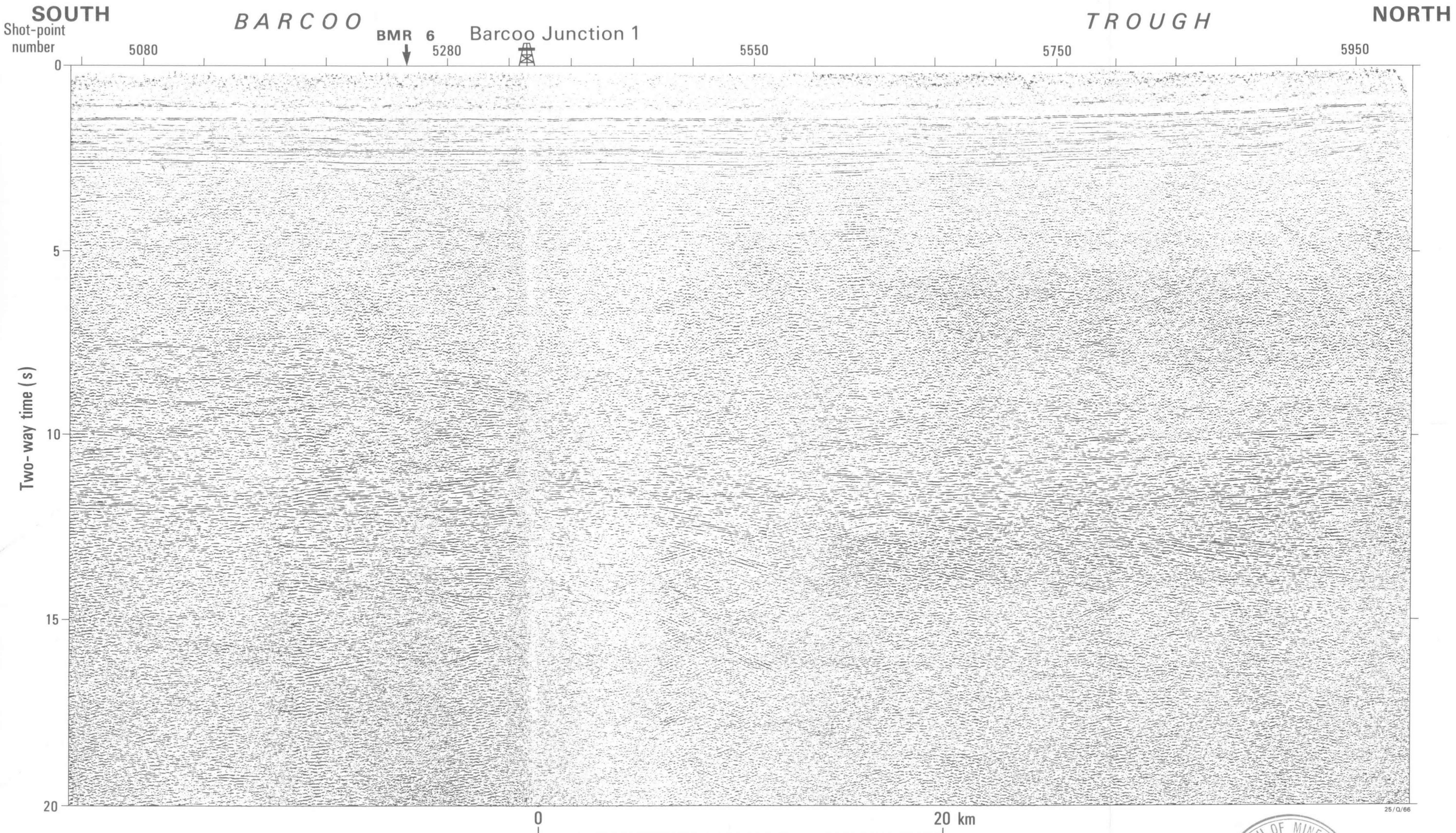
BMR TRAVERSE 13, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 13.

