BULLETIN 191

Seismic and Gravity Investigations along The Geotraverse, Western Australia, 1969

S. P. MATHUR, F. J. MOSS AND J. C. BRANSON

DEPARTMENT OF NATIONAL RESOURCES
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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A BMR contribution to
the Upper Mantle Project

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ABSTRACT

On the recommendation of the Australian Upper Mantle Committee, the Bureau of Mineral Resources carried out a seismic reflection and refraction survey along the Geotraverse, a line across the Precambrian shield in southwestern Australia. The quality of the analogue-processed reflection sections obtained was generally poor, but was improved significantly by digital processing. The quality of the refraction data was reduced by irregular spacing of the recording stations, insufficient lengths of some traverses, and irregular clusters of data points near the critical recording distances for the various layers, but the reliability of the refraction analysis depends largely on the correlation of second and later arrivals. Because of the lack of any distinctive reflection character and definitive vertical velocity information, the probable reflection events could not be correlated from one area to the other. The reflection information was, however, useful in providing support to the interpretation of the refraction data.

Analysis of the seismic data indicates that the shield crust is 34 km thick, consists of two layers with velocities of 6.12 and 6.66 km/s, and is of normal continental type in the east, but changes to an abnormal crust is the west which is 44 km thick and consists of three layers owing to the presence of a high-velocity (7.42 km/s) extra basal layer. The velocity of the upper mantle underneath the abnormal crust is 8.25 km/s. This structure is consistent with a crust in or close to isostatic equilibrium, and with the observed gravity anomaly field in southwestern Australia for two possible density models of the crust, one of which is also consistent with the hypothesis that the high-velocity basal layer in the abnormal crust is garnet-granulite overlying eclogitic upper mantle.

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SUMMARY

On the recommendation of the Australian Upper Mantle Committee, the Bureau of Mineral Resources carried out a seismic survey across the Precambrian shield in southwestern Australia between June and December 1969. Deep crustal reflection and refraction information was obtained from explosions set off in five areas along the Geotraverse, a line extending from Perth through Coolgardie in the east to Point Culver in the southeast. The results have been combined with those from gravity surveys and from other seismic refraction surveys in southwestern Australia to obtain an integrated interpretation of the structure and composition of the crust and upper mantle.

The reflection surveys included continuous profiling, offset recording, expanded spread velocity profiling and common-depth-point profiling along short traverses in the five areas. The quality of the analogue-processed sections was generally poor, and the probable reflection events, of very low relative amplitude, could be picked only from repetition of events over a few traces. Digital processing of the data effectively increased the relative amplitudes of the events and generally improved their continuity, but it also raised the level of some noise events and produced a smearing of all events over a greater number of traces than before processing. The lack of any distinctive reflection character and definitive vertical velocity information in the poor-quality data makes it impossible to correlate probable reflection events from one area to another along the Geotraverse. The reflection information was, however, useful in providing support to the interpretation of the refraction data between Perth and the Jubilee Mine about 60 km northeast of Kalgoorlie.

Refractions from the large reflection shots were also recorded at temporary and permanent seismograph stations between Perth and the Jubilee Mine, and between Perth and Albany. The quality of the refraction data recorded during the Geotraverse project, and of those recorded earlier but used in the analysis here, suffers from irregular spacing of the recording stations, insufficient lengths of some traverses, and irregular clusters of data points near the critical recording distances for the various layers. The reliability of the refraction analysis depends largely on the correlation of second and later arrivals. However, the generalized structure interpreted from the refraction data is considered to be the most probable one as it is consistent with the interpretation of reflection and gravity results.

The analysis of the seismic data indicates that the crust is of normal continental type in the east but changes towards the Perth Basin in the west. Near Kalgoorlie it consists of two layers with velocities of 6.12 and 6.66 km/s and is 34 km thick, whereas near Perth, close to the continental margin, it is 44 km thick and includes an extra basal layer of velocity 7.42 km/s, which thins out towards the east and southeast. The upper two crustal layers near Perth, on the other hand, thicken to the east and southeast. In the Perth Basin, about 7.5 km of sediments overlies a block of the crust which has been thrown down to the west along the Darling Fault. Southeast of Coolgardie, the high-velocity basal layer is shown to be thin and the southeastern part of the crustal block has been upthrust to the northwest along the Fraser Fault. The measured velocity of the upper mantle underneath the abnormal crust is 8.25 km/s.

The seismically determined structure is consistent with a crust in or close to isostatic equilibrium, and with the observed gravity anomaly field in southwestern Australia for two possible density models of the crust and upper mantle. One of the density models is also consistent with the hypothesis that the high-velocity basal layer in the crust is garnet-granulite overlying eclogitic mantle.

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INTRODUCTION

Following recommendations by the International Union of Geodesy and Geophysics in 1960, many countries began projects to study the Earth's upper mantle. The Australian Upper Mantle Committee, which was formed to foster and if necessary co-ordinate national projects, has reported on the work in this field up to the end of 1967 (Australian Academy of Science, 1965 and 1967). In 1965 the Committee recommended that a national project should be undertaken to study the Earth's crust and upper mantle along a line, designated the 'Geotraverse', across the Precambrian shield in southwestern Australia.

The general survey area was selected because it contained the largest outcrops of the oldest rocks in the Australian continent, it was readily accessible for geological and geophysical investigations, and a considerable number of geological and geophysical reconnaissance surveys had already been made in the region. The survey proposal was to carry out detailed geological, geophysical, and geochemical studies along the Geotraverse from Perth to Coolgardie and southeast to Point Culver on the Great Australian Bight. This line crosses the oldest outcropping rocks in the shield and major tectonic features including the Darling and Fraser Faults.

The Bureau of Mineral Resources, Geology and Geophysics (BMR), one of the participating organizations in the Geotraverse project, undertook to assist in the project by making seismic, gravity, and magnetic surveys along the Geotraverse. BMR made a seismic reflection survey at five sites on the Geotraverse from June to December, 1969. Seismic refraction recordings were made, on the east-west part of the Geotraverse between Perth and Coolgardie, concurrently with the seismic reflection work.

The results obtained from the BMR geophysical surveys, particularly from the seismic reflection and refraction surveys and from the gravity survey (Fraser 1973), have been used to provide an integrated interpretation of the structure of the crust and the upper mantle along the Geotraverse. Mathur (1973 and 1974) has previously summarized the results of the geophysical investigations. The staff, and equipment and operational statistics for the gravity survey are given in Fraser (1974); those for the seismic refraction survey made concurrently with the reflection work are given in Gregson & Paull (1971).

GEOLOGY

The geology of southwestern Australia has been described in detail by a number of authors including Prider (1965), Sprigg (1967), and Wilson (1969). A generalized map of the geology and main tectonic features of the area is presented in Plate 1.

The Precambrian shield in southwestern Western Australia is bounded by the Perth Basin in the west, the Eucla Basin in the east, and the Indian Ocean in the south. The Perth Basin, which developed as a rift marginal to the relatively stable continental edge, is filled with Palaeozoic and Mesozoic sediments. The Darling Fault, a major normal fault, separates the Perth Basin from the Precambrian shield and a partly submerged north-trending ridge of Precambrian rocks, exposed between Cape Leeuwin and Cape Naturaliste, defines the western margin of the basin. The Leeuwin-Naturaliste Block is believed by Heezen & Tharp (1965) to extend westwards as the submerged Naturaliste Plateau. East of the Fraser Fault, the shield is covered by marine Tertiary sediments of the Eucla Basin. In the south, the shield abuts the Indian Ocean and forms a narrow continental shelf.

The Yilgarn Block, the largest part of the shield, is made up of Archaean gneisses, with lenticular greenstones and metasediments (whitestones) elongate in a north-northwest direction, and massive granitic intrusions which have been dated at 2700 to 2900 m.y. These granitic batholiths are also slightly elongate in the same direction as the older rocks. Basic dykes of Late Proterozoic or Lower Cambrian age, which intrude the older rocks, show an east-northeast trend superimposed on the main north-northwest trend. Along the southern margin of the block, the main strike is parallel to the coast.

The Albany-Esperance Block in the south, the Fraser Range Block in the southeast, and the Leeuwin-Naturaliste Block contain exposed Proterozoic granulites. The Albany-Esperance Block appears generally to have been welded on to the Archaean rocks in the north, but there is evidence of large-scale faulting in the Bremer Fault along the presumed junction. The gneisses and granulites in this block trend east-northeast in the south, and north farther west. Granitic intrusions in the block are dated at 1100 m.y. In the Fraser Range Block, basic granulites and metagabbros show northeast to north-northeast trends. Deformation of the granulites, and garnetization of the gneisses suggest thermal metamorphism resulting from a substantial rise of basic magma along the Fraser Fault, a suggested major mantle rupture. In the Leeuwin-Naturaliste Block, the granulites show effects of intrusive deformation and are assumed to form part of the complex Proterozoic orogenic belt which girdles the Archaean nucleus in southwestern Australia.

A thin cover of sediments including Permian Coal Measures, marine Eocene and Tertiary sediments, superficial soils, aeolian sands, and saltlake evaporites overlies the Precambrian shield in many areas. The Archaean rocks are deeply weathered in some other places.

The Geotraverse was surveyed to cross a number of important geological provinces and features in the Precambrian shield in southwestern Australia. From Perth eastwards, the traverse crosses the Darling Fault onto the Archaean gneisses and granites of the Yilgarn Block, then runs through the greenstone belts of the Coolgardie goldfields before turning southeast to cross the Fraser Fault and the eastern boundary of the shield in the Eucla Basin.

PREVIOUS GEOPHYSICAL INVESTIGATIONS

Numerous geophysical surveys have been made in southwestern Australia before the Geotraverse survey. These include aeromagnetic, gravity, and seismic surveys for petroleum and mineral exploration in the Perth Basin, and on the Precambrian shield mainly in the Kalgoorlie-Widgiemooltha area.

Aeromagnetic

The results from several total magnetic intensity traverses radiating in different directions from Kalgoorlie, and total magnetic intensity maps of the Kalgoorlie area and the Perth Basin have been published by BMR during the period 1954-1964. The magnetic results have been interpreted to provide information on the geology of the shield and the basement topography in the Perth Basin by several authors including Wells (1962), Quilty (1963), Thyer (1963), Dockery & Finney (1965), and Tipper (1968).

The most pronounced magnetic anomalies are associated with the Perth Basin and with the greenstone outcrops in the central part of the shield. In the Perth Basin the anomalies indicate a narrow graben near Cape Leeuwin, which widens considerably to the north of 31°S. The magnetic results also indicate subsidiary basement ridges parallel to the boundaries of the basin, and a maximum thickness of sediments of about 6 km near Perth. The lineation of the magnetic anomalies over most of the central part of the shield is as irregular as the greenstone-gneiss contact. Nevertheless, a general north-northwest trend is most prominent and a secondary east-northeast trend is associated with the basic intrusive dykes in the Coolgardie goldfields. As expected, zones of varying magnetic intensity are generally found to be associated with outcropping rocks of different magnetic susceptibilities.

The magnetic results thus provide useful information about the rocks in the upper part of the crust but contribute nothing to an understanding of the composition of the crust deeper than the Curie Point, at a depth of about 15 km, where the rocks lose their magnetic properties.

Gravity

Extensive gravity surveys made by BMR in the Perth Basin in 1951-52 and in the southwestern part of the shield in 1969 have been reported on by Thyer & Everingham (1956) and by Fraser (1973), respectively. These authors and Daniels (1971) indicated good correlations between the Bouguer anomalies and the major geological and tectonic features.

Bouguer and regional free-air anomaly maps of the area are shown in Plates 2 and 3, respectively. Bouguer anomalies were computed for a correction density of $2.2\ g/cm^3$; use of a more representative density of $2.67\ g/cm^3$ for the surficial rocks in the shield area would decrease the values of the anomalies by about 10 mGal but would not significantly alter their relations. The principal features shown in the gravity maps are as follows:

- Generally small free-air anomalies, within $\pm$ 20 mGal. characteristic of a stable continental shield.
- Zones of steep gravity gradients defining the western, southern, and southeastern margins of the Yilgarn Block. The directions of the gradients indicate an excess of mass along the southeastern boundary and deficiencies along the western and southern boundaries.
- High negative Bouguer anomalies, with a minimum of about -125 mGal, along the western coast reflecting the Perth Basin. The magnitudes of the gravity gradients on the edges of the basin suggest that the downthrown block is tilted to the east.
- A large gravity low in the south corresponding to the intrusive mass of low-density Albany granite.
- A northeast-trending zone of high positive anomalies in the southeast indicating an uplift of denser material in the Fraser Range Block.
- Several short-wavelength low-amplitude Bouguer anomaly highs in the northeast reflecting denser greenstone outcrops in the Kalgoorlie area.
- A large area of high positive free-air anomalies with $+50$ mGal maximum, and Bouguer anomalies with $+30$ mGal maximum, in the southwest part of the shield suggesting a mass excess in the crust.

The gravity anomalies provide information on the structure and composition of rocks at all depths when constraints from geological and other geophysical evidence are applied to the interpretation. Mainly the short-wavelength components are related to the surficial and near-surface features, and the long-wavelength components reflect mass anomalies deeper in the crust and the upper mantle. The gravity data cannot be interpreted alone, but together with seismic results provide a less ambiguous interpretation of the composition and structure of the crust and the upper mantle.

Seismic

Several seismic surveys on land and at sea in the Perth Basin and on the adjoining areas of the shield have been made by BMR and others to investigate the sedimentary section in the Perth Basin and the basic features of the deeper parts of the crust in the region.

Seismic reflections recorded by Vale & Moss (1962) on both sides of the Darling Fault showed reflecting horizons dipping eastwards under the Perth Basin and westward under the shield. Seismic refraction studies in the southwest of Western Australia by Everingham (1965) suggested that the crust consisted of two layers with velocities of 6.18 and 7.24 km/s and that the mantle had a velocity of 8.48 km/s. Everingham estimated the thicknesses of the two crustal layers to be 14 and 28 km respectively on the shield east of the Perth Basin. The downthrown block of the older crust in the Perth Basin was estimated to be overlain by about 6 km of sediments with an average velocity of 2.94 km/s. In relating preliminary gravity and seismic data in the southwest of Western Australia, Everingham (1965 and 1966) suggested that a change in the structure of the crust and possibly the upper mantle occurs along a north-northwest-trending seismically active zone, the Yandanooka/Cape Riche Lineament (Pl. 4) on the shield east of Perth, where the Bouguer anomalies change from negative in the east to positive in the west.

Seismic refraction results from the 1956 atomic explosions at Maralinga indicated a single layer crust of 32 km thickness and westward P-wave velocities of 6.03 km/s in the crust and 8.21 km/s in the upper mantle in South Australia and in the eastern part of Western Australia (Bolt, Doyle, & Sutton, 1958). Doyle & Everingham (1964) recomputed the crustal thickness in this area to be 35 km using a more realistic crustal velocity of 6.30 km/s obtained on a refraction profile southeast of Maralinga.

Marine seismic, gravity, and magnetic investigations by Hawkins, Hennion, Nafe, & Thyer (1965) indicated that the Perth Basin had multiple axes of sedimentation, broadened westward north of Perth, had about 5.7 km of sediments west of Perth, and that an eastwards-tilted basement formed its western margin.

Marine refraction studies in the southeast Indian Ocean by Francis & Raitt (1967) indicated that the structure along a line extending northwest from Perth is that of a normal two-layer oceanic crust whereas that under Broken Ridge, about 1000 km west of Perth, is almost continental. The crust under Broken Ridge is about 20 km thick and consists of four layers with velocities of 5.81, 6.07, 6.43 and 7.25 km/s overlying the mantle with a velocity of 8.23 km/s. East of the ridge, in the deep basin, the crust thins to an oceanic type commonly observed in the Indian Ocean beneath deep water areas immediately adjacent to shallow banks. Because of the physiographic similarity of Broken Ridge to the Naturaliste Plateau, Francis and Raitt suggested the possibility that the ridge was at one time part of the West Australian shield and that the crust in between was thinned tectonically or the mantle had risen at the expense of the crust by some process at the Mohorovicic Discontinuity (Moho).

Results of marine seismic refraction surveys by Hawkins, Hennion, Nafe, & Doyle (1965) on the continental margin south of Point D'Entrecasteaux indicated shallowing of the base of the oceanic crustal layer towards the continent to depth of approximately 10.5 km roughly 120 km south of the coast. The mantle velocity there was calculated to be 8.07 km/s. These results may be inconclusive as travel times from an intermediate layer in the transition zone could be included but not accounted for.

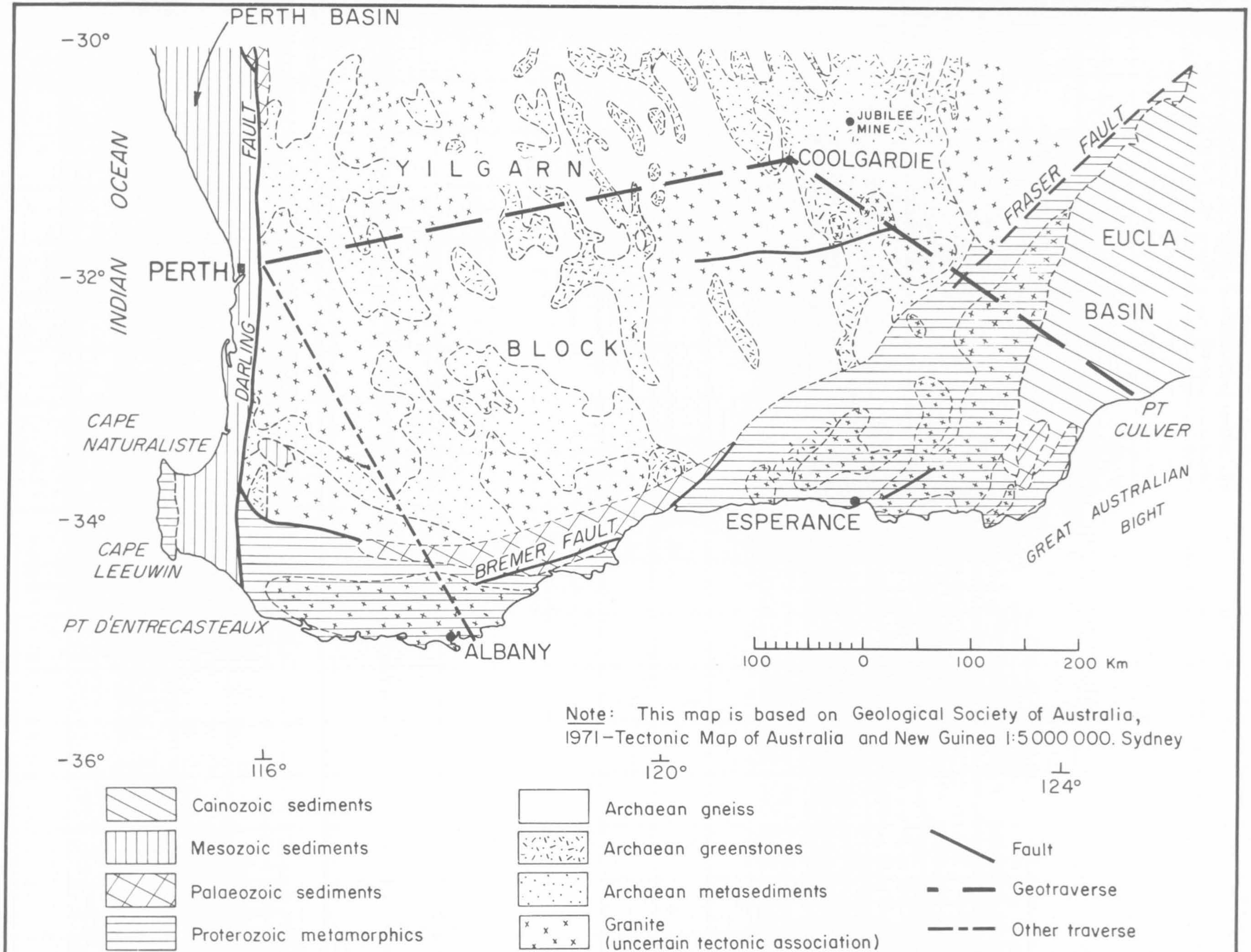

PLATE 1 GENERALIZED GEOLOGICAL MAP OF SOUTHWESTERN AUSTRALIA

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A preliminary review of all deep crustal seismic studies in the Australian region has been made by Dooley (1970). He made several general conclusions on the nature of the crust and the upper mantle in Australia. The depth to the mantle on the mainland, where seismic data are available, is generally about 35 to 40 km. The P_n velocity ranges from 7.67 km/s under Bass Strait to 8.42 km/s in the western part of the shield in Western Australia; this increase in the P_n velocity from east to west may be correlated with a decrease in heat flow in the same direction. Dooley also indicated the presence of an intermediate deep crustal layer in a number of places in Australia. From an analysis of the results of large-scale deep crustal refraction surveys in Australia, Cleary (1971) also concluded that both P, and P_n velocities are higher in the Precambrian shield region than in eastern Australia and appear to increase from east to west across the continent, that there is good evidence in all parts of Australia for an intermediate layer with an average depth of 20 km to the Conrad discontinuity, and that the average crustal thickness is about 40 km.

During the Fremantle Region Upper Mantle Project in 1967, BMR with the assistance of the Royal Australian Navy recorded seismic refraction data in the area between Perth and Albany from marine explosions in these areas (Gregson & Wood, 1968). The interpretation of data from this survey has not been published but has been used in the present study to determine the crustal structure along a northwest traverse between Perth and Albany.

Heat Flow

Howard & Saas (1964) found lower heat-flow values in the shield in Western Australia than in other regions on analysis of twenty measurements made throughout Australia. They suggested that the difference may be mainly due to a much higher concentration of radioactive material in the crust and upper mantle in eastern Australia than in the shield area and calculated that there is probably a temperature difference of 200°C or greater between the two regions at a depth of 37 km. Hyndman, Lambert, Heier, Jaeger, & Ringwood (1968) made one heat-flow measurement near Hines Hill on the Geotraverse and two measurements in the Kalgoorlie area. These authors confirmed the earlier observations that the heat-flow values in the shield are low and concluded that the low values are due to the layer in which the radioactive elements are concentrated being very thin. These observations and conclusions support the suggestion by Ringwood (1962) that low heat values might be characteristic of all Archaean shields and also support his interpretation that the continental crusts evolved through partial melting and metamorphism causing a strong upward concentration of radioactive elements and that erosion processes removed part of the surface layer to form a shield crust depleted of heat-producing elements. The consequences of this interpretation, according to Clark & Ringwood (1964), are that under shield areas the crustal and upper mantle temperatures would be lower than at the same depths under non-shield areas so that the lower temperatures would explain the tectonic rigidity of the shields, the seismic velocities would be higher, and the seismic low-velocity zone in the upper mantle would be less pronounced or absent.

Magneto-tellurics

The magneto-telluric investigations made by Everett & Hyndman (1967) across southwestern Australia suggest a two-layer model, a higher-resistivity layer overlying a 10 ohm-metres low-resistivity layer. The upper layer was estimated to be 200 km thick and its resistivity increases from 10^3 ohm-metres near the west coast to 10^5 ohm-metres in the east. The low resistivity of the upper layer in the west was ascribed to the sediments in the Perth Basin and a major temperature gradient along the western boundary of the Precambrian shield. The results also give some indication of a low-resistivity layer at a depth of 70 km, which may be associated with a seismic low-velocity layer in the mantle.

Summary

The previous geophysical studies in southwestern Australia indicate that the shield, which consists of a nucleus of Archaean acid and basic granulites girdled by a belt of Proterozoic gneisses, is a deeply eroded part of the oldest, tectonically stable crust showing low heat-flow values which imply depletion of radioactive elements. A major temperature gradient is indicated along the western boundary of the shield at the Darling Fault which has been tectonically active throughout geological history. There is some evidence that the seismic low-velocity zone in the upper mantle is about 70 km under the shield area and it is less pronounced than in other areas. The magnetic anomalies and short-wavelength components of gravity anomalies generally show good correlation with the surficial geology and tectonic features in the area. Seismic investigations indicate that the crust is abnormally thick on the shield near Perth by comparison with that in normal shield areas.

OBJECTIVES AND PROGRAMS

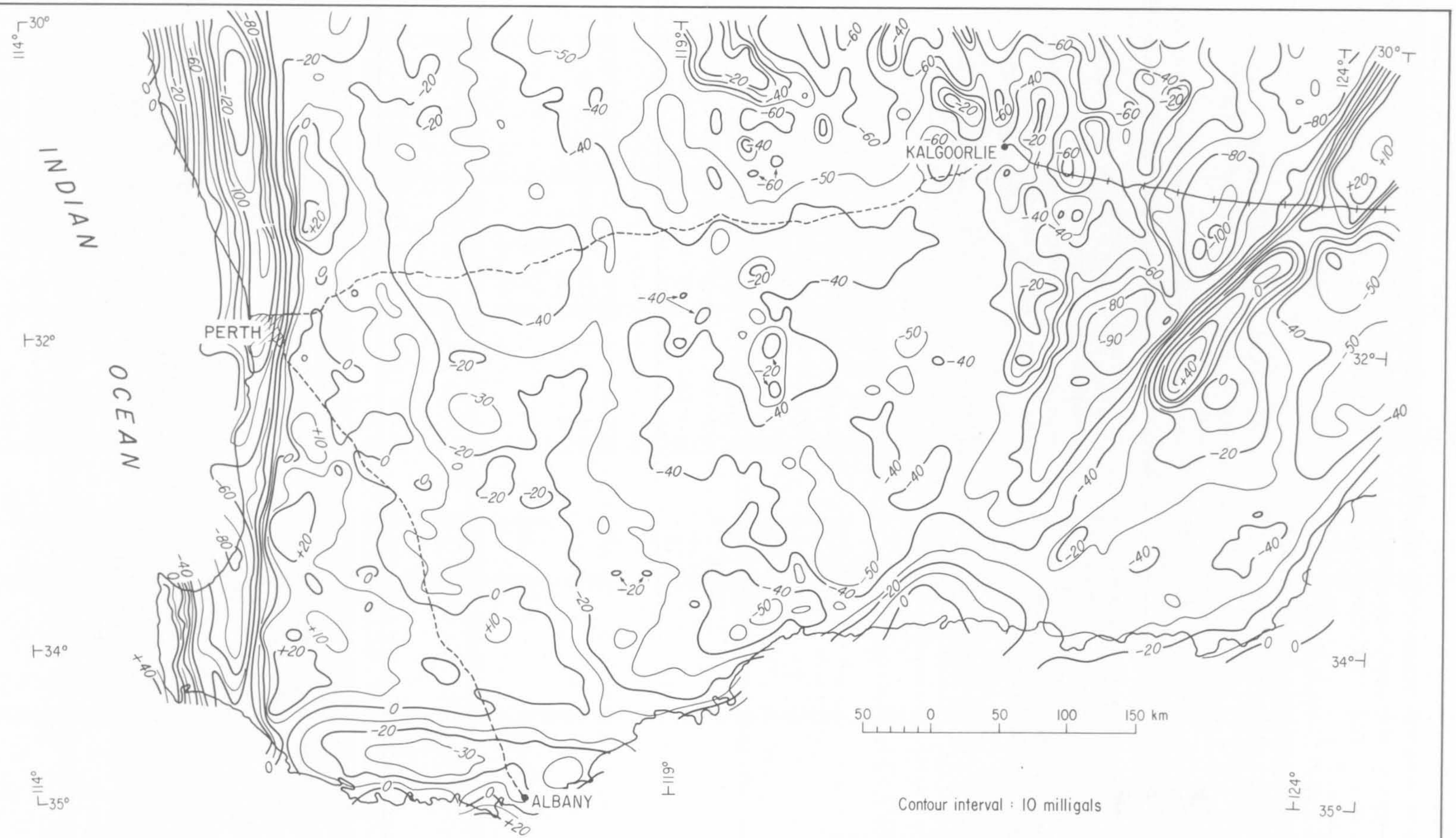
Geophysical surveys on the Geotraverse were planned to obtain data to supplement geological information from surface mapping and stratigraphic holes and hence to provide an integrated interpretation of the structure and nature of the crust and the upper mantle of the Precambrian shield in southwestern Australia. The main objective of the seismic survey was to record deep seismic reflection soundings on the Geotraverse; the recording of seismic refraction information between Perth and Coolgardie, concurrently with the reflection work on that part of the Geotraverse, was a secondary objective.

Five areas along the Geotraverse were selected by BMR as sites for detailed seismic reflection investigations. The sites chosen, after study of available geological and geophysical information and their proximity to heatflow measurement and stratigraphic drilling locations, are outlined in Plate 4.

Fraser Range	— near the eastern boundary of the Yilgarn Block
Widgiemooltha	— in the greenstones of the goldfields area
Boorabbin	— in acid and basic granulites of the shield
Hines Hill	— in high-grade metamorphic rocks, east of the seismicity zone along the Yandanooka/Cape Riche Lineament
Wundowie	— in granites near the western boundary of the shield.

The reflection surveys included continuous profiling, offset recording, expanded spread velocity profiling and common-depth-point (CDP) profiling along short traverses, and the refraction recordings were made at temporary and permanent seismograph stations along the Geotraverse up to distances of 500 km from the reflection shots. The locations of these shots and the recording stations are also shown in Plate 4, and details of the refraction recordings are given by Gregson & Paull (1971).

All available geophysical information on the Precambrian shield in southwestern Australia was used in deriving an integrated generalized interpretation of the structure and



Note : This map is based on Preliminary Bouguer Anomalies Map of Australia, 1:2 534 400 scale, published by the Bureau of Mineral Resources, Geology and Geophysics, 1970.

Bouguer correction density used – 2·2 g/cm^3

PLATE 2 BOUGUER ANOMALY MAP

WA/83–18

nature of the crust and the upper mantle in the area. The seismic reflection and refraction and the gravity results, which provided the most useful information, were studied as follows:

- The reflection results in the five survey areas (Pl. 5) were processed and analysed to determine if reflections were recorded at times expected for recordings from deep crustal layers and from the upper mantle and to determine if reflections recorded could be correlated from one area to another.
- The refraction results from recordings on the Geotraverse and from earlier recordings in south-western Australia were analysed to derive the generalized crustal structure of the shield.
- Checks were made to determine if the reflection information recorded was consistent with the generalized structure derived from the refraction information.
- The gravity information was analysed to ascertain if it was consistent with the seismically derived generalized structure, to determine the isostatic stability of the region, and to provide further information on the nature of the crust and upper mantle under the shield.

SEISMIC REFLECTION RESULTS AND INTERPRETATION

The seismic refraction method has been used for most major seismic deep crustal and upper mantle investigations throughout the world. In some areas, however, seismic reflection surveys have been made successfully to obtain information on the structure and nature of the deep part of the crust and the upper mantle. Moss (in prep) briefly reviewed the deep crustal and upper mantle reflection investigations made in other countries, mainly in U.S.S.R., West Germany, Canada, and U.S.A., and discussed the investigations made by BMR in Australia. The reflection method has considerable advantages over the refraction method in its precision, resolving power, and ability to distinguish low-velocity layers. The reflection method may also yield vertical velocity information from which depth determinations may be made. Reflection surveys, however, are usually more expensive than refraction surveys which normally provide more general regional information than reflection surveys.

The criteria for recognizing primary reflected energy in deep crustal and upper mantle seismic reflection studies were specified by Kanasewich & Cumming (1965):

- Reflection energy should be recorded at near-vertical incidence; thus events should be recorded at the same record time on geophone spreads mutually at right angles. Recordings should be made using vertical and horizontal geophones to check the direction of incidence of the reflected energy.
- Reflected events should be recorded on expanded spreads to determine average velocities which will be high velocities characteristic of the deep crust and upper mantle if events are primary reflections or low velocities characteristic of the sedimentary or near-surface crustal layers if events are multiple reflections.
- Every reflected event should be suspected as a multiple unless the data are sufficiently unambiguous to exclude this possibility.
- A particularly high-amplitude late event, which is not at a time close to a simple multiple of an earlier event, is likely to be a primary reflection.

The basic principles for recording deep crustal and upper mantle reflections were described by Steinhart & Meyer (1961); however, little information is generally available on the reflection recording techniques used by workers in this field. Thus experimental seismic surveys were made at Mildura, Victoria and Broken Hill, N.S.W. in 1968 (Branson, Moss, & Taylor, 1976) and at Tidbinbilla, A.C.T. and Braidwood, N.S.W. in 1969 (Taylor, Moss, & Branson, 1972) to develop techniques for recording deep crustal and upper mantle reflections before the seismic reflection survey on the Geotraverse.

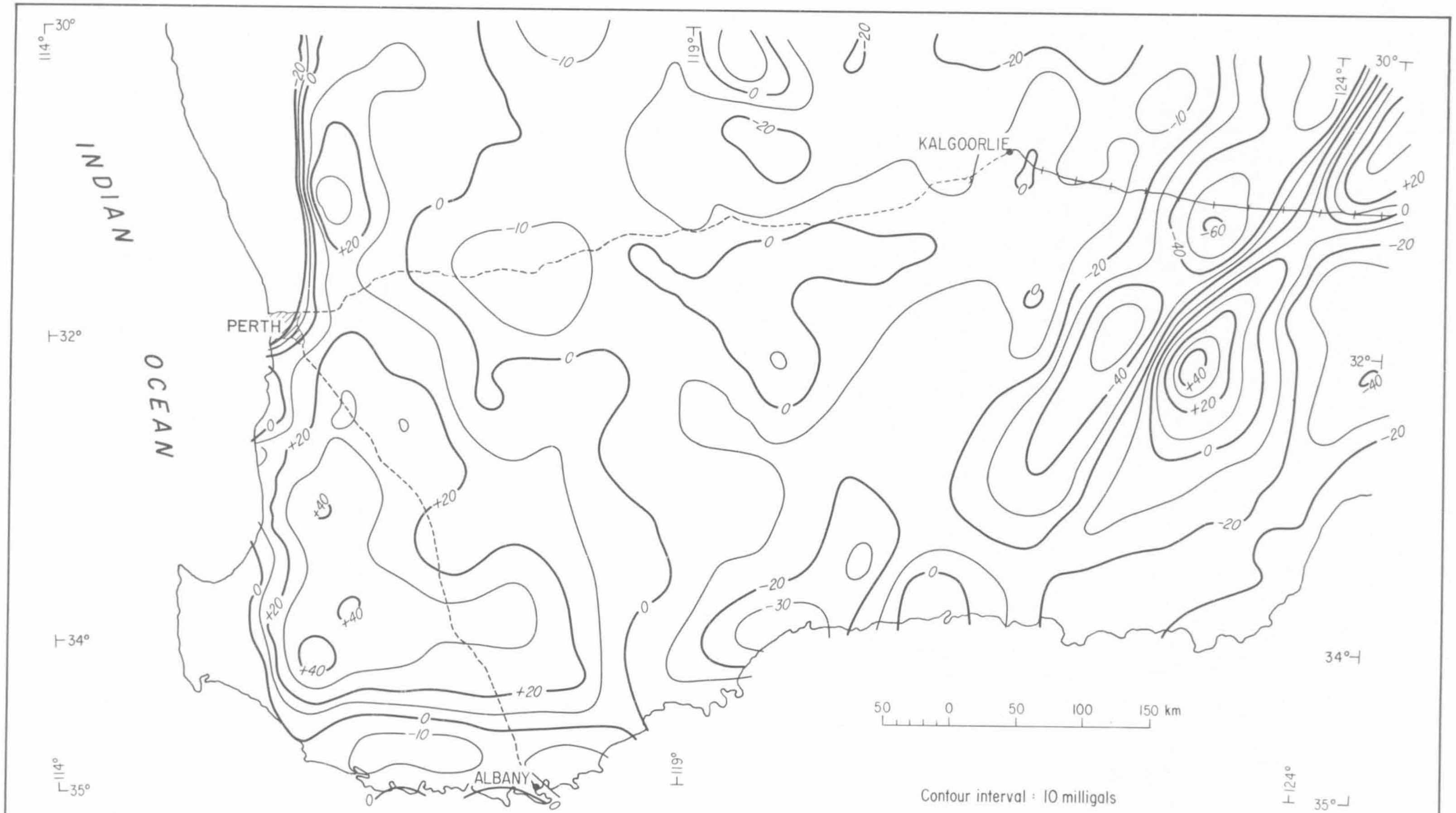
Experimental deep crustal and upper mantle seismic reflection test surveys in eastern Australia before the Geotraverse survey

Noise tests, expanded reflection spreads, and continuous reflection profiles mutually at right-angles, mainly with split spreads of 1080-0-1080m, were recorded at both Mildura, Victoria and Broken Hill, N.S.W. Arrays of up to 48 geophones per station and shot-hole patterns of length 100 m or more were used to attenuate random and coherent noise. Seismic energy return from within the crust and the upper mantle was fair at Mildura in the Murray Basin where charges of up to 115 kg of Geophex explosive were used. However charges of up to 4500 kg were necessary to obtain fair-quality deep seismic reflections at Broken Hill on the Precambrian Willyama Complex, an area of high-grade metamorphics with outcrops of schist, gneiss, and quartzite similar in many respects to the surface and immediate subsurface conditions on the Geotraverse. Reflection tests using similar techniques as at Mildura and Broken Hill were made at Tidbinbilla and Braidwood to investigate the use of long spreads and common-depth-point (CDP) profiling techniques for deep crustal and upper mantle seismic reflection surveys. The tests made on granite outcrops indicated that split spreads of 2160-0-2160 m can be used without any obvious deterioration in reflection quality, that there are no distinct advantages in using CDP profiling techniques, and that large charges of up to 4500 kg could be necessary to achieve effective seismic energy return on the Geotraverse, which is in a somewhat similar geological environment to that of the test survey areas.

It was concluded that suitable equipment and recording parameters for deep crustal and upper mantle reflection surveys in eastern Australia are as follows:

Geophone type	— HS-J 14 Hz
Geophone pattern	— 48 geophones in 2 rows of 24 in-line. Rows 6 m apart, geophones 6 m apart
Shot-hole charge	— 23 kg per hole
Shot-hole pattern	— 20 holes in 2 rows of 10 in-line. Rows 20 m apart, holes 10 m apart
Spread length	— 2160-0-2160 m
Recording filter	— K14-K125.

An observation that the apparent frequencies of the deep crustal and upper mantle reflection events are greater than 15 Hz is consistent with results described elsewhere in the world since the surveys in eastern Australia. Fuchs (1969) referred to special studies with low-frequency instrumentation which failed to record very low-frequency reflections from the deep parts of tne crust and stated that deep crustal reflections have a low-frequency cut-off at about 10 Hz. Davydova, Kosminskaya, & Michota (1970) discussed the results of tests which indicate that subcritical deep crustal reflections were recorded with highest amplitude at a peak reflection frequency of 16 Hz. The amplitudes of the deep crustal and upper mantle reflections recorded on the BMR surveys varied widely in the same general areas, as found



Note: Regional anomalies were obtained after applying a Normal Curve Smoothing Function to the observed free-air anomalies. Values were computed at 15' grid points using the weighting function, $W(r) = e^{-(\frac{r}{R})^2}$, where r = distance between grid point and observation, and R = 15'

PLATE 3 REGIONAL FREE-AIR ANOMALY MAP

WA/B3-20

elsewhere by Kanasewich & Cumming (1965) and others. The appearance of the reflections differs considerably from that of reflections from sedimentary formations. The reflections generally correlate only over short distances, seldom more than a few kilometres, and are recorded usually with many phases. This agrees with the findings of Dohr & Fuchs (1967).

Seismic reflection survey along the Geotraverse

A summary indicating reflection recordings made on the Geotraverse is shown in Table 1, traverse locations are shown in Plate 5, and specific information on particular recordings are given in illustrations showing record sections in Plates 6 to 26. No reflection sections are included from experimental recording comparisons made at Fraser Range Traverse A, but the best records were incorporated in the continuous coverage sections.

An increase in staff over normal sedimentary basin seismic survey requirements was necessary because extra field hands were employed to assist the surveying team and to assist in laying long geophone spreads with large numbers of geophones in patterns. Equipment was normal except for the use of long magnetic tapes on the DS7-7 to record up to 24s of seismic data instead of 6s of data recorded on other surveys.

No special arrangements were made to record refraction information from the deeper part of the crust and the upper mantle from shots in the Fraser Range and Widgiemooltha areas, but recordings of the larger shots in these areas were made at the Mundaring Geophysical Observatory. A program of systematic recordings of refraction information along the east-west part of the Geotraverse began with recordings from large reflection shots in the Boorabbin area and continued with recordings from large shots in the remaining areas of the reflection survey and from a special shot in the abandoned Jubilee Mine near Kalgoorlie. Three large reflection shots at Wundowie, near the western margin of the shield, were also recorded on a line towards Albany in the southeast to obtain reversed refraction profile information for previous refraction shots offshore from Albany. VNG standard time signals were recorded on all refraction shots to assist in timing refraction arrivals.

Field experimentation Tests were made at the commencement of the survey at Fraser Range to check the applicability of recording techniques established on the surveys in eastern Australia to reflection work on the Geotraverse survey. Geophone comparison tests were made to check the effectiveness of different spacings of geophones in groups, different numbers of geophones per trace, different lengths of geophone patterns, and the use of 4.5-Hz geophones instead of 14-Hz geophones. A charge comparison test was also made.

The test results indicated that field recording techniques similar in most respects to those used in eastern Australia were equally applicable to reflection work on the Geotraverse. However, because of the large charges generally necessary for good energy penetration in most areas, it was necessary to use an increased number of holes in shot-hole patterns up to a maximum number of 40 holes in 4 rows of 10 in-line generally with rows and holes 15 m apart.

Production recording Attempts were made to record continuous reflection profiles and expanded reflection spreads in most areas. The techniques used and the amount and type of coverage obtained were modified as necessary by surveying, drilling and recording conditions in particular areas.

Generally the first shots in each area were made on split-spread reflection profiles on continuous reflection traverses before selecting sites for expanded reflection spreads. However, in places poor drilling conditions or initial poor-quality results dictated moves to other locations in the same general survey areas to attempt to obtain better progress and results. On some traverses it was expedient to move shot-points and keep spreads in the same position and on others to move spreads and keep shot-points in the same position where initially drilling conditions were good. In some areas additional traverses or single spreads were shot to obtain additional sampling.

Reflection traverses at *Fraser Range* were shot on the northwest, southwest, and over the Fraser Fault. Continuous and offset reflection profiles were recorded using relatively small charges compared with charges used later in the survey. Because of the poor quality of the reflection results no site was selected for a large-scale expanded reflection spread for velocity information. Air drilling was generally used, and drilling conditions varied considerably from slow in granites and granulites to fast in unconsolidated weathered sediments. In some places where long charges were used, they extended from consolidated rocks into the weathered zone, resulting in a decrease in seismic energy efficiency compared with that from charges wholly within consolidated rocks. Surface noise, high-frequency noise, diffractions, and steeply dipping probable reflection events over only a few traces were recorded in the geologically complex area near the Fraser Fault.

Reflection traverses at *Widgiemooltha* were located mainly on greenstones and rocks of low metamorphic grade except for the northern part of Traverse K which was on Lake Lefroy, a salt lake with water channels only alongside a causeway crossing the lake. Damage to roads by drilling rigs and other survey vehicles caused abandonment of plans to complete an expanded reflection spread on Traverse G. Traverse H was shot at right angles to Traverse J in an attempt to record dip information for reflectors at great depths. Drilling was variable in the survey area. In places it was very slow, drilling through gravel beds and sections of loose running sand, and in others it was fast with the Mayhew drilling rigs achieving a rate of about 600 m per day. Ninefold CDP coverage was recorded on Traverse K using 4.5-kg Geophex charges shot in water channels alongside the causeway over Lake Lefroy.