PLATE 17

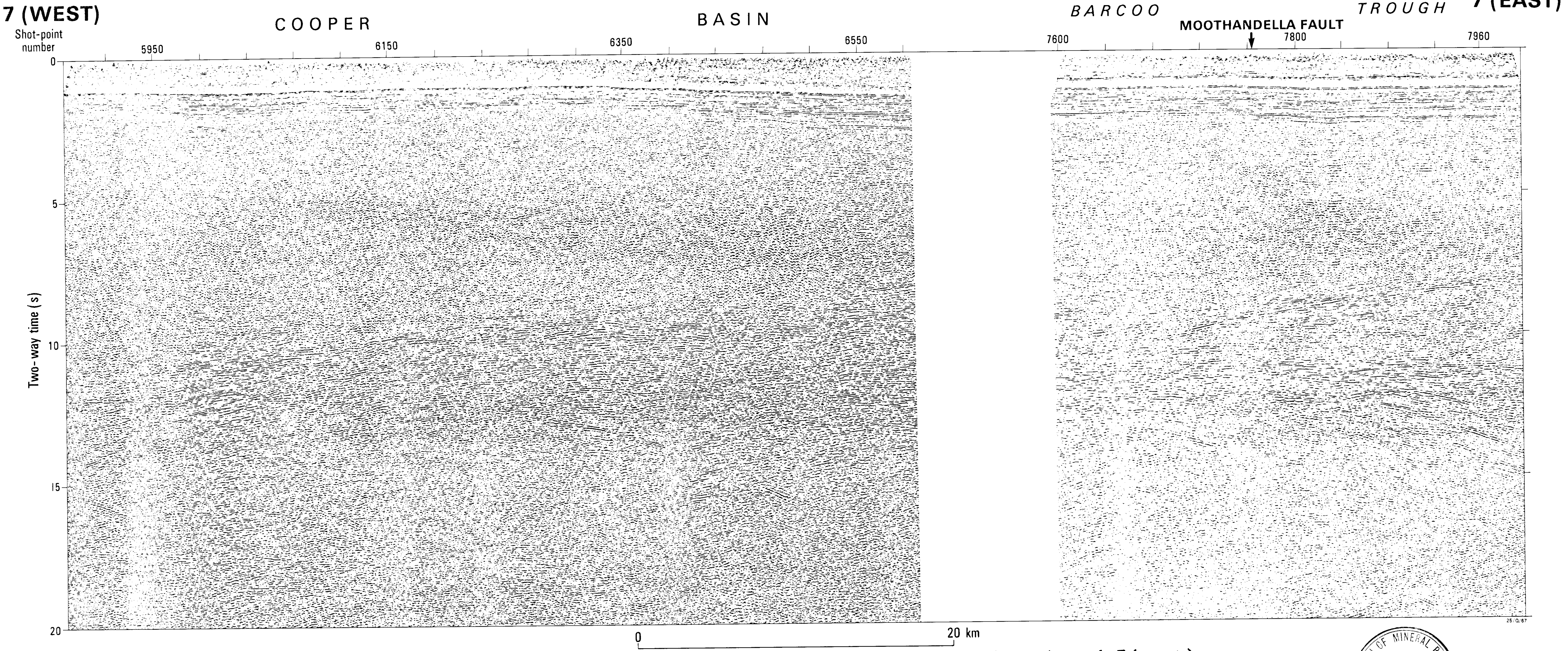
BMR TRAVERSE 5, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 5.