Energy penetration was generally poor in the *Widgiemooltha* area and it was decided that wherever possible large charges would be used for reflection shots in the remaining survey areas. An analysis of the explosives availability for the survey indicated that charges of up to 4500 kg of Geophex per shot would be available for most shots in the other areas. Geophex and ammonium nitrate were used to make up the charges, but all references in the text are given in terms of Geophex equivalents; 8 kg of ammonium nitrate is considered to be equivalent to 5 kg of Geophex for seismic purposes.

In the *Boorabbin* area, considered to be an 'average shield area' with high-grade metamorphics, isolated monoliths of granite, and granite gneisses, all shots were made with large charges of 2300 to 4300 kg of Geophex. Drilling was generally poor in areas with hard bands and decomposed granite, and large numbers of holes were required to accommodate the charges. An expanded spread was shot on Traverse L, a north-south traverse in the southern part of the survey area, and an expanded spread and continuous reflection traverse were shot on Traverse N along the Geotraverse. Single spreads were recorded on Traverse O, a cross-spread on Traverse N and on Traverse P located east

TABLE 1. RECORDINGS — SEISMIC REFLECTION SURVEY

Area	*Traverse*	*Plate No.*	*Program*	*Comments*
Fraser Range	A	Experimental	Geo. spacing comparison	Traces 1-12, 13-24 parallel; 48 geophones/trace @ 2 m & 6 m. Noise cancellation better with longer spacing ne = 288 m.
	A	Experimental	Geo. no/trace comparison	Traces 1-12, 80 geophones/trace in 5 rows of 16 @ 6 m; traces 13-24, 16 @ 6 m. No improvement with longer group.
	A	Experimental	Geo. pattern length comparison	Traces 1-12, 48 geophones/trace @ 6 m; traces 13-24, 48 geophones/trace in 2 rows of 24 @ 6 m. No difference with longer group.
	A	Experimental	Geo. frequency comparison	Traces 1-12, 48 geophones, 14 Hz/trace in 2 rows of 24 @ 6 m; traces 13-24, 8 geophones, 4.5 Hz/trace @ 6 m. Ground roll cancellation with 14-Hz geophones.
	A	Experimental	Charge size comparison	Common spread; charge 7272 kg c.f. 1526 kg. Large charge, better penetration but small charge less noisy.

Area	*Traverse*	*Plate No.*	*Program*	*Type of Spreads*			*No. of Shots*	*Max. Subsurface Coverage (km)*	*Max. Shot-Geophone Offset (km)*	*Comments*
				Split	*Offset*	*CDP*				
Fraser Range	A	6	Continuous coverage	1	4		5	9.72	16.20	Variable air drilling at Fraser Range
	A	6	Continuous coverage	5			5	10.80	2.16	Max. charge at SP505
	C	7	Continuous coverage	2			2	4.32	2.16	Small charges
	D	8	Continuous coverage	1	1		2	4.32	6.48	Shallow holes in granite, granulite
	E	9	Continuous coverage	2			2	4.32	2.16	Good drilling
	F	10	Continuous coverage		4		5	5.94	11.88	Shot also for velocity determination, one record unusable
Widgiemooltha	G	11	Continuous coverage		3		3	6.48	12.96	Shot also for velocity determination
	G	11	Continuous coverage	4			4	8.64	2.16	
	H	12	Continuous coverage		5		5	10.80	4.32	Off-end shots, in greenstones
	J	13	Continuous coverage		3		3	6.48	4.32	Cross-traverse on Traverse H, off-end shots
	K	14	Continuous coverage		5		5	11.88	23.76	Shot also for velocity determination
	K	15/16	Continuous coverage			9 fold	10	4.32	4.32	Common spread, shots in water channels in Lake Lefroy for CDP.
	K	16	Continuous coverage		2		2	4.32	4.32	Common spread, off-end shots
Boorabbin	L	17	Expanded spread	1	2		3	2.16	6.48	Common subsurface, drilling in decomposed granite difficult
	N	18	Continuous coverage	2	1		3	6.48	6.48	
	N	19	Expanded spread	1	4		5	2.16	15.12	Common subsurface, centre shot common to profiling, difficult drilling
	O	20	Continuous coverage		1		1	2.16	4.32	Cross-spread on Traverse N, charge below water-table, recorded at Meekatharra
	P	21	Continuous coverage	1			1	2.16	2.16	Reflection quality test
Hines Hill	Q	—	Continuous coverage		3		3	6.48	6.48	Charges at Hines Hill below water-table, power line pick-up on all records
	Q	22	Continuous coverage	4			4	8.64	2.16	
	Q	23	Expanded spread		6		7	2.16	15.12	Common subsurface, centre shot common to profiling, one reshoot
	R	24	Continuous coverage	2	1		3	6.48	6.48	
	S	25	Continuous coverage	1	2		4	6.48	6.48	Same shotpoint, different spread, one reshoot
Wundowie	U	26	Continuous coverage	1	2		3	6.48	6.48	Same spread, different S.P., access for drills easier than for spread

of the main traverses near an Upper Mantle Project borehole, for heat flow measurements, at Woolgangi.

Energy penetration in the *Boorabbin* area was generally good for shots below the water-table. Some ground roll and high-frequency noise were recorded for the large charges but these were not a major problem.

At *Hines Hill*, traverses were recorded on road reserves, with the northernmost traverse located near an Upper Mantle Project borehole at Doodlakine. Drilling was variable with hard bands in some areas and sticky clay in others. Charge sizes were reduced to a maximum of 2270 kg of Geophex and care was taken to prevent damage to nearby houses and public utilities.

Energy penetration was good for charges located below the water-table but power line pick-up was particularly bad and is present on most records despite efforts made in the field to eliminate the interference.

A single traverse, with three spreads, was shot at *Wundowie* east of the shield boundary. The reflection traverse was located on a short straight section of road reserve in a timbered, hilly area of granites and high-grade metamorphic rocks. Drilling was slow in areas of loose gravels and sticky clay.

Geotraverse reflection data processing

Magnetic tapes were played back in the field mainly for quality control of recordings made on the survey. Magnetic tapes were processed in the BMR analogue playback centre in Canberra where seismic reflection sections were produced for analysis and interpretation. Reflection sections were reduced photographically to 35 mm negatives for processing on the BMR LaserScan optical data processing system. Magnetic tapes from reflection traverses and expanded spreads were digitally processed under contract by Western Geophysical Company in Sydney.

Field playbacks Magnetic tapes recorded in the field were played back to produce oscillograph records at the same scale as original reflection records to check that the quality of information recorded on the magnetic tapes was equivalent to that of the monitor seismic records. Records were also produced from the magnetic tapes with reduced time scale, a number of different filter-passbands, different AGC actions, and in variable area display mode. No weathering, elevation, or normal moveout corrections were applied as it was considered that in most cases the corrections for deep reflections would be relatively insignificant. Records were assembled in the field to provide continuous subsurface coverage sections as an aid to planning survey operations and as a guide to further analogue and digital processing.

Analogue processing Direct recorded field magnetic tapes were transcribed to produce FM transfer tapes for analogue and digital processing. Field magnetic tapes, containing 24s of seismic information recorded on the DS7-7 at 3¾in/s, were played back on the DS7-7 at a speed of 7½ in/s and recorded on the MS-42 analogue playback system operating with a drum speed of 3¾ in/s instead of the normal drum speed of 7½ in/s. Thus the 24 s of field information was transcribed onto tapes which normally store 6 s of data.

Analogue data processing on the MS-42 equipment was limited to the production of record sections in variable area mode with application of filters, different AGC actions, and mixing. The filters, which were found to give the most significant improvement in the quality of the data, had a passband of 12 to 25 Hz with slopes of 18 and 36 dB/octave respectively for the low and high sides. With this filter, however, probable reflection events in the early part of the section were slightly attenuated and the numbers of cycles or 'legs' of most probable reflection events were increased. Mixing more than eight traces destroyed the character of probable reflections and severely attenuated dipping events. The best analogue record sections produced for the reflection coverage and the expanded reflection spreads are included in Plates 6 to 26 which also show processing parameters used.

The *LaserScan* optical data processing system was used to obtain information on the frequency content of the seismic data recorded on most analogue processed sections, and to assess the frequency and velocity filtering parameters for later application in digital processing. Because of the general low signal-to-noise ratio of probable reflection events on the record sections, no distinctive LaserScan two-dimensional frequency transforms were obtained; thus attempts at frequency and velocity filtering were made on a trial-and-error basis. Frequency filtering tests confirmed that a high-frequency cut-off of 25 Hz was most effective and velocity filtering tests indicated an improvement in the quality of the probable reflection events by using wedges to attenuate events dipping at greater than −8 to +8 ms over three traces. Steeply dipping events were significantly attenuated and events with low dips were relatively enhanced.

Digital processing Parameters used by the Western Geophysical Company for processing the reflection information are shown in Plates 6 to 26, together with the best processed sections. A flow chart indicating the main digital processes used is shown in Plate 27. The main processing techniques used were designed using information obtained from the preliminary MS-42 system and LaserScan analogue processing.

The analogue information on the FM magnetic tapes was converted to digital information at an apparent 2 ms sampling rate; this was equivalent to sampling the original data at 8 ms, for which the Nyquist frequency is 62.5 Hz. The anti-alias filter used in the processing was considerably lower at 35 Hz.

In the editing process, operators computed from the amplitude envelope of the probable reflection signal were applied to equalize the overall amplitudes of all traces. Auto-correlations of selected representative traces were computed mainly to determine a suitable length for a deconvolution operator; a short operator of length 0.5 s was selected. A second-zero-crossing Weiner-Levinson Least-Squares minimum-phase predictive type deconvolution process, proprietary to the Western Geophysical Company, was applied. The first full cycle of each reflection event was retained and later cycles were severely attenuated. The resolution of probable reflection events was generally improved by the deconvolution process. Further auto-correlations were made after deconvolution to check the effectiveness of the processing.

Normal moveout corrections applied were based on velocity information derived from the analyses of refraction data in the east-west part of the Geotraverse.

The time-variant filtering was done using a zero-phase bandpass filter computed from the average power spectra of selected traces over particular time-gates. The power spectra obtained in tests made in the survey areas are shown in Plate 28, and the frequency bandwidths at the 3 dB-down points are shown in Plate 29. The minimum frequency of the time-variant filter was 8 Hz, with an 18 dB/octave slope, and the maximum was 26 Hz, with a 36 dB/octave slope. An undesirable feature of using the narrow bandpass filter was the cancellation of some of the improvement achieved by deconvolution process.

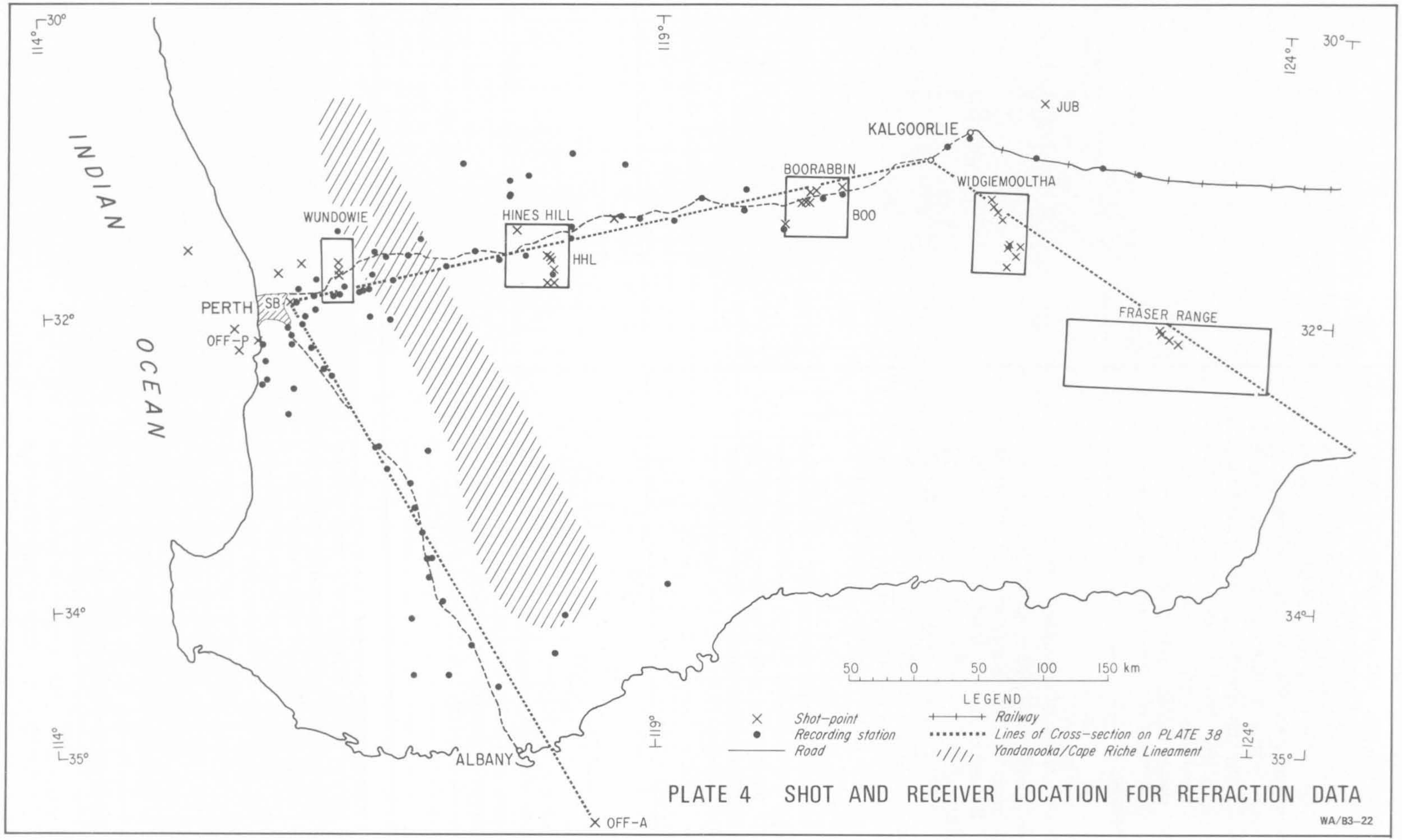


PLATE 4 SHOT AND RECEIVER LOCATION FOR REFRACTION DATA

Power filtering was applied to increase the level of the possible reflection events. This process computes an average power trace from a given number of preceding input traces and multiplies the last input trace of this group by the average energy trace, sample by sample. A disturbing effect of this multi-channel operation was that all coherent events, including the noise, were extended (smeared) over a greater number of traces than before processing.

The radial predictive filtering (velocity filtering), which is also a multi-channel process, was applied to attenuate all coherent events outside a specified apparent velocity limit. Various tests were made with filters to attenuate seismic information and coherent noise with apparent dips outside a range up to ±15 ms over three traces. The best quality digitally processed sections were produced using a filter which attenuated events dipping outside the range ±5 ms over three traces; c.f. ±8 ms over three traces in the LaserScan processing.

Analysis and interpretation of Geotraverse reflection data

Analogue and digitally processed reflection sections from the five survey areas on the Geotraverse are shown in Plates 6 to 26. Reflection power spectra and reflection frequency bandwidths for particular time-gates on representative traces from recordings in each survey area are shown in Plates 28 and 29. Histograms showing the number of probable reflection events picked within 0.4 s time-gates over 24 trace records in all survey areas, except Wundowie, are shown in Plate 32.

The power spectra curves indicate that the frequency of the seismic energy recorded from 2 to 16 s, measured at the 3-dB-down points, lies broadly in the frequency range of 7 to 37 Hz with the seismic energy in most areas concentrated in the range from 10 to approximately 25 Hz. Analysis of the power spectra information assisted in selecting the 8 to 26 Hz passband of the time-variant filter. The apparent peak frequency of the seismic events is in the range 16 to 20 Hz which agrees with that found in eastern Australia (Branson et al., 1976) and elsewhere in the world by Davydova et al. (1970) and others. A considerable amount of energy was recorded with frequencies below 14 Hz. Energy in this region will have been considerably attenuated using the 14-Hz geophones and 14-Hz low-cut recording filter. The signal-to-noise ratios of probable reflection events on the analogue sections are generally low. Events are of very low relative amplitude and in a few records may be picked only from repetition of events over a few traces. Digital processing increased the relative amplitude of probable reflection events and generally improved the continuity of the events. An adverse effect of the power and velocity filtering is the enhancement of some noise events by increasing their amplitudes and smearing them over a greater number of traces than before processing. Probable reflection events generally lack continuity over more than a few traces and are recorded with many phases or legs as found elsewhere. It is, however, possible to correlate bands of reflections on some sections.

The quality of probable reflection events varies considerably on different records on the same traverses, from traverse to traverse in the same survey area, and from survey area to survey area. Attempts to obtain velocity information from expanded spreads were unsuccessful because of the poor quality of results. Thus the lack of any distinctive reflection character and lack of definitive vertical velocity information makes it impossible to use these methods to correlate probable reflection events from one area to another to define the deep crustal and upper mantle structure along the Geotraverse.

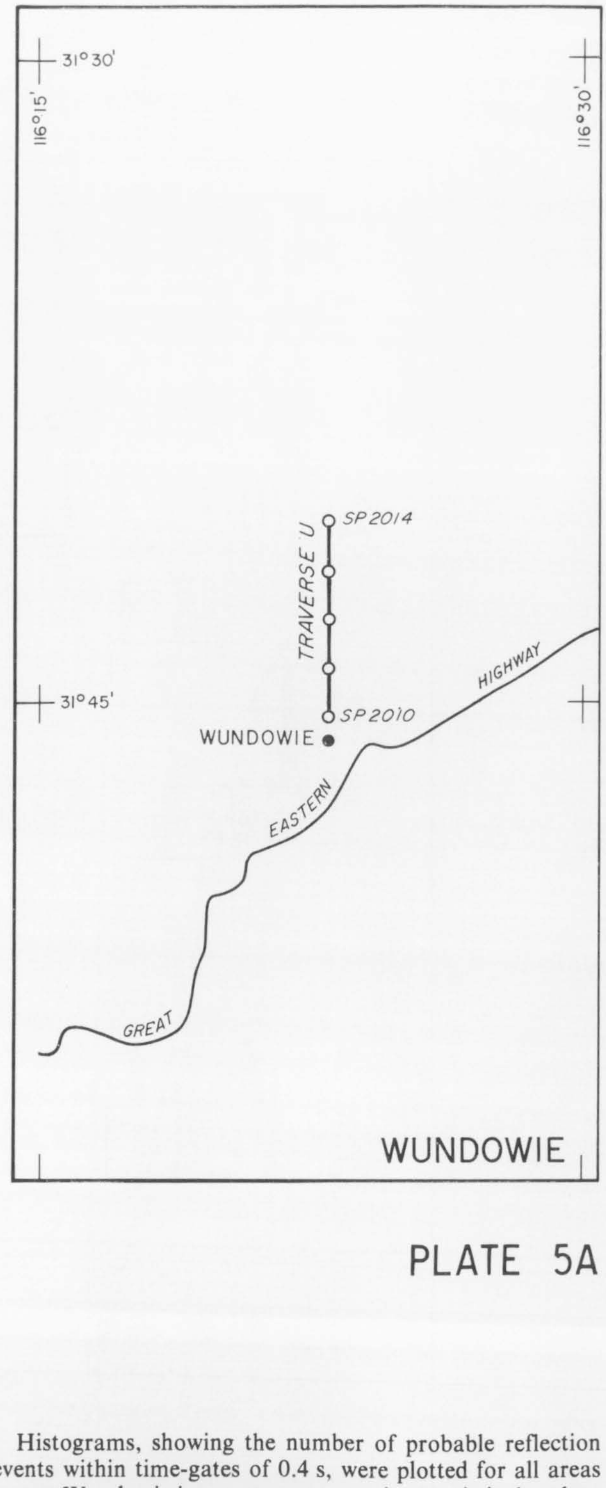
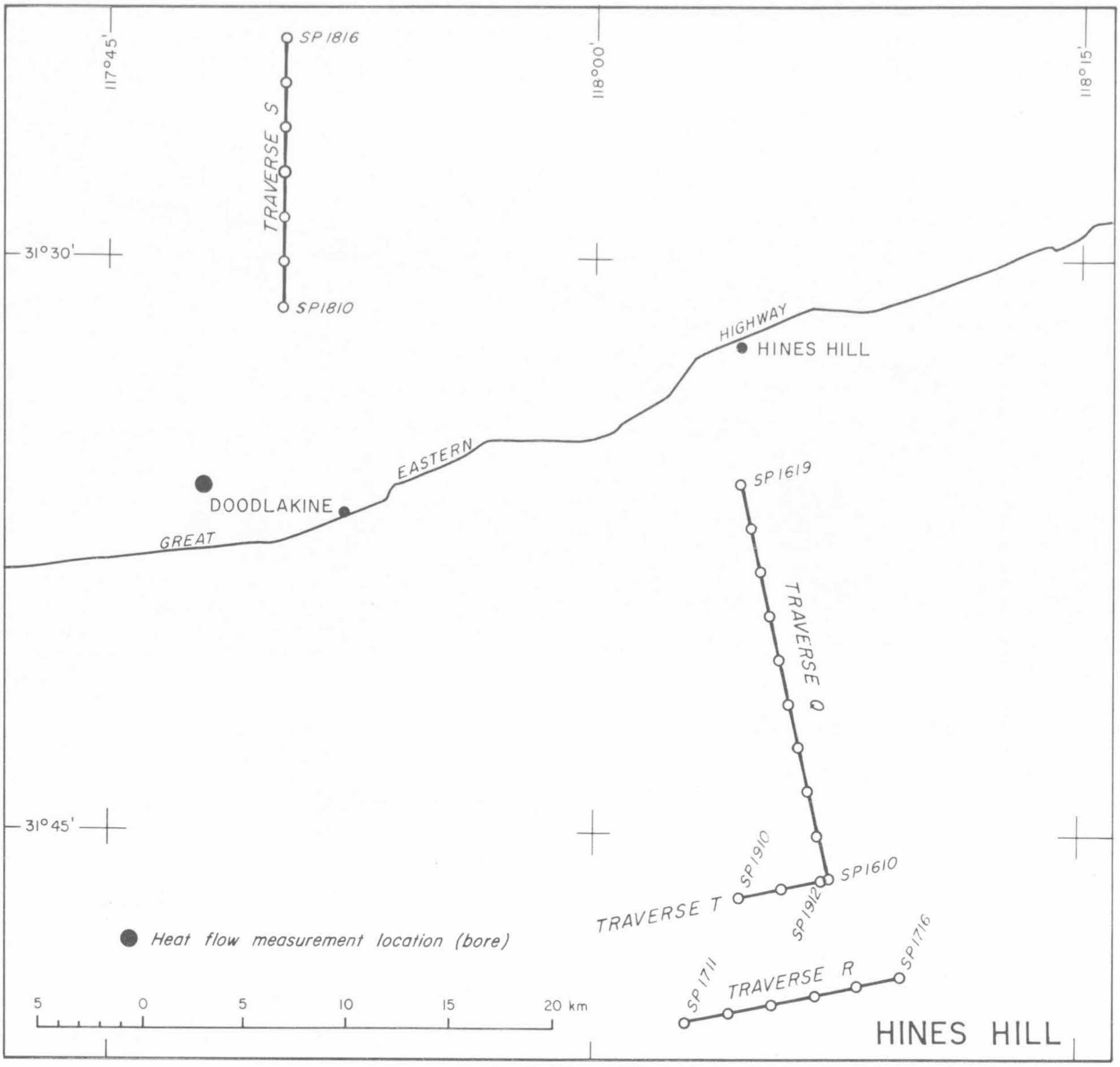


PLATE 5A

Histograms, showing the number of probable reflection events within time-gates of 0.4 s, were plotted for all areas except Wundowie in an attempt to apply a statistical evaluation of the data similar to that made in Germany by Dohr & Fuchs (1967). Probable reflection events were picked independently on analogue and digital sections. The histograms of the events picked from the analogue and digital sections are generally different except for those at Hines Hill and Boorabbin where the signal-to-noise ratio is generally higher than elsewhere on the Geotraverse. The histograms from the different survey areas all show distinctive patterns which have been analysed and are discussed later in this report in relation to the results of the refraction investigation on the Geotraverse.

Although the reflection information was not sufficient for an independent interpretation along the Geotraverse, it was



LOCATIONS OF REFLECTION TRAVERSES

used together with the results of the refraction work, and the reconnaissance gravity information to provide an integrated geophysical interpretation of the deep crustal and upper mantle structure.

SEISMIC REFRACTION RESULTS AND INTERPRETATION

Refraction data interpreted here were obtained from recordings made on the Geotraverse concurrently with the reflection survey (Gregson & Paull, 1971) and recordings made earlier from both land and marine explosions (Gregson & Woad, 1968; and Everingham, 1969 and 1970). The shots were fired at the three probe locations along the east-west part of the Geotraverse, in the offshore Perth (OFF-P) and offshore Albany (OFF-A) areas and recorded in a general east-west direction along the Geotraverse and in a general southeast-northwest direction along a line between Perth and Albany.

Shot and recording positions for the refraction surveys are shown in Plate 4. The shot locations form six groups about offshore Perth (OFF-P), shield boundary near Perth (SB), Hines Hill (HHL), Boorabbin (BOO), Jubilee Mine near Kalgoorlie (JUB), and offshore Albany (OFF-A). The travel time data from the shots recorded in the two directions are plotted in Plates 30 and 31 as continuous profiles centred on the above-mentioned group locations. In all cases the travel-times are plotted for the actual distances from individual shots and therefore the interpretation represents the generalized crustal and upper mantle structure along the traverses.

The equations for the travel-time segments were determined from first and later arrivals, using the method of

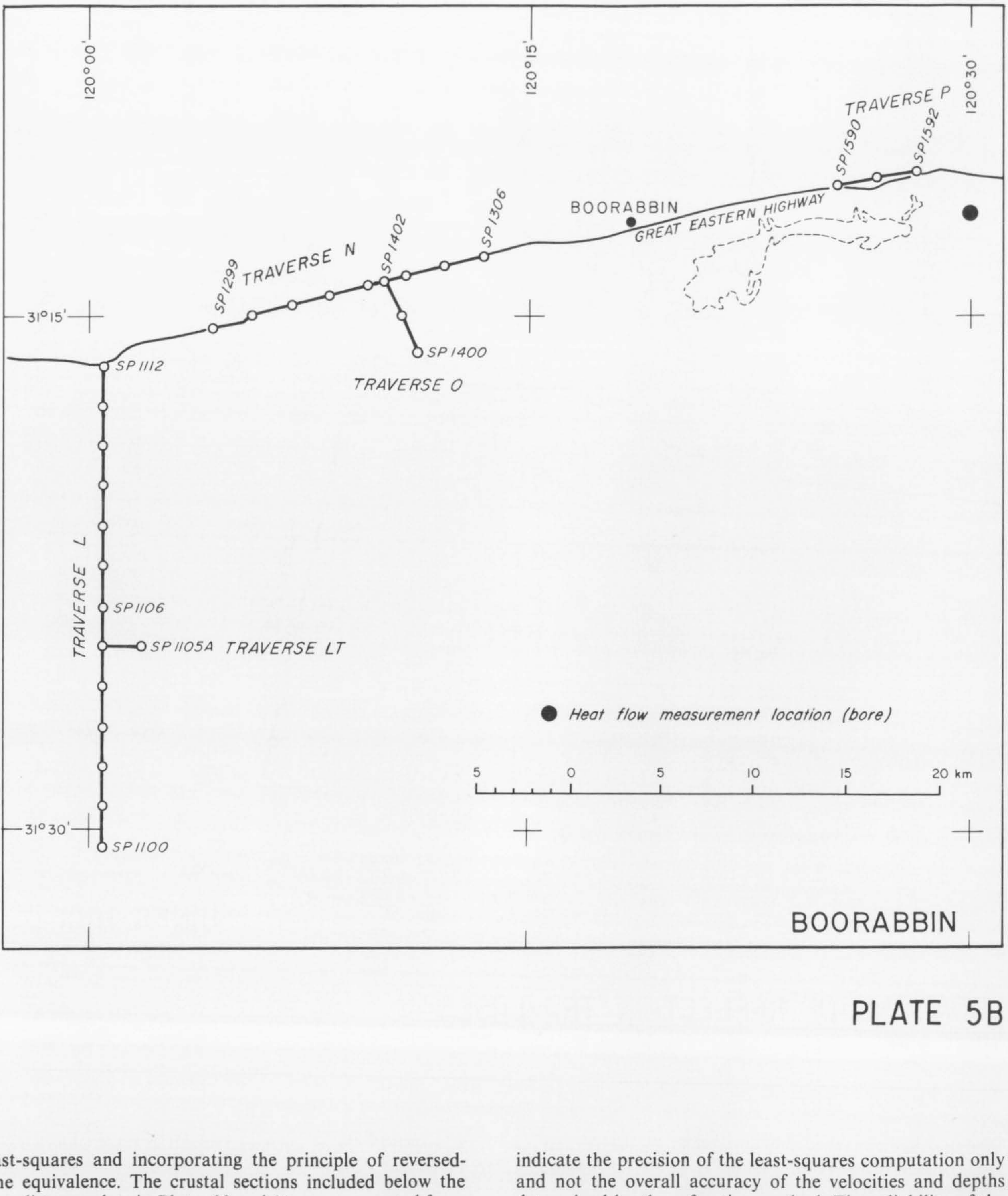
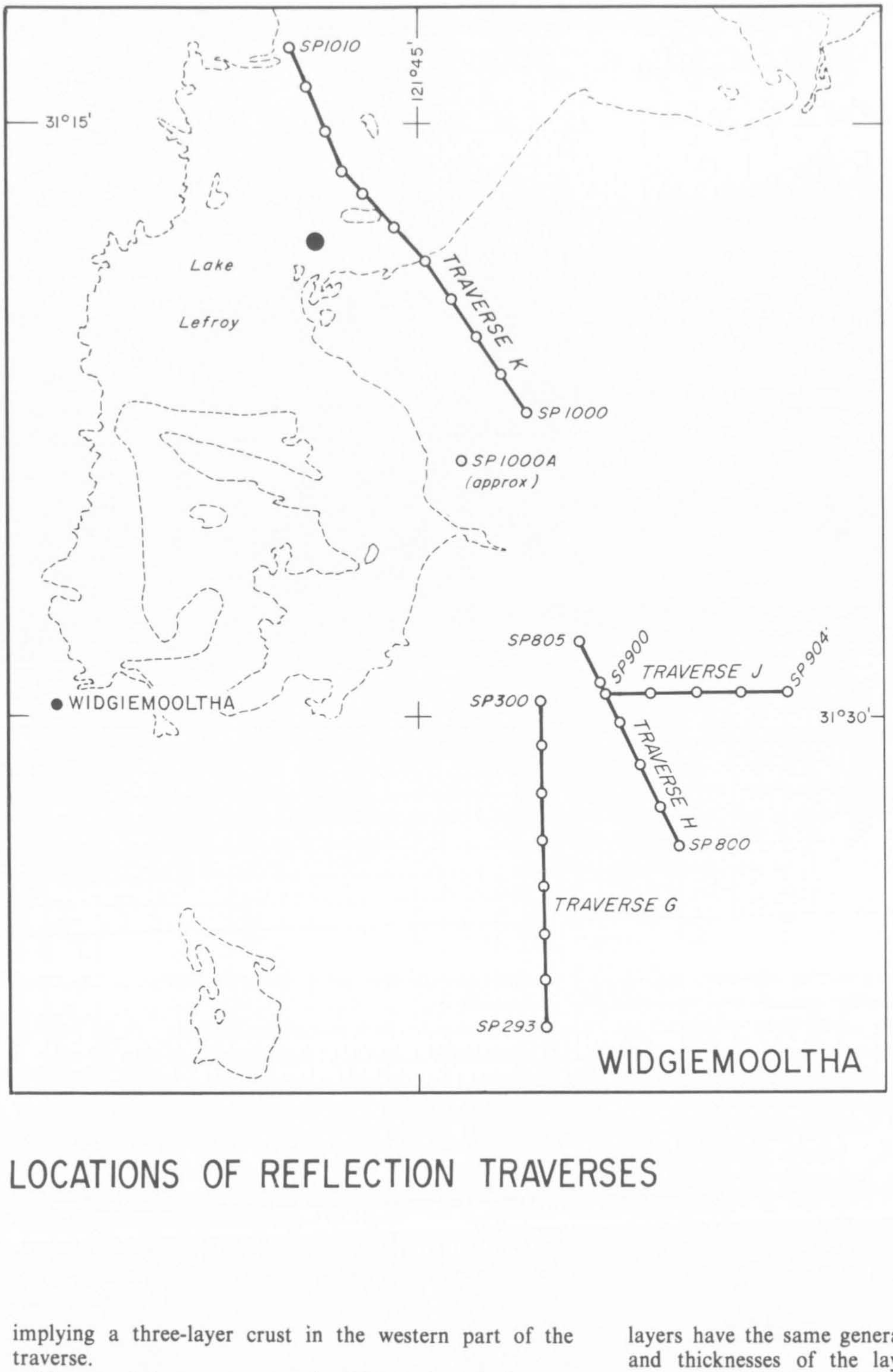


PLATE 5B

least-squares and incorporating the principle of reversed-time equivalence. The crustal sections included below the time-distance plots in Plates 30 and 31 were computed from the apparent velocities and time-intercepts for each layer using formulae for uniform plane-dipping layers (Dooley, 1952). The correlations of second and later arrivals on which many of the line segments are based are of varying degrees of reliability. In Plates 30 and 31 thick lines indicate the interfaces where the data are considered to be reliable, thin lines where the data are poor, and broken lines where the interfaces are inferred. No corrections to the computed velocities and depths to account for the curvature of the Earth, as suggested by Mereu (1967), have been made as the corrections are estimated to be less than 1 percent for the traverse lengths involved. The time, velocity, and depth values shown to two decimal places in the following pages indicate the precision of the least-squares computation only and not the overall accuracy of the velocities and depths determined by the refraction method. The reliability of the method depends on basic assumptions of homogeneity of the crustal layers, absence of velocity inversions in the crust, and correct identifications of the refracted phases. Woollard (1959) estimated that depths computed from refraction surveys generally are accurate to approximately ± 10 percent.

Perth-Jubilee Mine refraction traverse The analysis of the travel-time data shown in Plate 30 was difficult because of irregular spacing of the recording stations, unsufficient lengths of some traverses, clusters of refracted arrivals, and the presence of the Darling Fault near Perth. The BOO (W) profile only shows clear line-ups of data points which can be interpreted unambiguously into four velocity segments



LOCATIONS OF REFLECTION TRAVERSES

implying a three-layer crust in the western part of the traverse.

The travel-time curves for the OFF-P shots indicate a time displacement attributable to the Darling Fault. The refraction information near the shots is interpreted to obtain three velocity segments implying two main sedimentary layers overlying basement in the Perth Basin, and the refraction information recorded on the shield is interpreted to obtain four velocity segments implying three crustal layers east of the Darling Fault. Although no data are available from which the westward velocities of the sedimentary layers in the Perth Basin can be obtained, approximate determinations of their true velocities, dips, and thicknesses were made by assuming that the eastward velocity of 5.65 km/s is the apparent velocity of the first crustal layer in the shield area, and that the sedimentary layers have the same general eastward dip. The velocities and thicknesses of the layer computed are in general agreement with those obtained by Hawkins et al. (1965) in the offshore area of the Perth Basin. Reversed profiles SB (E) and BOO (W) were analysed using the principle of reversed-time equivalence. The former refraction plots were interpreted to give three velocity segments of eastward velocities for the three crustal layers. The refraction arrivals from the mantle boundary were insufficient for an accurate determination of the mantle velocity. The eastward mantle velocity of 8.37 km/s, obtained from the OFF-P travel-time curves, was assumed to be the same for the SB (E) profile because the travel paths along the boundary should be the same in both cases.

If straight lines, parallel to the SB (E) and BOO (W) velocity segments, are drawn through the HHL (E) and

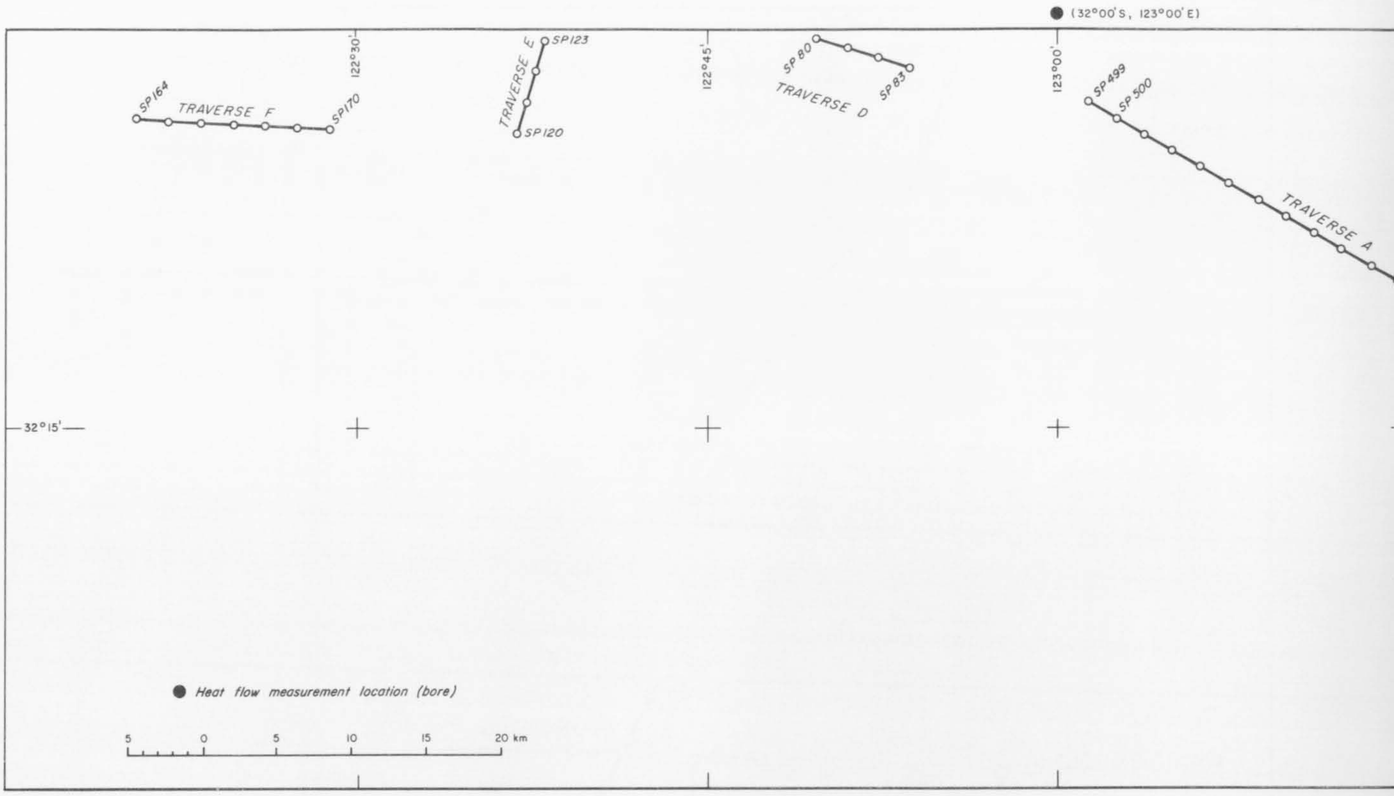


PLATE 5C

HHL (W) data, for which the travel-time equations are not given in Plate 30, the plotted points fall on these lines and the time-intercepts for each layer at SB, HHL, and BOO are collinear. Thus although of poor quality, the refraction data from the HHL shots support the analysis of information from the SB (E) and BOO (W) reversed profiles.

The sparse travel-time data from the BOO (E) and JUB (W) shots are insufficient for a reliable analysis of the crustal structure in this area but yield an approximate solution. The travel-time curves are interpreted to obtain three velocity segments indicating a two-layer crust overlying the mantle with an assumed velocity of 8.39 km/s as calculated in the western part of the traverse. The basal crustal layer pinches out or becomes negligibly thin east of Boorabbin.

The clusters of data points are due mainly to the locations of recording stations near the critical recording distances for the various layers. The interpretation of a third crustal layer depends mainly on the analysis of later arrival times.

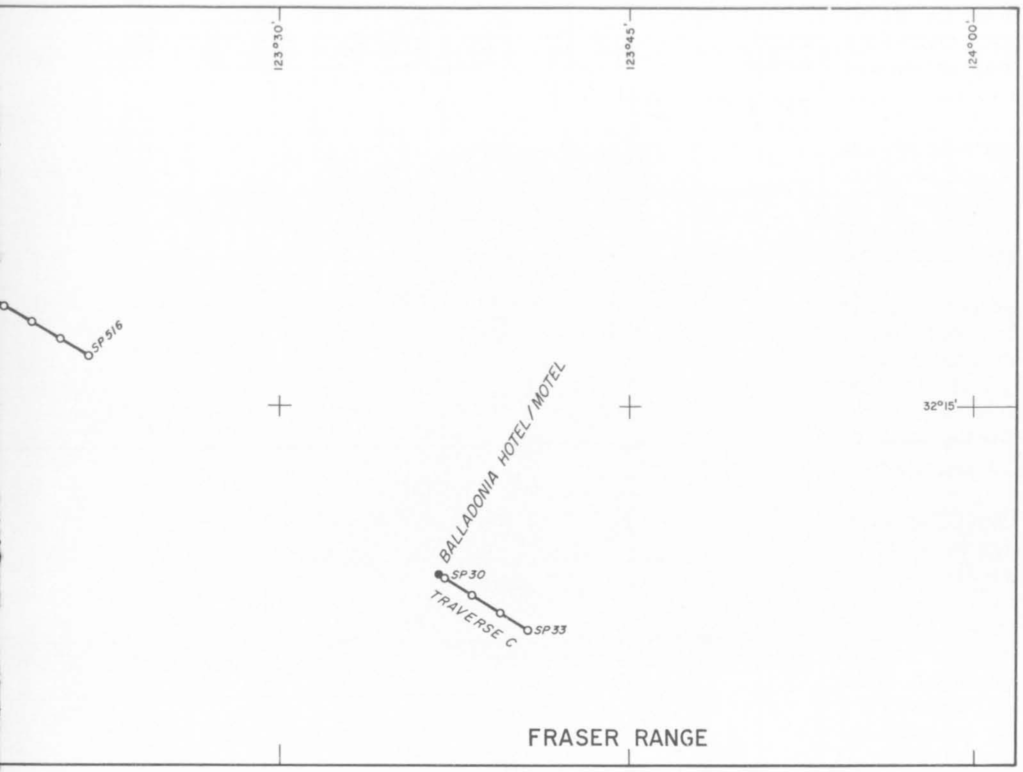
Correlation of refraction and reflection information on the Geotraverse

The better-quality digitally processed reflection sections recorded in the five areas along the Geotraverse are shown in Plate 33*. They are superimposed on a time crustal structure model based on the refraction interpretation along the east-

TABLE 2. REFLECTION COEFFICIENTS AT BOUNDARIES OF CRUSTAL LAYERS AND UPPER MANTLE

	Average Velocity (km/s)	Model 1		Model 2	
		Density (g/cm^3)	Reflection Coefficient	Density (g/cm^3)	Reflection Coefficient
Crustal layer 1	6.12	2.78		2.78	
			0.066		0.071
Crustal layer 2	6.66	2.91		2.94	
			0.075		0.080
Crustal layer 3	7.42	3.04		3.10	
			0.094		0.106
Mantle	8.25	3.30		3.45	

*Inside back cover.