PLATE 18

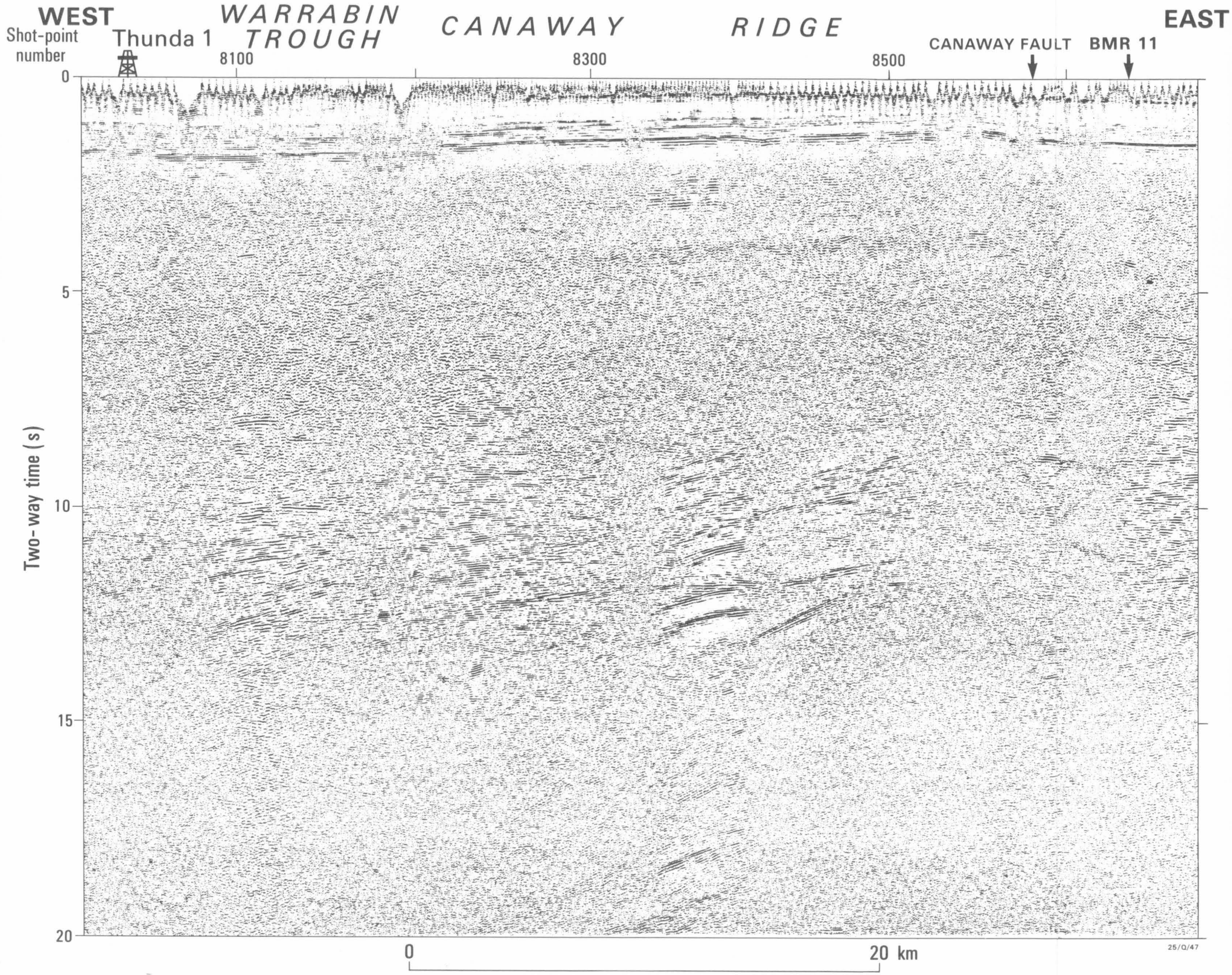
BMR TRAVERSE 7, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 7(west) and 7(east).

PLATE 19

BMR TRAVERSE 8, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 8.

PLATE 20

BMR TRAVERSE 11, CENTRAL EROMANGA BASIN

Deep seismic reflection profile along BMR traverse 11.