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west part of the Geotraverse, and an extrapolation along the southeast-northwest part of the Geotraverse including a proposed reversed throw of 2 km along the Fraser Fault. No refraction information in the southeast-northwest part is available to provide a direct constraint on the proposed model. The apparent reflection times for the crustal boundaries have been calculated from the refraction depths using refraction velocities in the absence of reflection velocity information. The confidence limits shown on the reflection times indicate the reliability of the refraction depths. On the sections at Wundowie, Hines Hill, and Boorabbin, zones of fair-quality reflections can be identified corresponding to the refracting horizons. At Widgiemooltha and Fraser Range, such identification is questionable.

A more quantitative correlation between refraction and reflection information becomes evident if the apparent reflection times from the crustal layer 2, C2, the crustal layer 3, C3, and the Moho, M, are plotted on the histograms in Plate 32. At Hines Hill and Boorabbin, the apparent reflection times for C2 and M show excellent agreement with major peaks on the histograms, especially for analogue events, whereas the times for C3 agree only fairly with minor peaks between C2 and M. At Widgiemooltha, the apparent reflection times for C2 and M are in fair agreement with peaks in histograms, but the time for C3 correlates with the broad band of events close to the reflection time for M. At

TABLE 3. COMPARISONS OF VELOCITIES AND DEPTHS NEAR PERTH.

	Velocity (km/s)			Depth (km)		
	E-W	SE-NW	Diff	E-W	SE-NW	Diff
Crustal layer 1	6.13	6.11	.01	0	0	0
Crustal layer 2	6.72	6.60	.12	6.94	7.95	1.01
Crustal layer 3	7.49	7.34	.15	13.26	16.24	2.98
Mantle	8.39	8.11	.28	45.00	43.60	1.40

Fraser Range, however, only the apparent times from the proposed depths of M are in agreement with the histograms which show an almost even distribution of events between 4 and 16 s owing to low signal-to-noise ratio of the reflected events and the small number of record sections available for sampling.

Assuming that the reflecting interfaces are simple and that the refraction velocities are a reasonable estimate of the reflection velocities, probable reflection coefficients at the tops of the crustal layers 2 and 3 and at the Moho were calculated using these velocities, and the densities estimated from the gravity data (see Table 2). The estimates of the probable reflection coefficients are very low compared with those normally expected for reflections from sedimentary formations. The coefficients at the tops of the crustal layer 2 and 3 are similar and that at the Moho is about 20 percent greater. This relatively higher value for the coefficient at the Moho is therefore probably responsible for the generally greater number of analogue events seen in the histograms at about the reflection times for the Moho.

Additional peaks at about 2-3 s earlier than C2 apparent reflection times and at about 5 s later than M reflection times are also apparent, though not always well-defined, on the analogue reflection histograms at Hines Hill, Boorabbin, and Widgiemooltha. The former peak may indicate a shallow crustal layer about 6 to 9 km above the base of crustal layer 1, assuming 6.10 km/s average velocity in the top layer, and the latter may indicate a layer about 21 km below the Moho assuming 8.39 km/s average velocity in the upper mantle. Low-velocity reversals in the shallow part of the crust have been recognized in eastern Australia by Branson et al. (1976) and elsewhere, and sub-Moho layering has been recognized in eastern Australia and also in U.S.A. (Woollard, 1970). The reflection data for the histograms at Fraser Range are not considered reliable for any further interpretation.

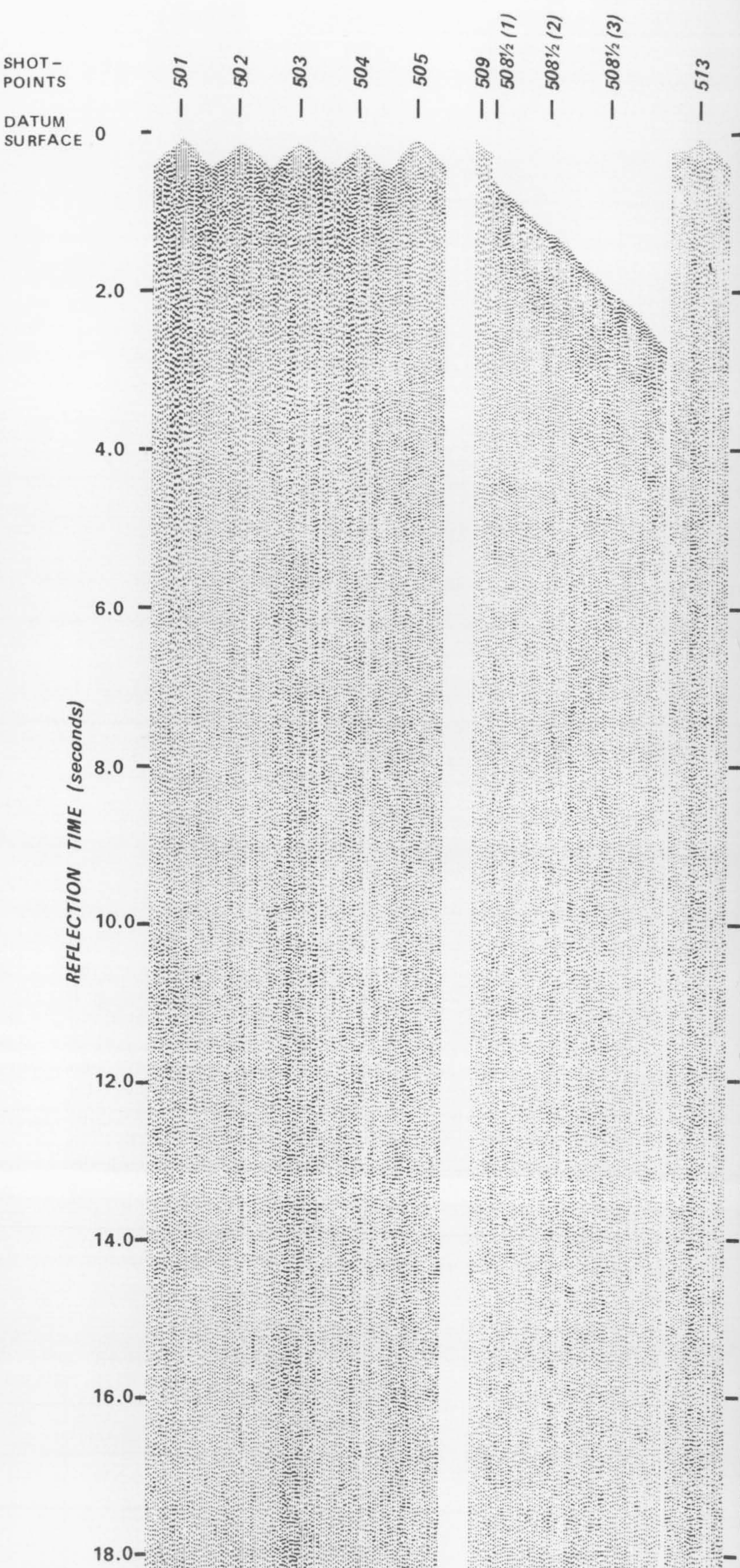
Perth-Albany refraction traverse

Three sets of travel-time curves in the southeast-northwest direction, across the southwestern part of the shield, are shown in Plate 31. In the OFF-P (SE) curve, there are large variations in the travel-times from the shots to recording stations close by. No corrections were made in the OFF-A (NW) curves to account for increased delay times due to travel paths in the sedimentary section offshore from Albany because of lack of information on depths and velocities of the sediments. Despite these sources of error, the data from the SB (SE) and OFF-A (NW) reversed profiles are interpreted to imply a three-layer crust, and the OFF-P (SE) curves give southeast velocities similar to those obtained from the SB (SE) travel-time curves.

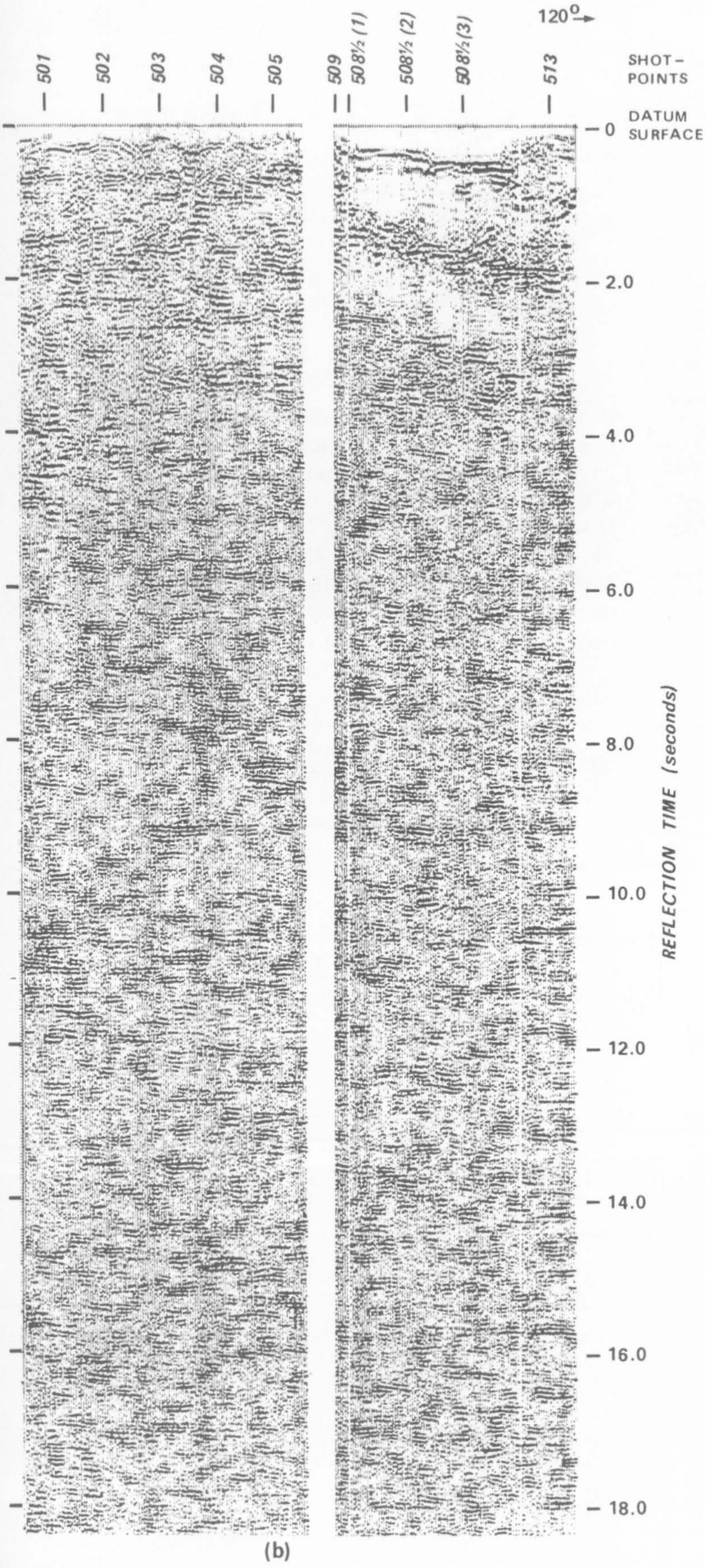
The crustal section for the Perth-Albany traverse is included below the time-distance curves in Plate 31. The thickness of the uppermost crustal layer in the OFF-A area is computed to be about 2.5 km greater than its thickness in the eastern part of the shield. Although there is no evidence of sediments in the area of the offshore explosions, it is proposed that sediments do exist and are responsible for the greater calculated thickness of the uppermost crustal layer. One kilometre of unconsolidated sediments would produce time delays sufficient to account for the excess thickness of the layer computed. The calculated thickness of the crust at the coast near Albany, however, may not be correct as the assumption of plane-dipping surfaces implied in the formulae would not hold if the rise in the mantle is steeper in the coastal area than farther inland.

Discussion of refraction results

The analysis of the refraction results on the Perth-Jubilee Mine traverse indicates that the crust is about 34 km thick



(a)



(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : –6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart. Geophones 6 m apart
Shot–hole pattern :
6 – 30 holes in rows of 10 in line
Rows 30 m apart. Holes 15 – 42 m apart
Depth 6 – 50 m. Charge 773 – 7272 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

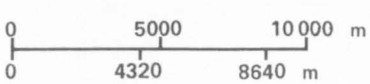
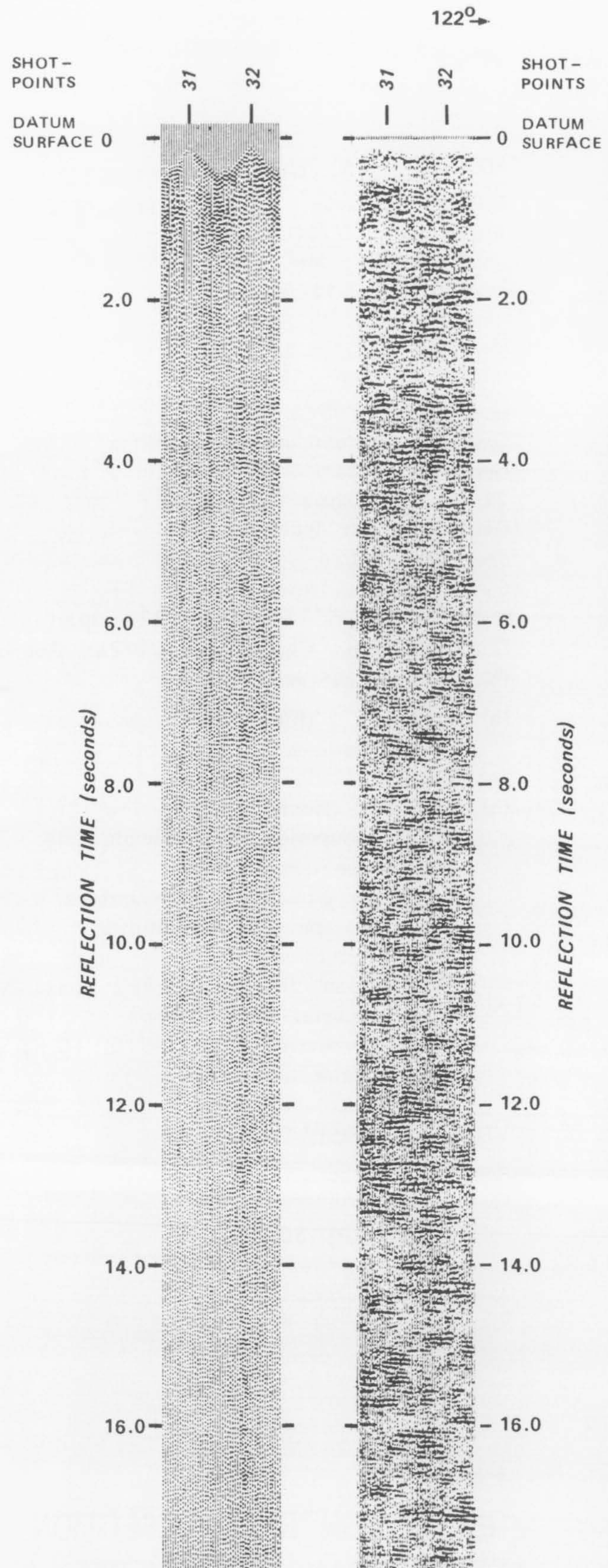


PLATE 6
REFLECTION RECORD SECTION, FRASER RANGE, TRAVERSE A

WA/B3–35



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
10 – 21 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 5 – 21 m. Charge varied

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

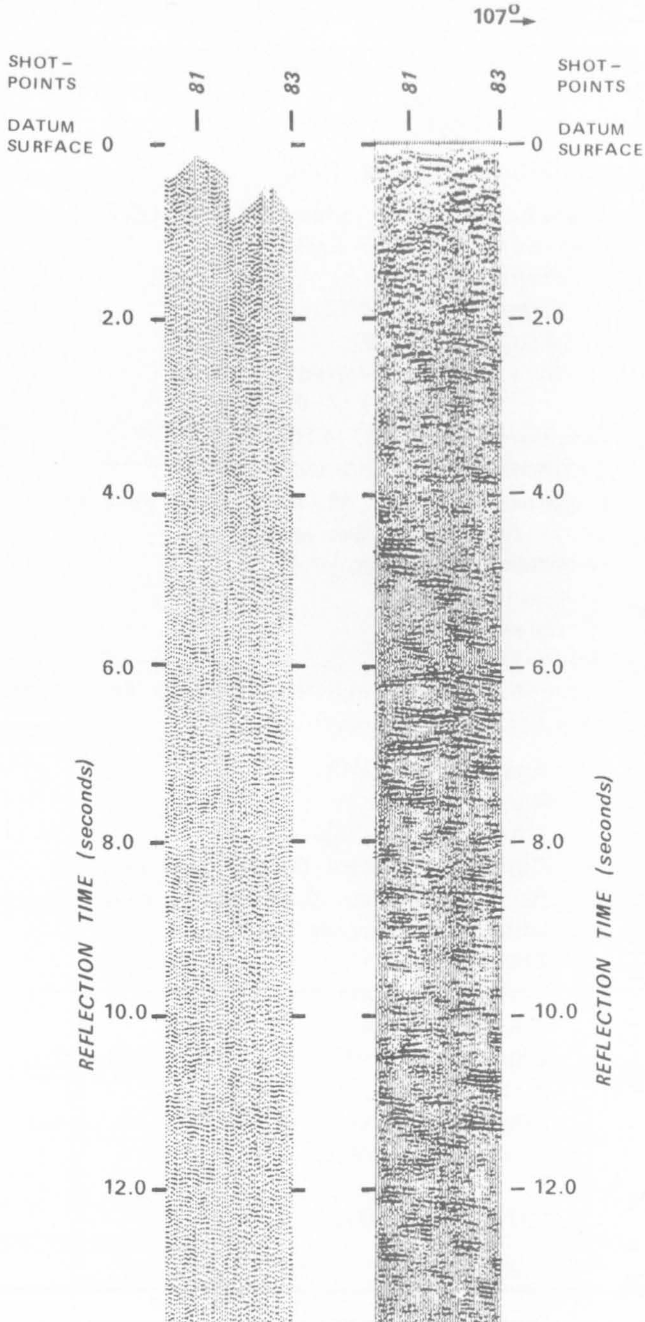
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 7
REFLECTION RECORD SECTION, FRASER RANGE, TRAVERSE C

WA/B3–36



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart. Geophones 6 m apart
Shot–hole pattern :
10 – 20 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 5 – 23 m. Charge varied

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

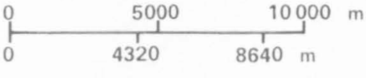
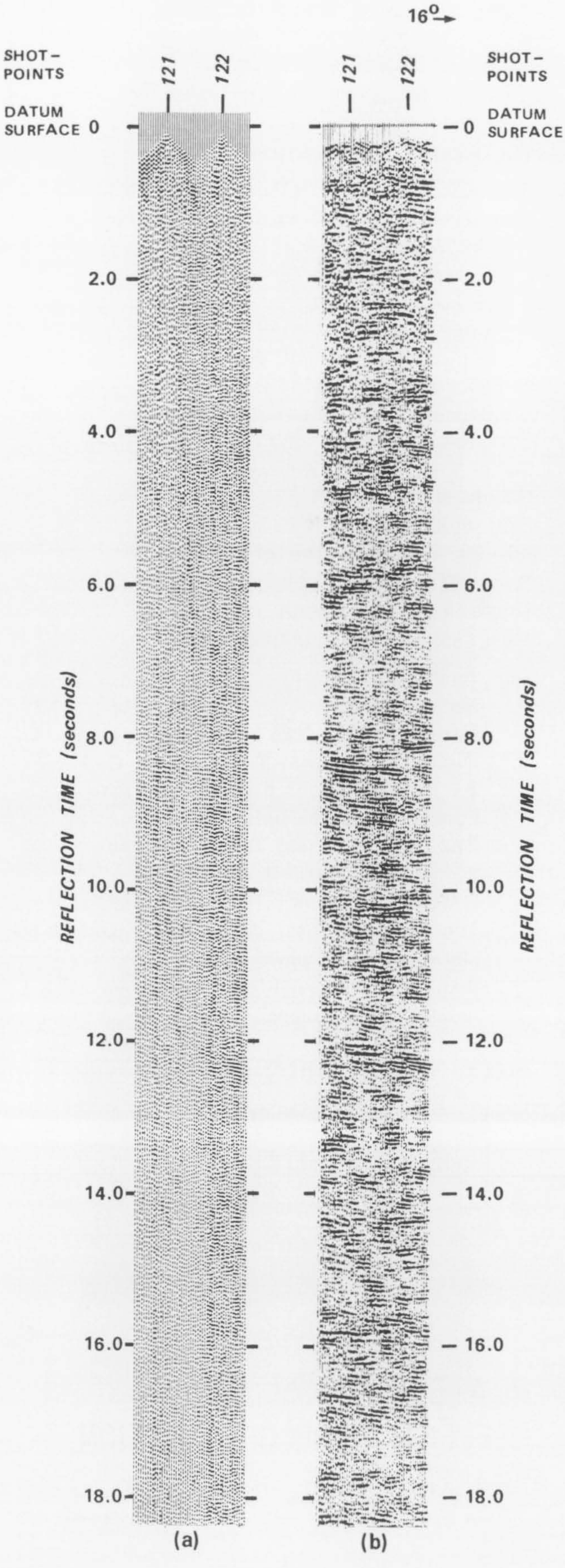


PLATE 8
REFLECTION RECORD SECTION, FRASER RANGE, TRAVERSE D

WA/B3–37



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
10 holes
Holes 15 m apart.
Depth 6 – 37 m. Charge 909 – 1454 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

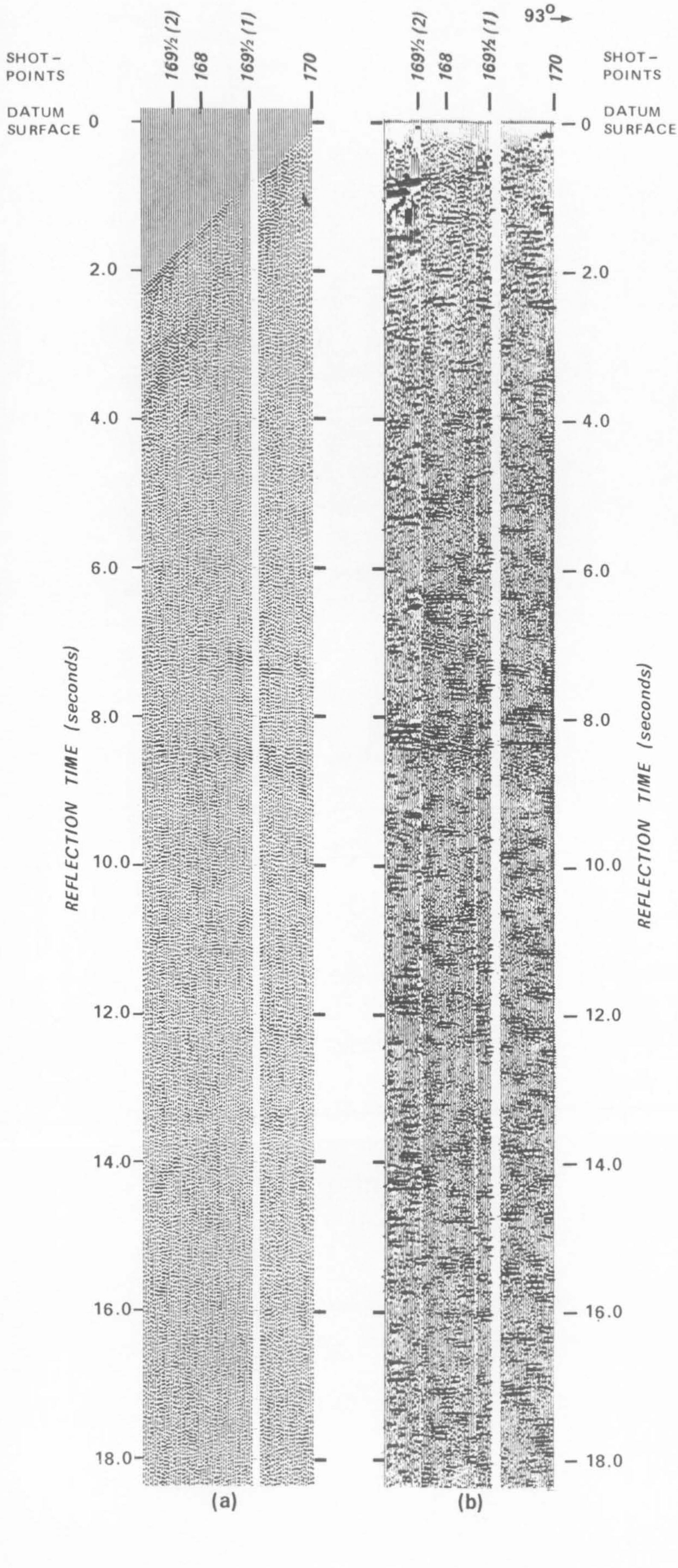
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 9
REFLECTION RECORD SECTION, FRASER RANGE, TRAVERSE E

WA/B3–38A



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
14 – 20 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 6 – 27 m Charge 864 – 909 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

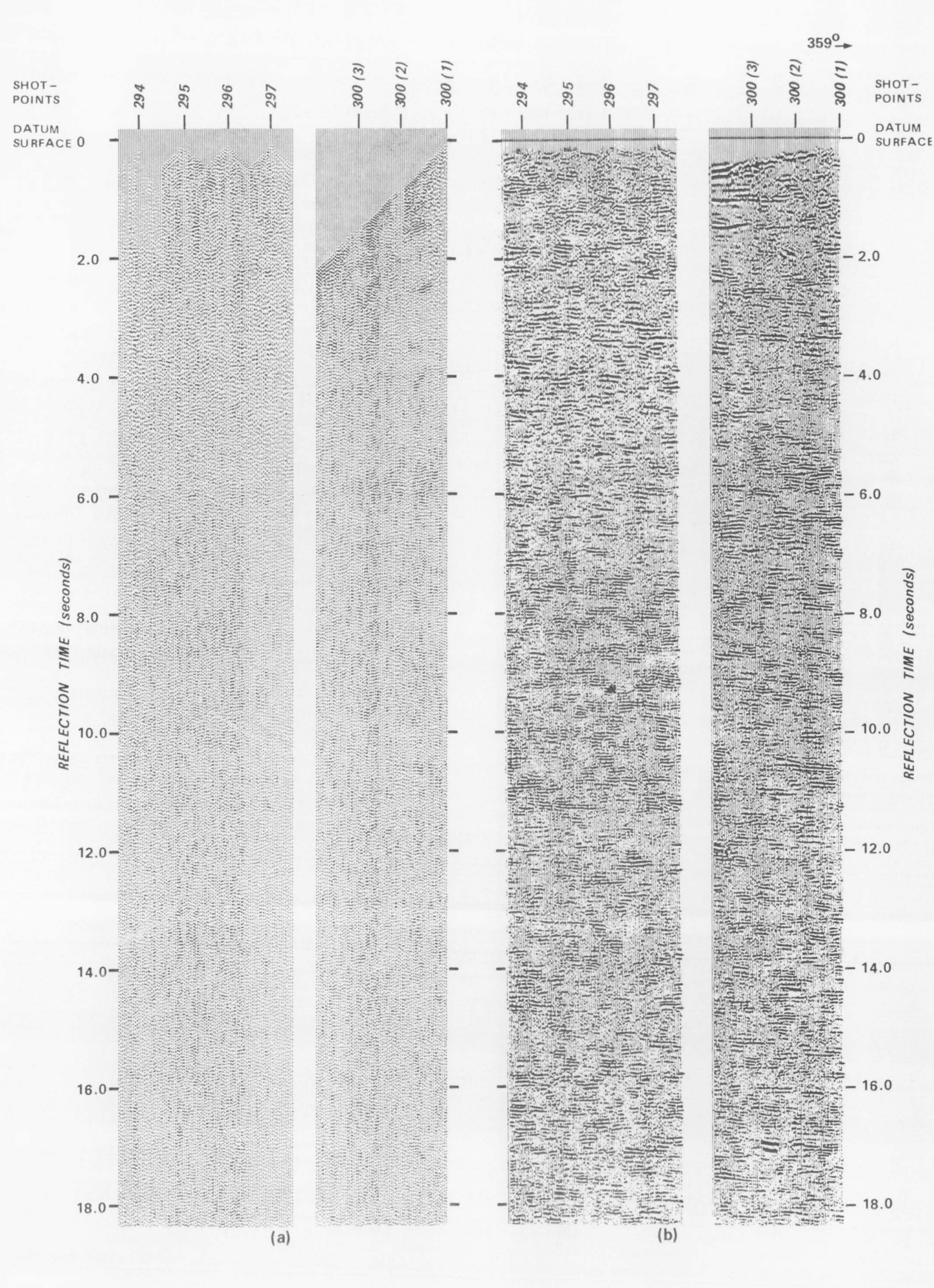
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 10
REFLECTION RECORD SECTION, FRASER RANGE, TRAVERSE F OFFSET RECORDING

WA/B3–39



359°
SHOT-POINTS
294
295
296
297
300 (3)
300 (2)
300 (1)
DATUM SURFACE
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)
(a)
(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
20 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 12 – 37 m. Charge varied

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 11
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE G

WA/B3–40

and consists of two layers with velocities of 6.13 and 6.74 km/s near Kalgoorlie, and the crust is about 45 km thick and consists of three layers with velocities of 6.13, 6.70, and 7.49 km/s near Perth close to the continental margin. The average upper mantle velocity is calculated to be 8.39 km/s under the shield. In the Perth Basin about 7.5 km of sediments, consisting of two main layers with velocities of 2.52 and 4.67 km/s, overlie an east-tilted, downthrown crustal block of velocity 6.13 km/s. The analysis of the refraction results in the Perth-Albany traverse indicates that the crust is about 34 km thick near Albany and 44 km thick near Perth and consists of three layers with velocities of 6.11, 6.60, and 7.34 km/s. The average upper mantle velocity is calculated to be 8.11 km/s on this traverse.

The reliability of the interpretation depends on the correlation of second and later arrivals. The evidence for the third crustal layer, C3, the main feature of the crustal structure in southwestern Australia, depends on the interpretation from first arrivals from SB (SE) shots and mainly on the second arrivals from OFF-P (E) (Plate 30) and OFF-A (NW) (Pl. 31) shots. C3 first arrivals could have been recorded from SB (E) shots if recordings had been made at appropriate distances between 100 and 250 km from the shots. The particular geometry of the crustal structure in the area is such that the C3 refractor could be recorded as first arrivals downdip and only as second arrivals updip.

The results from the analysis of the refraction data on the two traverses are compared for the shield area near Perth in Table 3. The depths calculated for refractors near Perth agree within 3 km and the velocities in the southeast-northwest direction are lower, by less than 4 percent, than those in the east-west direction. The variations are within the accuracy of the refraction method.

GRAVITY INFORMATION AND INTERPRETATION

The generally low amplitude, within ± 20 mGal, of the free-air anomalies (Pl. 3) over most of the shield, except in the areas of the Darling and Fraser Faults and the area between Perth and Albany in the southwest corner, indicates that the crust under the shield is generally close to isostatic equilibrium. The tectonic zones along these faults are too narrow to be compensated, and in the southwest the longer-wave-length positive anomalies of + 30 to + 40 mGal are believed to reflect the excess mass in the crust rather than a departure from isostasy.

The Bouguer anomalies (Pl. 2) show excellent correlation with the main geological and tectonic features in southwestern Australia. The extensive low along the western coast correlates with the Perth Basin, the low in the south with granites of the Albany-Esperance Block, the zone of high positive anomalies in the southeast with the dense rocks in the Fraser Range Block, and the short-wavelength highs in the northeast with the greenstones of the Kalgoorlie area. These and other relations are discussed by Daniels (1971) and Fraser (1973).

In order to determine if a crustal structure proposed or derived from other sources can produce the observed gravity field, a comparison is made between the observed Bouguer anomalies and the theoretical gravity effect computed for the model. The following assumptions are made:

- Two-dimensionality of the structural model. The body causing the anomaly is assumed to be uniform in cross-section and long, compared with its width, in the direction perpendicular to the line of the section.
- A sea-level standard crustal column. A Bouguer anomaly will be produced when the crust is different from this standard column.

TABLE 4. DENSITY MODELS OF THE CRUST AND UPPER MANTLE.

		Model 1		*Model 2*		*Model 3*	
Standard Thickness H_{st} (km)		30.0		31.0		32.0	
Column Density ρ_{st} (g/cm³)		2.83		2.84		2.86	
	Average Velocity (km/s)	*Density (g/cm³)*					
		ρ	$\Delta\rho$	ρ	$\Delta\rho$	ρ	$\Delta\rho$
Crustal layer 1	6.12	2.78		2.78		2.78	
			0.13		0.16		0.20
Crustal layer 2	6.66	2.91		2.94		2.98	
			0.13		0.16		0.20
Crustal layer 3	7.42	3.04		3.10		3.18	
			0.26		0.35		0.50
Mantle	8.25	3.30		3.45		3.68	

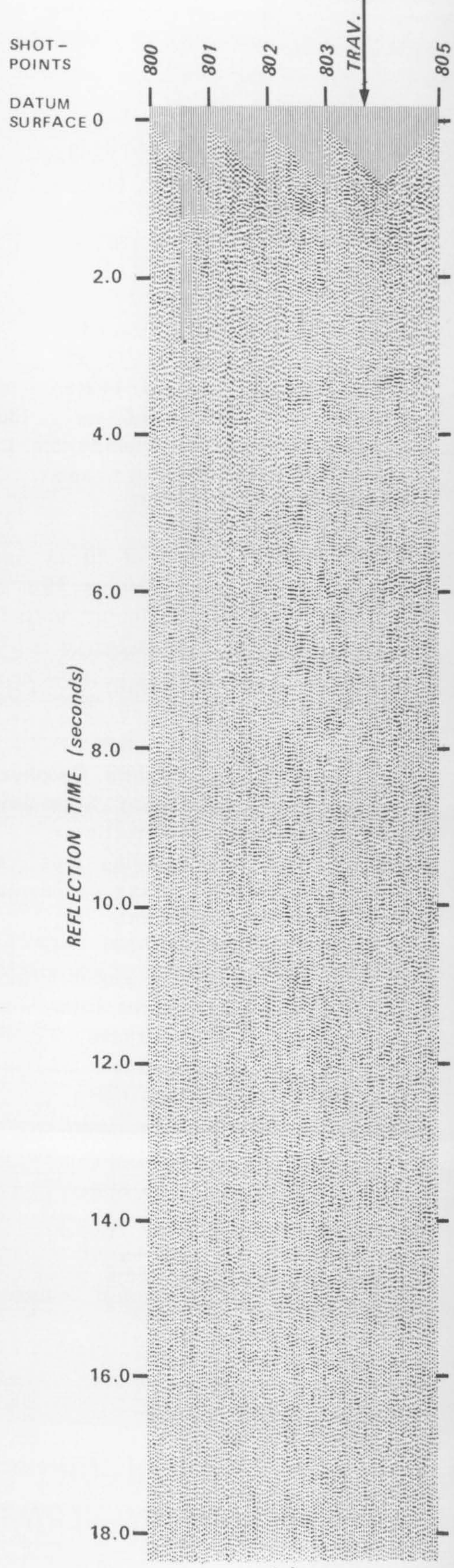
TABLE 5. UPPER MANTLE DENSITY CALCULATIONS BASED ON ARCHIMEDES PRINCIPLE.

		Shield Boundary	Hines Hill	Boorabbin	Jubilee Mine
Elevation Δh (km)		0.30	0.40	0.40	0.40
		Thickness (km)			
Crustal layer 1		7.45	13.60	19.76	19.61
Crustal layer 2		7.31	8.33	9.34	14.69
Crustal layer 3		29.64	18.02	6.39	—
Crustal thickness Hs		44.40	39.95	35.49	34.30
		Density (g/cm³)			
Model 1	Crust ρ_c	2.98	2.92	2.86	2.84
	Mantle ρ_m*	3.35	3.34	3.26	3.17
Model 2	Crust ρ_c	3.02	2.96	2.88	2.85
	Mantle ρ_m*	3.51	3.50	3.41	3.28

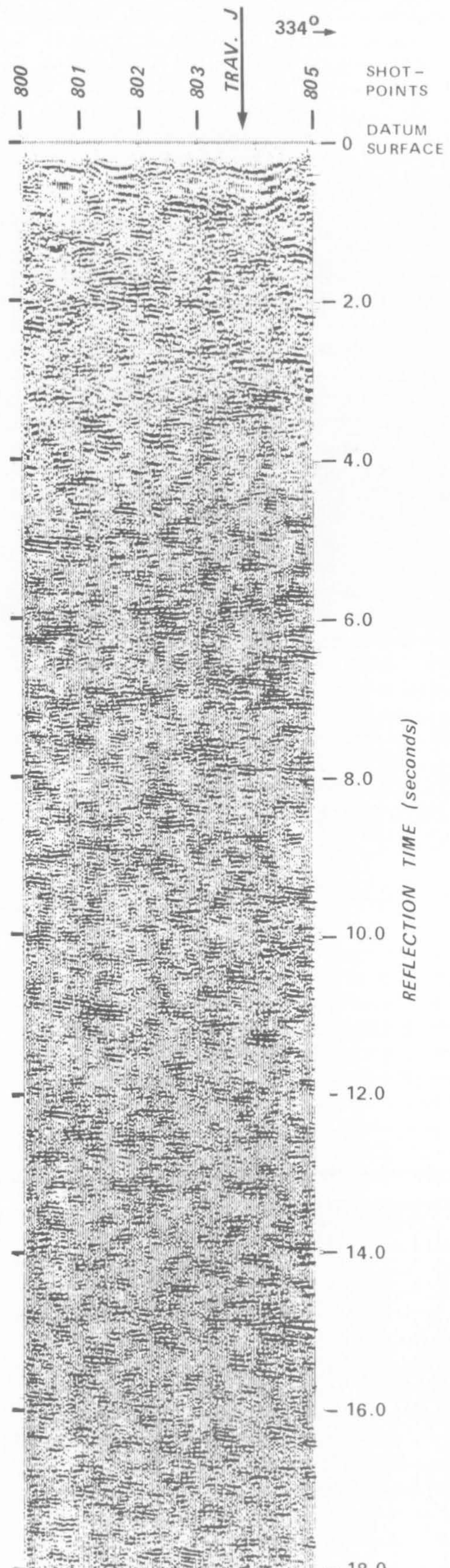
*Density computed from $\rho_m = \rho_c + \dfrac{\rho_c \cdot \Delta h + H_{st}\,(\rho_c - \rho_{st})}{H_s - H_{st}}$ after Woollard (1969)

— Densities are assigned to the various rock types according to observed or experimental velocity-density relations.

The assumption of a two-dimensional model is practically valid when the line of the section is perpendicular to the direction along which structures extend for long distances. Several different sea-level crustal columns ranging in thickness from 30.0 to 33.0 km and in density from 2.84 to 2.92 g/cm³ have been assumed in different areas of the world by a number of authors including Worzel & Shurbet (1955), Thompson & Talwani (1964), Rose, Woollard, & Malahoff (1968) and Woollard (1959, 1962, and 1969). Also, several different velocity-density relations have been observed by various authors including Nafe & Drake (**in** Talwani, Sutton, & Worzel, 1959), Birch (1961), Kanamori & Mizutani (1965), and Woollard (1962 and 1968), (Pl. 34).



(a)



(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
A G C : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart. Geophones 6 m apart
Shot–hole pattern :
20 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 12 – 37 m. Charge 1454 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (B M R)
No corrections
Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
N M O corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 12
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE H

WA/B3–41

These curves, which are based on laboratory observations, reflect the inadequate understanding of the nature of the relation between the velocity, density, and composition of rocks. Without a knowledge of the composition and elastic properties of rocks in their temperature-pressure environment in the actual crust and mantle, the choice of a standard column and densities for the layers is not simple. Therefore, estimates of appropriate values for southwestern Australia were made differently, as follows:

As the gravity effect computations involve density contrasts between the layers, not the densities, density-contrast models shown in Table 4 for three assumed standard-column thicknesses were obtained such that the computed effects for each model agree well with the mean observed Bouguer anomalies. Densities for the lower crustal layers and the upper mantle were then calculated from the density contrasts on the assumption of a density of 2.78 g/cm^3 for the uppermost crustal layer of velocity 6.12 km/s. This value is considered to be a reasonable estimate for the density of crystalline shield rocks. Model 3, which gives an unreasonably high density for the upper mantle, may be rejected; the mantle apparent density of 3.45 g/cm^3 of Model 2 implies an eclogitic subcrustal material and the mantle apparent density of 3.30 g/cm^3 of Model 1 implies a peridotitic subcrustal material.

The computed gravity curves for Model 2 along three traverses across the shield are shown in Plates 35, 36, and 37. The crustal structure shown in Plate 35 is based on refraction and reflection data, that in Plate 36 on refraction data only, and that in Plate 37 on extrapolation and poor reflection data only. On all traverses, the computed gravity curves match the observed mean Bouguer anomaly profiles reasonably well. Short-wavelength features on the observed profiles correlate well with the surface geology; the gravity highs correlate with the dense greenstone outcrops and the gravity lows correlate with the lighter granites.

If the crust, which the free-air anomalies show to be generally close to isostatic equilibrium, is floating in the mantle according to Archimedes Principle, the density of the upper mantle can also be calculated from the densities and thicknesses of the crustal layers and the standard column. Upper mantle densities computed for four areas of the shield and for crustal density Models 1 and 2 are given in Table 5. The average of the values for each model agrees with the density of the upper mantle derived independently (Table 4). The close agreement is rather fortuitous, considering the uncertainties involved in the assumptions.

The seismically derived crustal structure of the shield is thus in or close to isostatic equilibrium and is consistent with the observed Bouguer anomalies for both density models. The densities of the layers in both models are within the general range of values observed in Plate 34 for the corresponding seismic velocities.