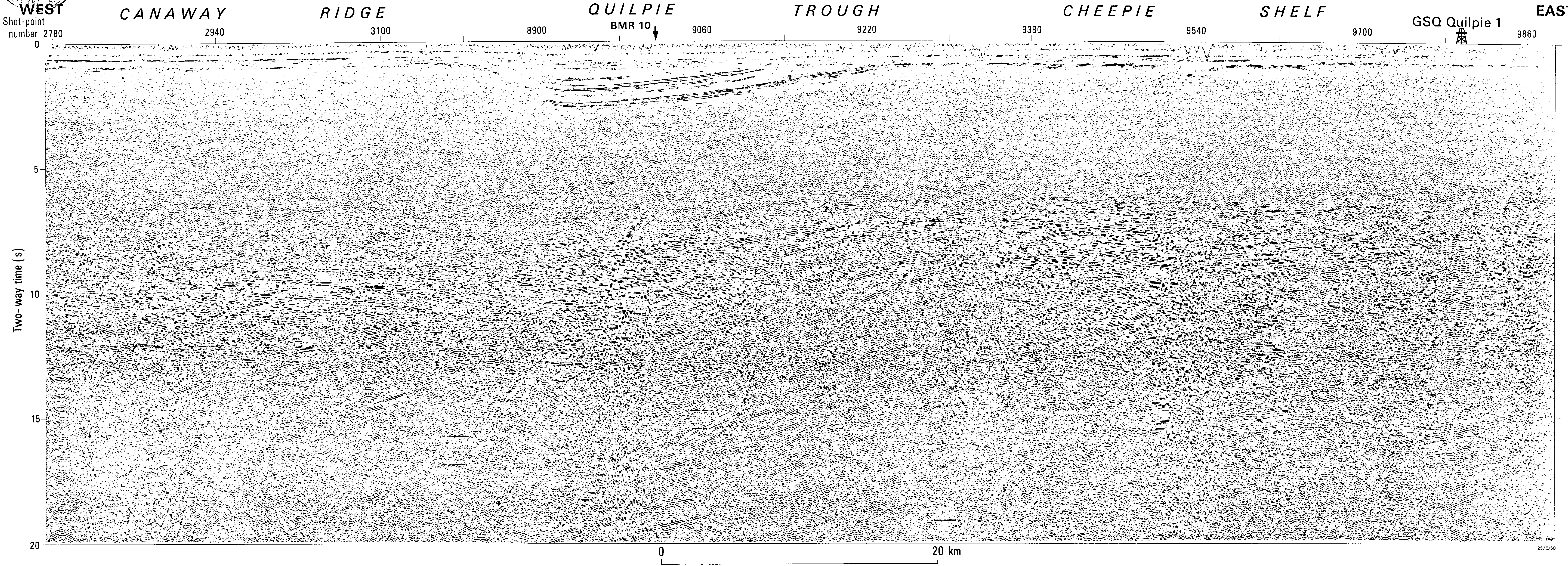
PLATE 21

BMR TRAVERSE 1, CENTRAL EROMANGA BASIN

Deep seismic reflection profile along BMR traverse 1.

PLATE 22

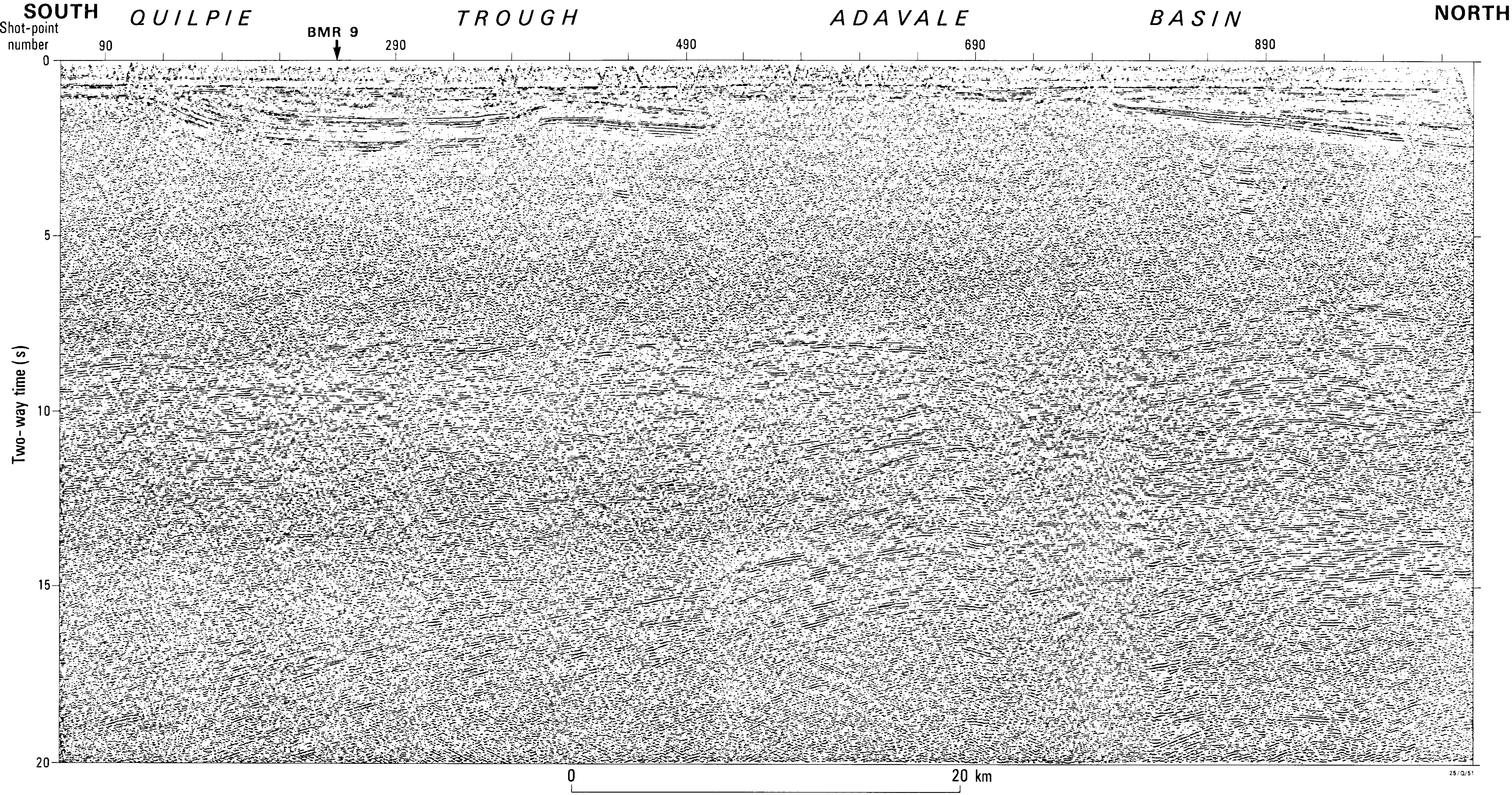
BMR TRAVERSES IX and 9, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse lX, and 9.

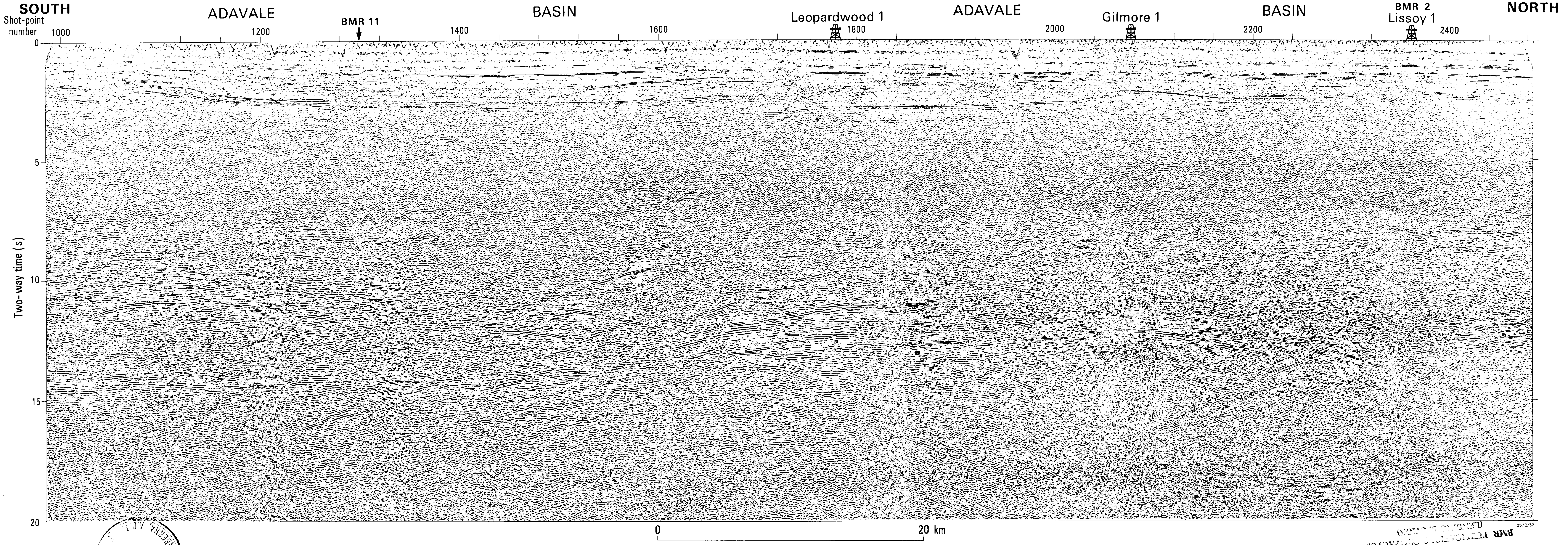
PLATE 23

BMR TRAVERSE 10 (SOUTH), CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 10(south).