DISCUSSION AND CONCLUSIONS

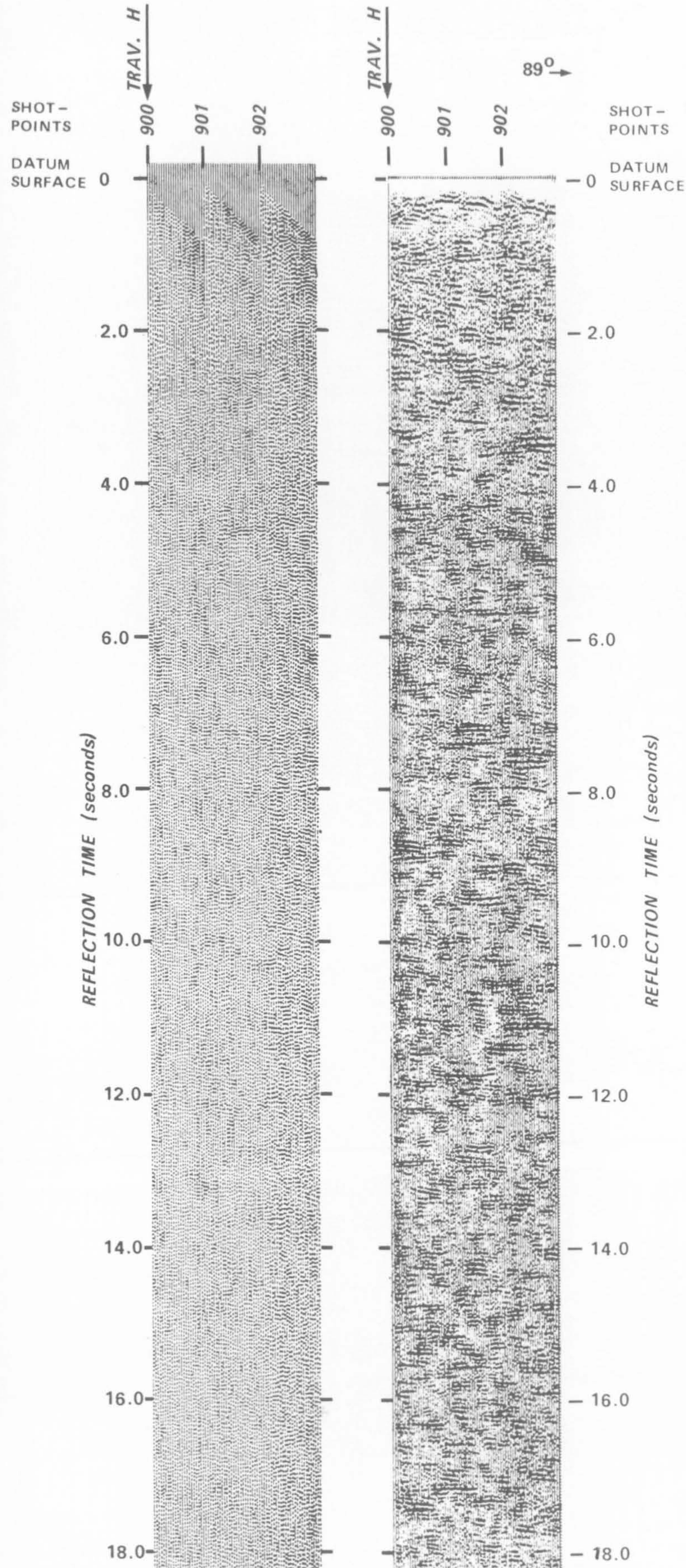
The results of the integrated analysis of seismic and gravity data in the southern part of Western Australia are shown in a generalized fence diagram in Plate 38. The crust is of normal continental type in the eastern part of the Precambrian shield but is abnormal in the western part of the shield near Perth. Near the Jubilee Mine it is 34 km thick and consists of two main layers with velocities of 6.12 and 6.66 km/s, and near Perth close to the continental margin it is 44 km thick and includes an additional main layer of velocity 7.42 km/s at the base of the crust. This layer thins towards the east and southeast whereas the uppermost two crustal layers thicken towards the east and southeast. In the Perth Basin about 7.5 km of sediments overlies a basement crustal block which has been downthrown to the west of the Darling Fault. Southeast of Coolgardie, the high-velocity basal crustal layer is shown to be thin and the southeastern part of the shield crust has been overthrust to the northwest along the Fraser Fault. The average velocity of the mantle material under the shield is 8.25 km/s. The interpreted crustal structure is consistent with a crust in or close to isostatic equilibrium, and with the observed gravity anomaly field in southwestern Australia for two possible density models of the crust and the upper mantle.

The refraction data used in the analyses were recorded on a regional scale; thus the interpretation represents the average structure of the crust. The reflection data were recorded in five widely separated survey locations and, with the lack of vertical velocity information from the reflection data, were inadequate for an independent interpretation of the crustal structure on the Geotraverse. The reflection results did, however, support the refraction interpretation. The seismic data are not detailed enough to detect features such as the seismically active zone, the Yandanooka/Cape Riche Lineament (Pl. 4), (Everingham, 1965 and 1966), which do not involve major displacements of all crustal layers. The rise in the Bouguer anomalies across the 20-mGal contour, suggested by Everingham to be related to the seismic zone, seems to be part of the regional gradient between the low anomalies in the centre and the high in the southwest of the shield (Pl. 2); this gradient reflects the southwestward thickening of the denser basal crustal layer.

A shallow crustal layer, 6 to 9 km above crustal layer 2, and a sub-Moho layering, about 21 km below the Moho, are suspected under the shield along the east-west part of the Geotraverse from the presence of additional significant peaks in the histograms for the seismic reflection data. The refraction data, however, provide no evidence for these layers.

The presence of a high velocity basal crustal layer with a velocity of 7.4 to 7.8 km/s has been detected in several regions of the Earth's crust. Ito & Kennedy (1970) summarized the relevant seismic data from these areas and observed that most of them have been associated with tectonic activity. Drake & Nafe (1968), in correlating the seismic refraction data with geological structure, suggested that the material in the velocity range 7.2 to 7.7 km/s may be of a transient nature and may appear and then disappear during the orogenic history of a region. In relating gravity anomalies to seismically defined crustal structure in North America, Woollard (1968 and 1970) concluded that areas of abnormal crustal thickness and density are characterized by a well-defined high-velocity basal crustal layer of 6.8 to 7.4 km/s, an abnormally high mantle velocity, positive gravity anomalies, and are usually associated with a basin. He also concluded that areas of subnormal crustal thickness and density are characterized by subnormal mantle velocity, negative gravity anomalies, and evidence of uplift. Woollard believes that at the Mohorovicic Discontinuity there is an active reversible process involving transfer of mass between the crust and the mantle in order to maintain isostatic equilibrium.

In an effort to explain the differences in crustal thicknesses observed in different areas, Kennedy (1959) proposed that the vertical movement of the Mohorovicic Discontinuity could result from a reversible transformation between basalt and eclogite controlled by differences in thermal gradient in the crust. Recent experiments by Ito & Kennedy (1970) further show that the basalt-eclogite transition consists of two abrupt density changes; from basalt and pyroxene granulite with ρ = 3.0 g/cm^3 to garnet granulite with ρ = 3.2 to 3.25 g/cm^3 and from garnet granu-



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot-hole pattern :
30 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 12 – 37 m Charge 1454 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

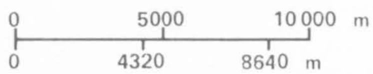
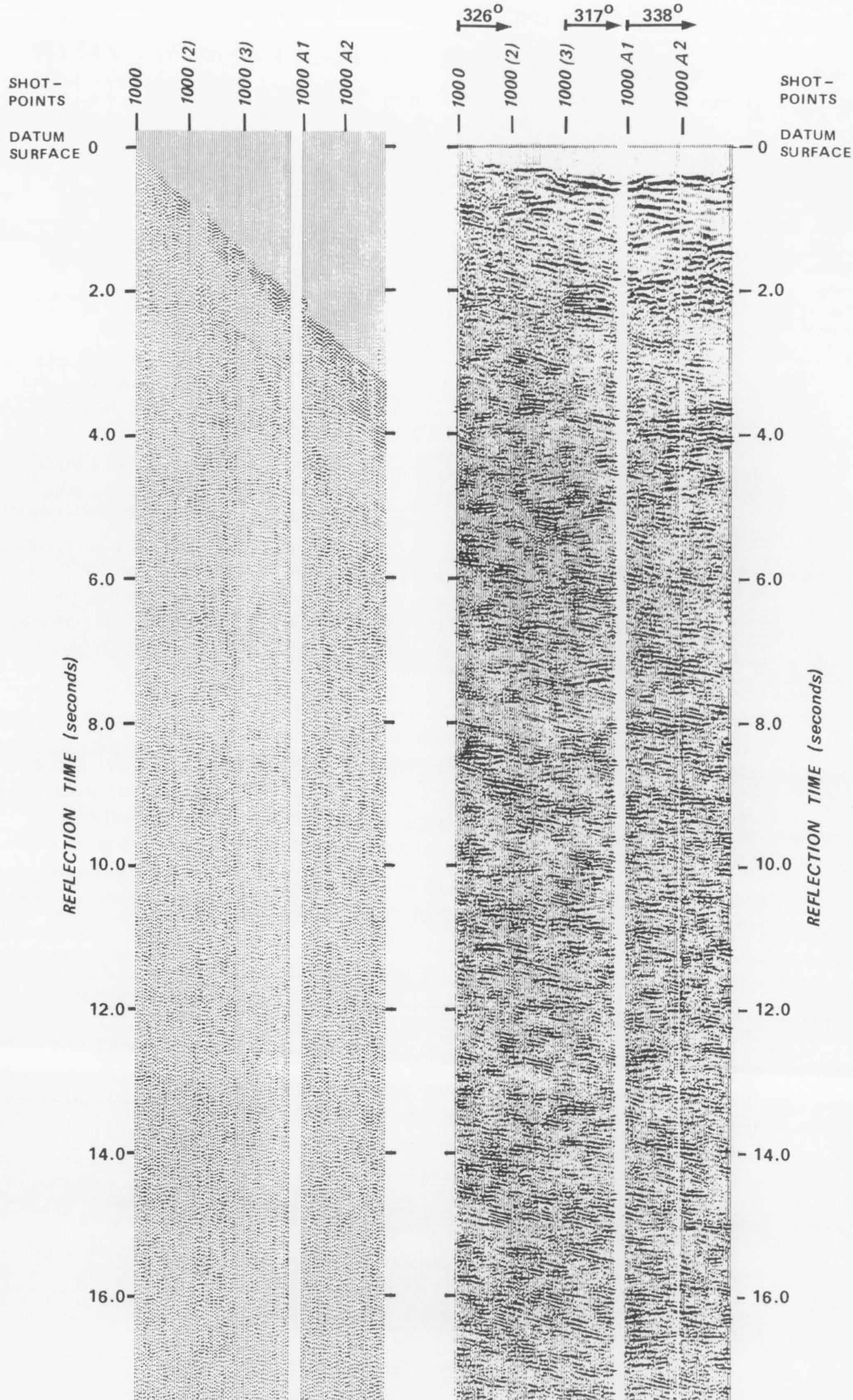


PLATE 13
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE J

WA/B3-42


SHOT-POINTS
DATUM SURFACE
1000
1000 (2)
1000 (3)
1000 A1
1000 A2
326°
317°
338°
1000
1000 (2)
1000 (3)
1000 A1
1000 A2
SHOT-POINTS
DATUM SURFACE
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)
(a)
(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot-holes pattern :
20 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 6 – 27 m. Charge varied

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 50

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 14
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE K OFFSET RECORDING

WA/B3—43

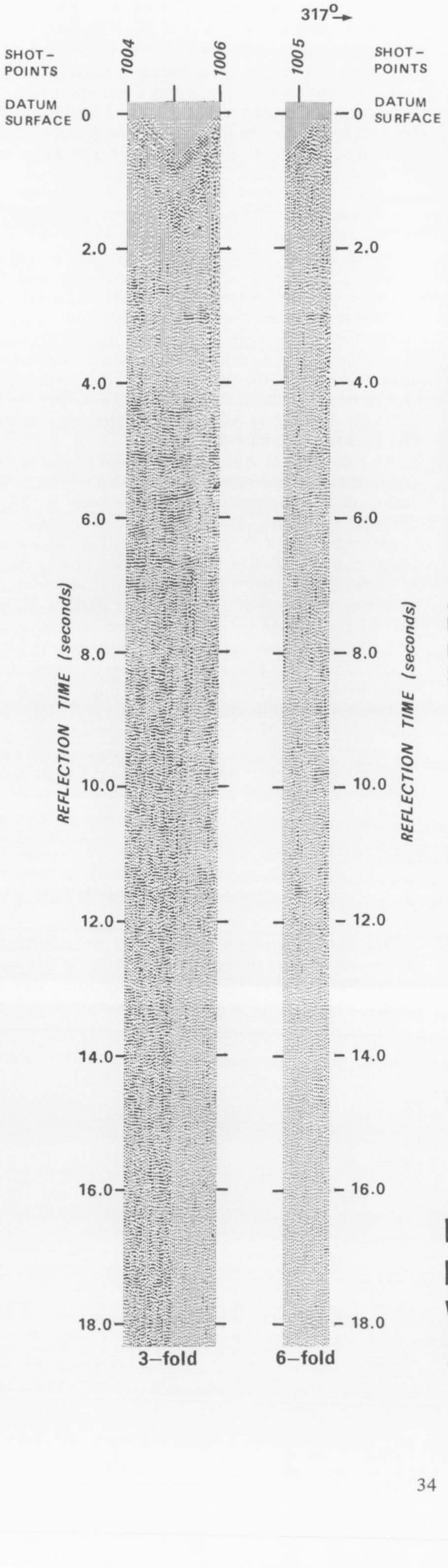
lite to eclogite with ρ = 3.4 to 3.5 g/cm^3. They propose that the high velocity basal crustal layer beneath areas which have undergone relatively recent vertical movement is garnet granulite and that its upper boundary is likely to represent a chemical change from acidic and intermediate rocks to basic garnet granulite and that its lower boundary is likely to represent a phase change from garnet granulite to eclogite. However, Green & Ringwood (1972) disagree with the interpretation of Ito and Kennedy of the experimental results in terms of two sharp density increases during basalt to eclogite transition and reaffirm their own earlier conclusions (Ringwood & Green, 1966) that the increase in densities and seismic velocities is uniformly spread over the entire garnet granulite transition interval and that the basalt-eclogite transition does not explain the existence of a Mohorovicic Discontinuity in stable continental crustal environments. In reply Kennedy & Ito (1972) refuted the objections raised by Green and Ringwood and held to their interpretation of the data that the layer with velocity 7.5 km/s may well be garnet granulite, and that the velocity increase from 7.5 to 8.2 km/s may represent the transition from garnet granulite to eclogite.

In southwestern Australia, the basal crustal layer is well defined by seismic refraction and reflection data, implying sharp density contrasts at its boundaries. If this layer is garnet granulite derived from an eclogite mantle underneath, density Model 2 presented in Table 4 would be most representative of the crustal structure in the area.

Although no deep crustal seismic studies have been made in the marine areas of the Naturaliste Plateau, the structure of the crust there has been suggested by Francis & Raitt (1967) to be similar to that under the Broken Ridge farther to the west in the Indian Ocean where they have detected a continental-type crust with a basal high-velocity layer of 7.25 km/s. Thus the anomalous crust is probably present not only in the western part of the Precambrian shield in Western Australia but also on the separated areas of the Naturaliste Plateau and the Broken Ridge, though its submarine parts are considerably thinner and its thickest part lies under the Perth Basin.

ACKNOWLEDGEMENTS

The authors are grateful to Dr G. P. Woollard of the University of Hawaii and Dr D. H. Green of the Australian National University for discussions during the interpretation of the seismic and gravity data.



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
A G C : 1 / 1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart. Geophones 6 m apart
Shot–hole pattern :
10 – 20 holes in rows of 10 in line
Rows 17 m apart. Holes 15 m apart
Depth 9 – 14 m Charge 46 – 455 kg Geophex

PROCESSING INFORMATION

Analogue : (BMR)
No corrections
Filters : L 12 – K 25
Stacking

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

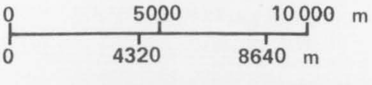
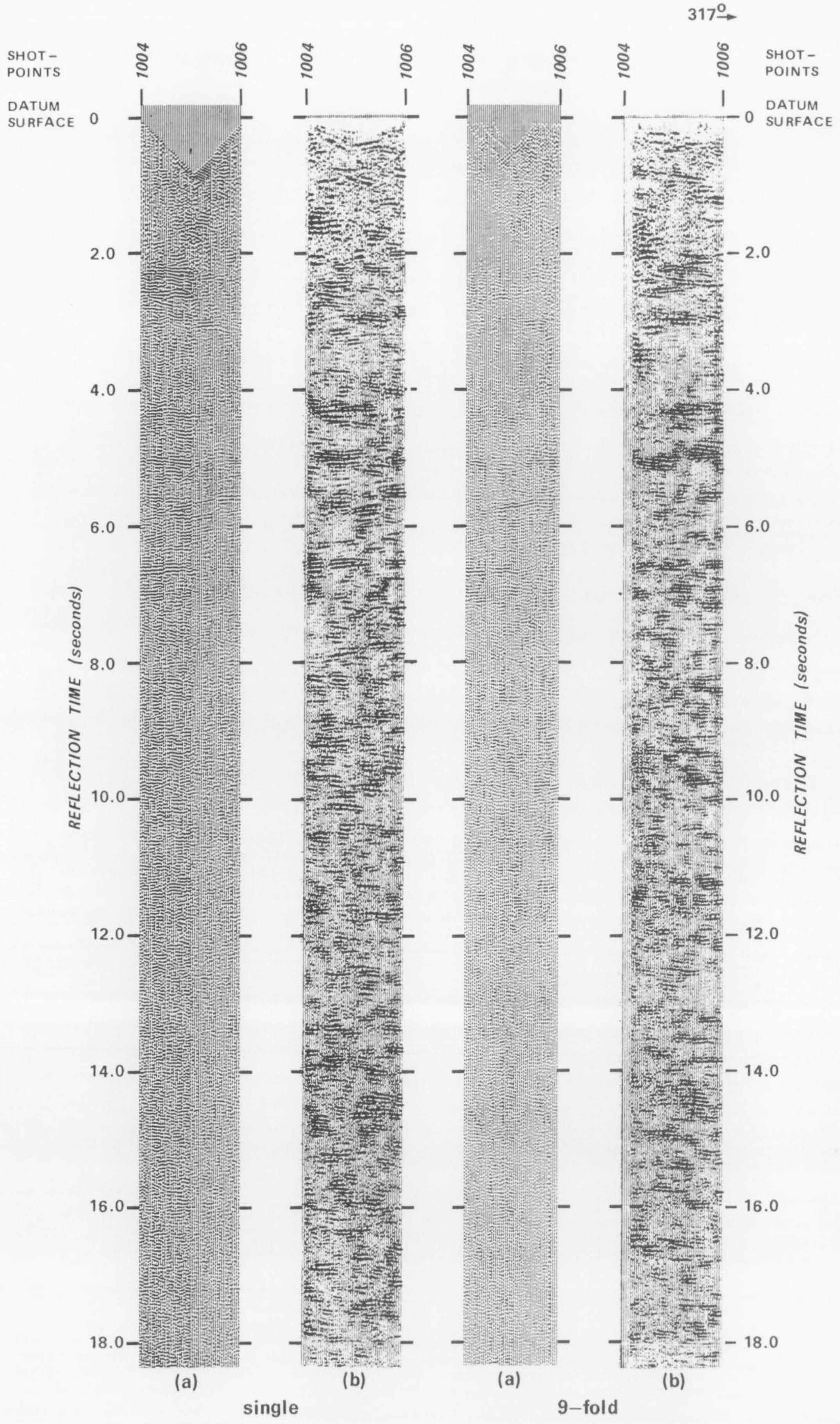


PLATE 15
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE K 3 AND 6–FOLD CDP

WA/B3–44A



317°
SHOT-POINTS
1004
1006
DATUM SURFACE
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)
(a)
(b)
single
9-fold

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
A G C : 1 / 1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
10 – 20 holes in rows of 10 in line
Rows 17 m apart. Holes 15 m apart
Depth 9 – 14 m Charge 46 – 455 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (B M R)
No corrections
Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
N M O corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

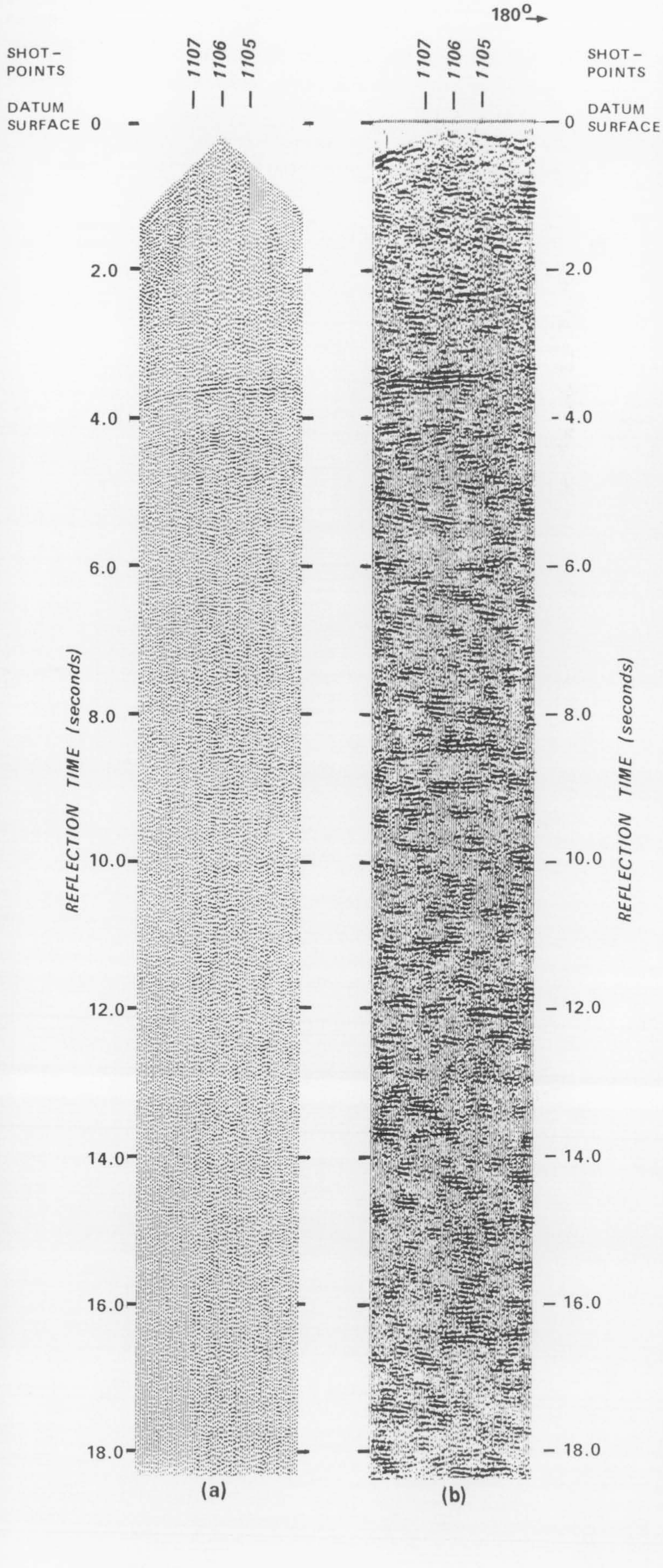
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 16
REFLECTION RECORD SECTION, WIDGIEMOOLTHA, TRAVERSE K