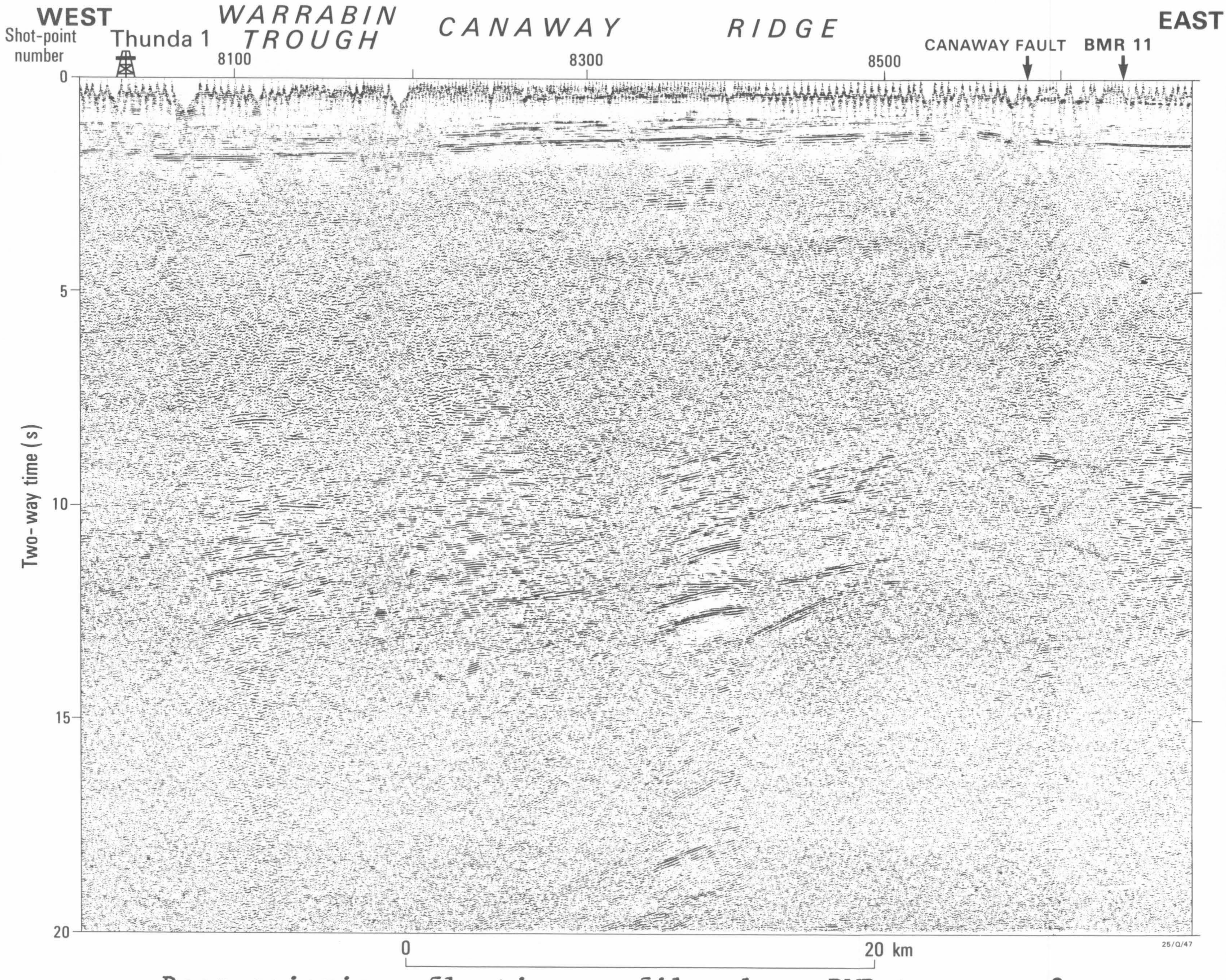
BMR TRAVERSE 10 (NORTH), CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 10(north).

PLATE 19

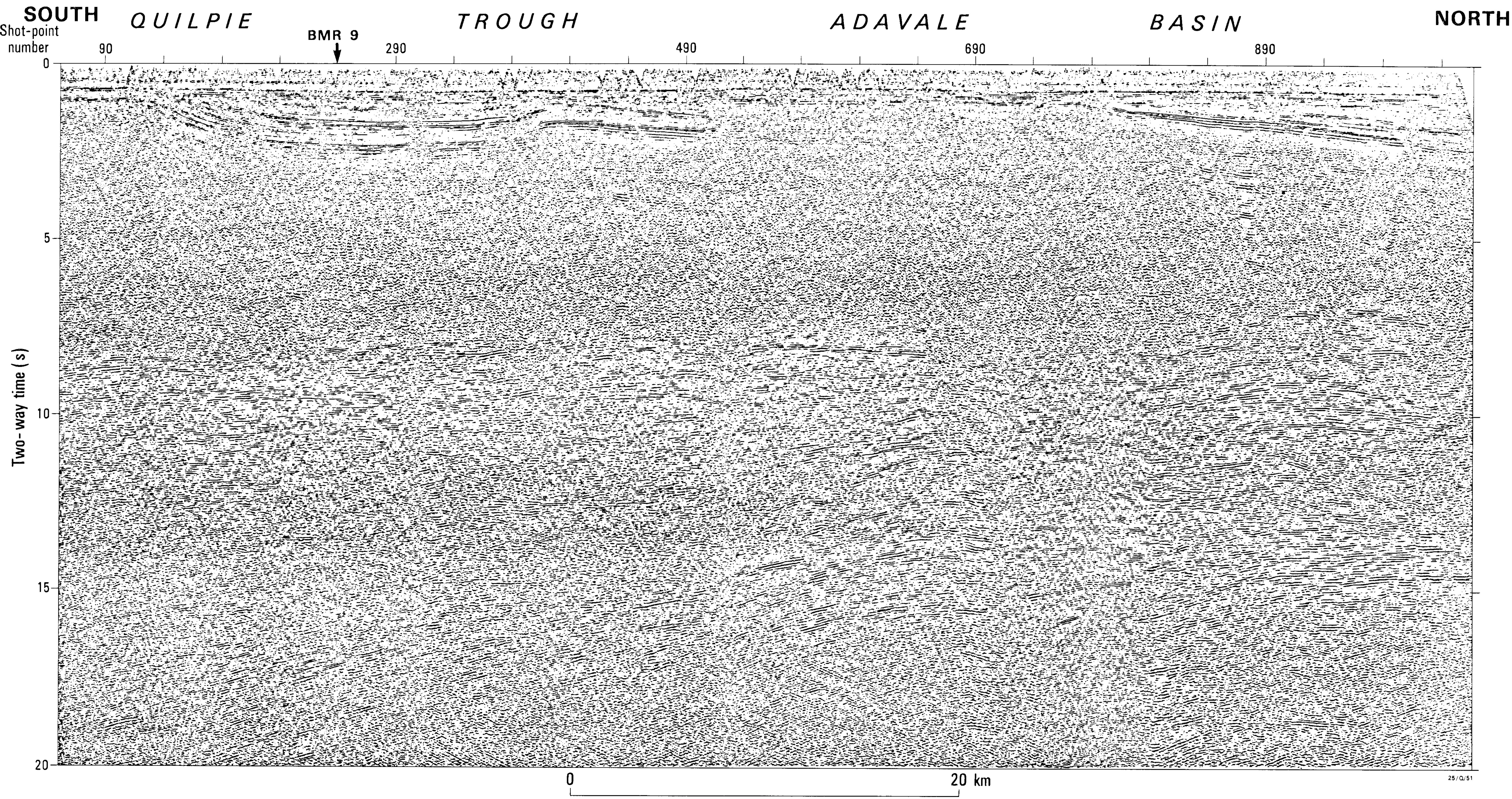
BMR TRAVERSE 8, CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 8.

PLATE 23

BMR TRAVERSE 10 (SOUTH), CENTRAL EROMANGA BASIN



Deep seismic reflection profile along BMR traverse 10(south).