WA/B3–45



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
    Prefilters : Nil
    Filters : K 14 – K 72
    AGC : 1/1 – 20
    Gain initial : Varied
        final **: – 6 to – 12 dB**
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–holes pattern **:**
30 – 70 holes in rows of 10 in line
Rows 33 m apart. Holes 15 m apart
Depth 5 – 37 m. Charge 4545 – 7272 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
    No corrections
    Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
    A – D conversion, 8 ms sample rate
    Edit, trace demultiplex
    2nd zero crossing least – squares minimum-phase deconvolution
    NMO corrections
    Time variant filter, min. 8 Hz, max. 26 Hz
    Multi – channel power filter
    Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

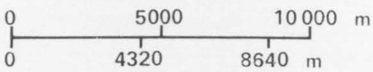
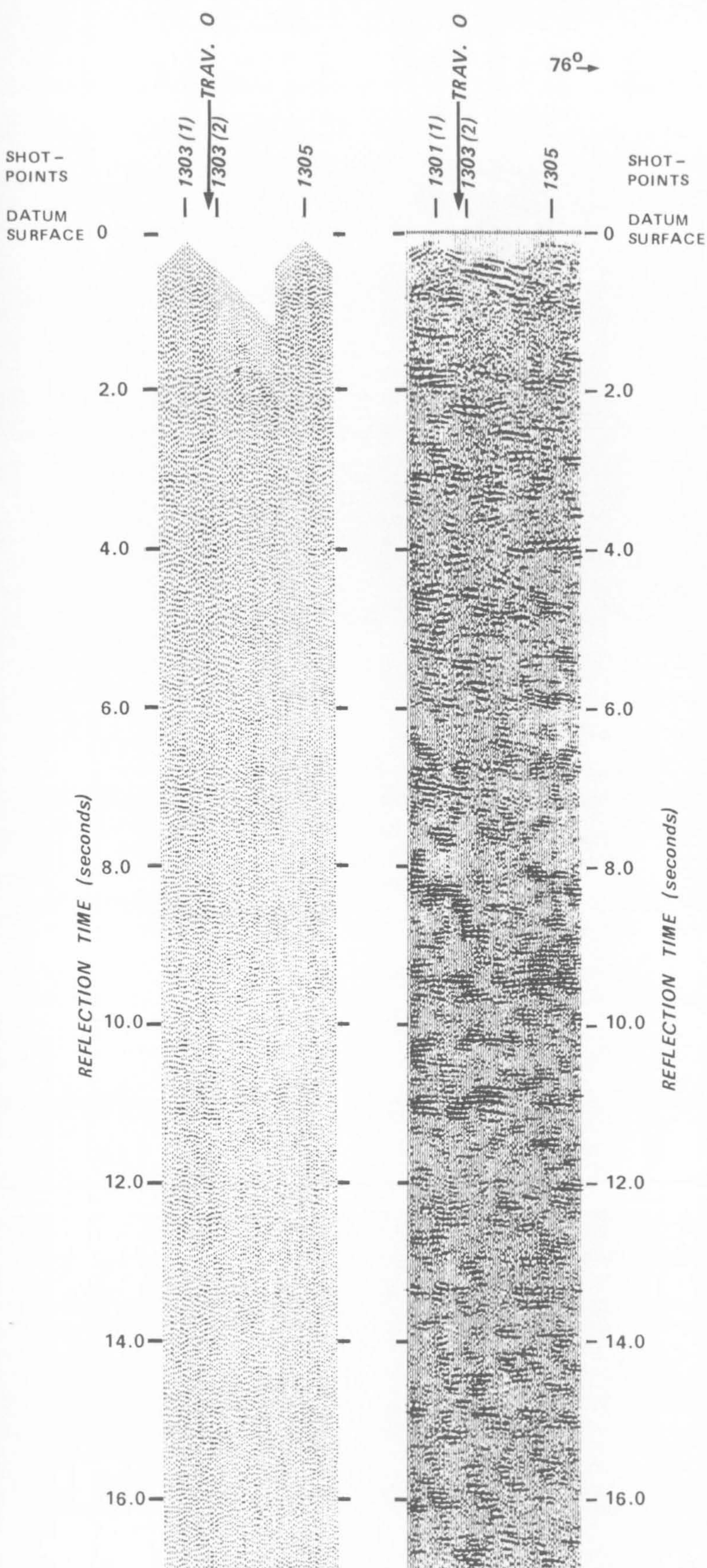


PLATE 17
REFLECTION RECORD SECTION, BOORABBIN, TRAVERSE L, EXPANDED SPREAD

WA/B3–46



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : –6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–holes pattern :
20 – 40 holes in rows of 10 in line
Rows 16 m apart. Holes 15 m apart
Depth 6 – 37 m. Charge 2045 – 7817 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

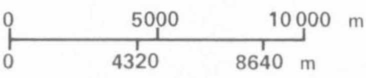
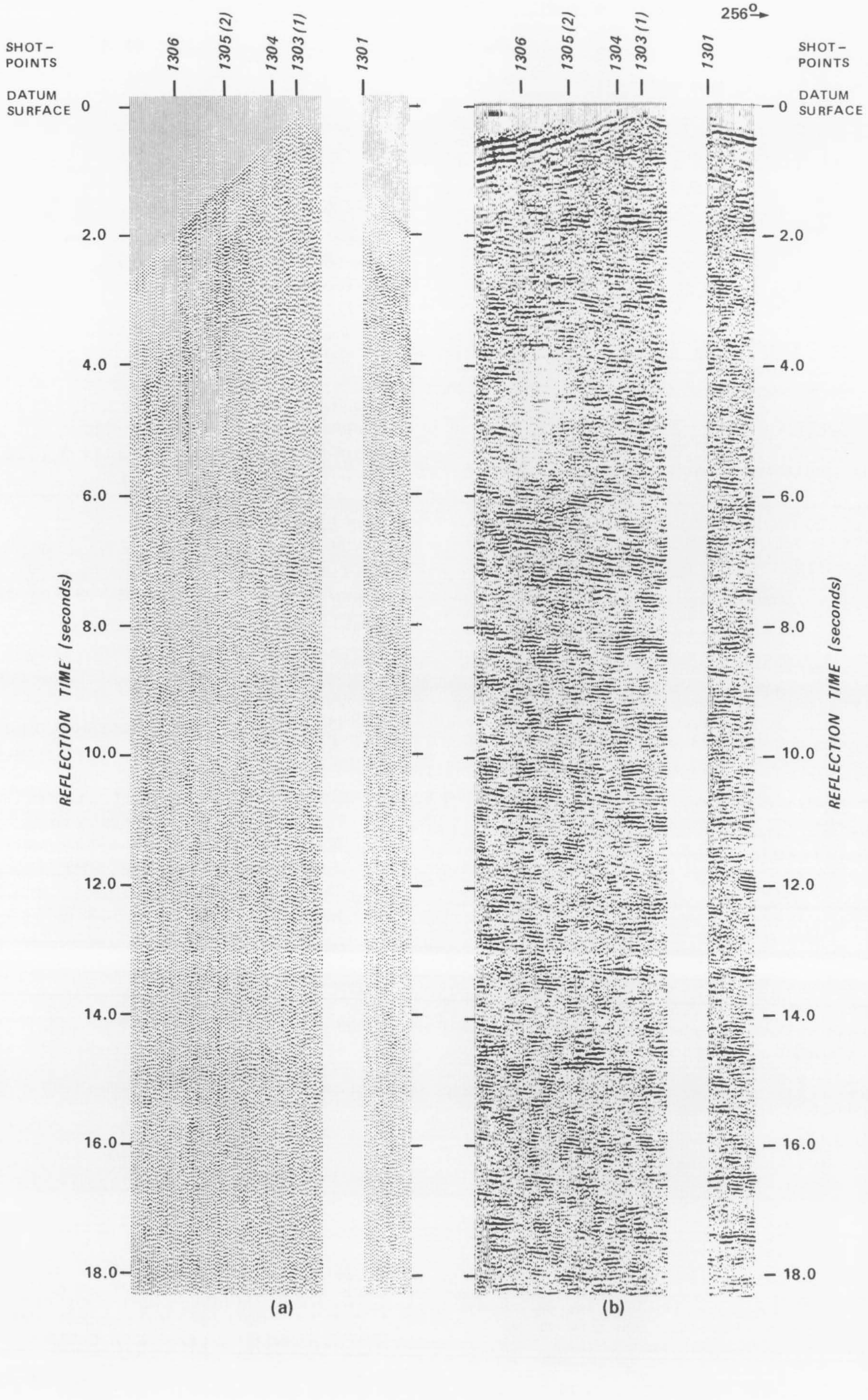


PLATE 18
REFLECTION RECORD SECTION, BOORABBIN, TRAVERSE N

WA/B3–47


SHOT-POINTS
1306
1305 (2)
1304
1303 (1)
1301
256°
DATUM SURFACE
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)
(a)
(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : – 6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–holes pattern :
20 – 40 holes in rows of 10 in line
Rows 16 m apart. Holes 15 m apart
Depth 6 – 37 m. Charge 2045 – 7817 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

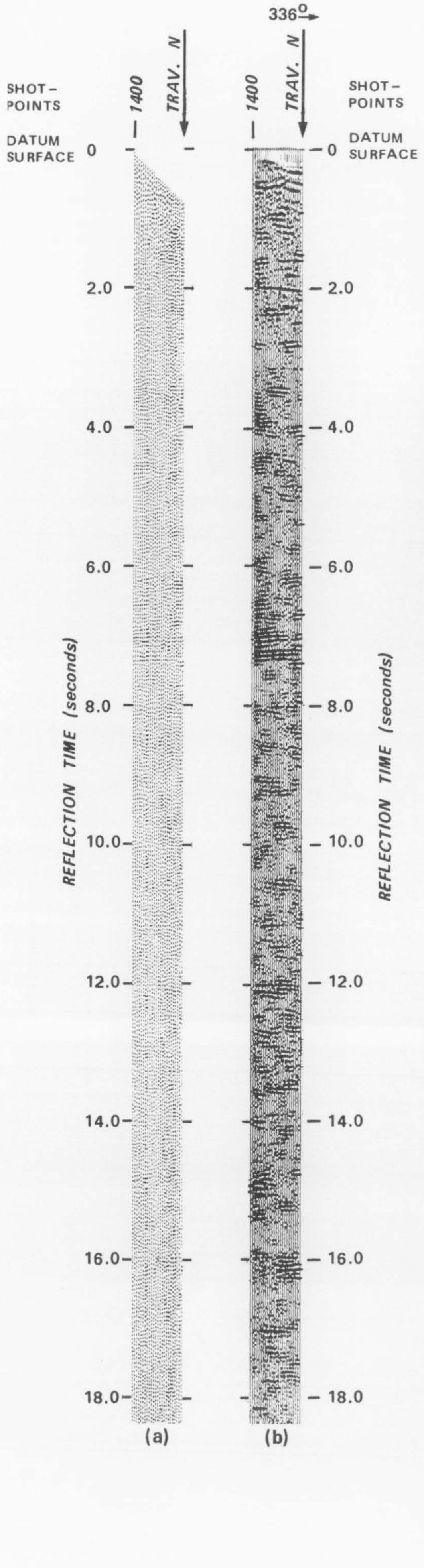
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 19
REFLECTION RECORD SECTION, BOORABBIN, TRAVERSE N EXPANDED SPREAD

WA/B3–48



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–holes pattern :
40 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 12 – 37 m. Charge 4545 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

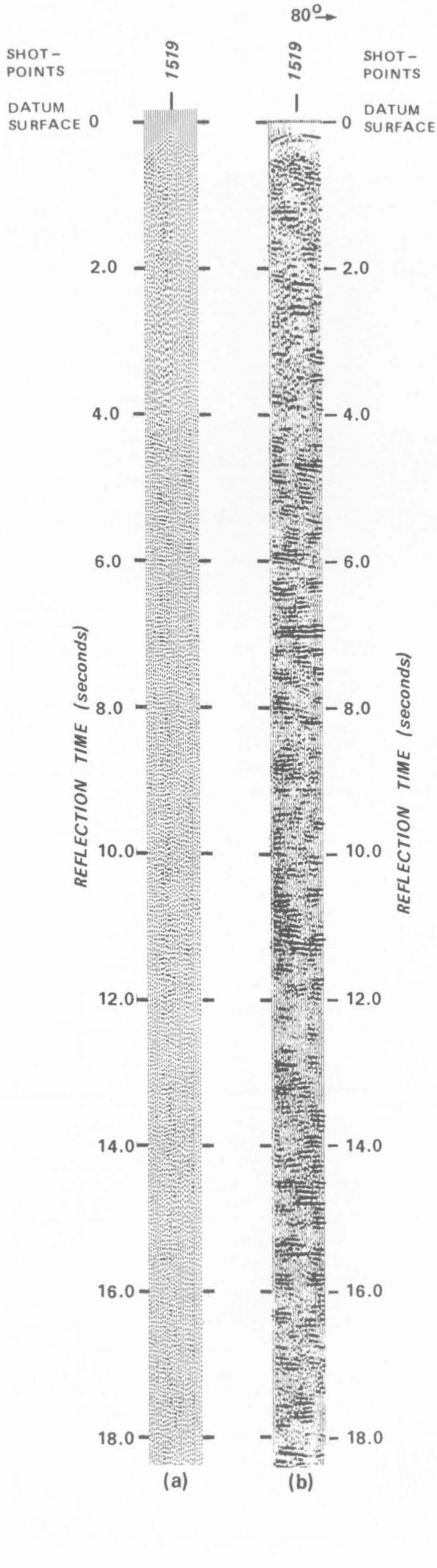
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 20
REFLECTION RECORD SECTION, BOORABBIN, TRAVERSE O

WA/B3–49A



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–holes pattern :
50 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 8 – 27 m Charge 4781 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

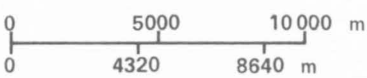
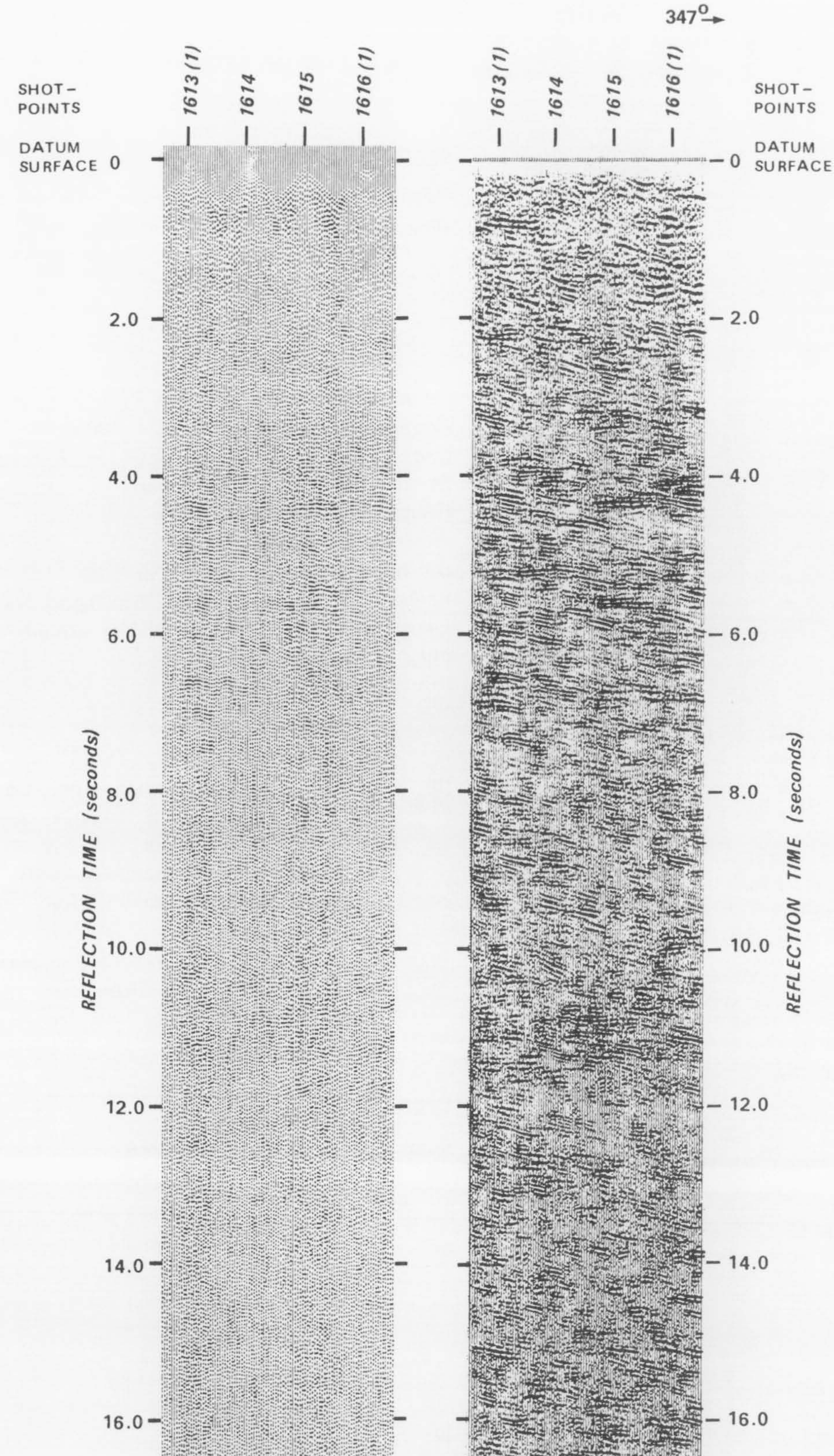


PLATE 21
REFLECTION RECORD SECTION, BOORABBIN, TRAVERSE P

WA/B3–50A


347°
SHOT-POINTS
1613 (1)
1614
1615
1616 (1)
DATUM SURFACE
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)

(a) (b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
A G C : 1 / 1 – 20
Gain initial : Varied
final : – 6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
20 – 30 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 10 – 27 m. Charge 955 – 2727 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (B M R)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
N M O corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

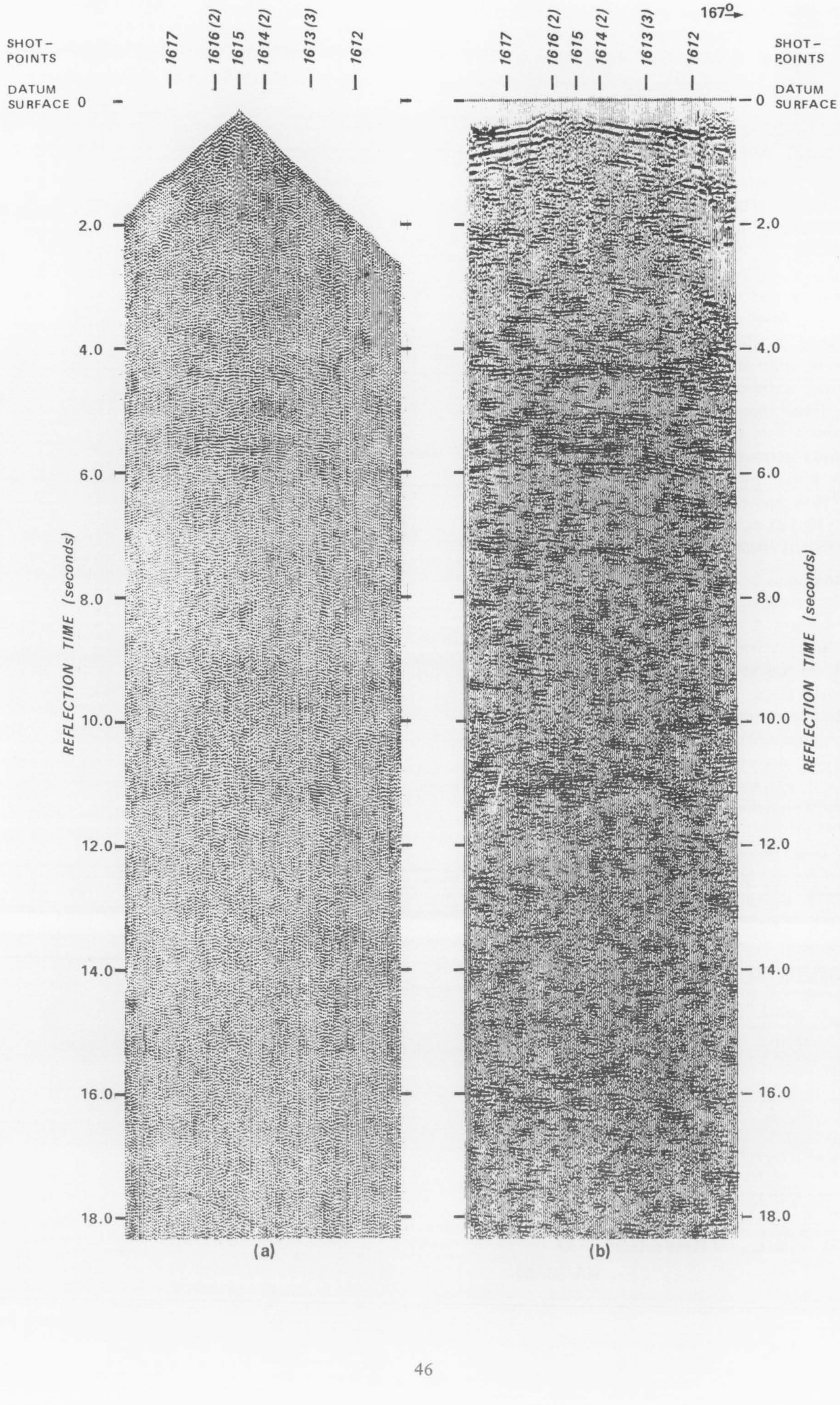
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 22
REFLECTION RECORD SECTION, HINES HILL, TRAVERSE Q

WA/B3–51


SHOT-POINTS
DATUM SURFACE
1617
1616 (2)
1615
1614 (2)
1613 (3)
1612
167°
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
REFLECTION TIME (seconds)
(a)
(b)

RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : –6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
20 – 30 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 10 – 27 m. Charge 909 – 2727 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

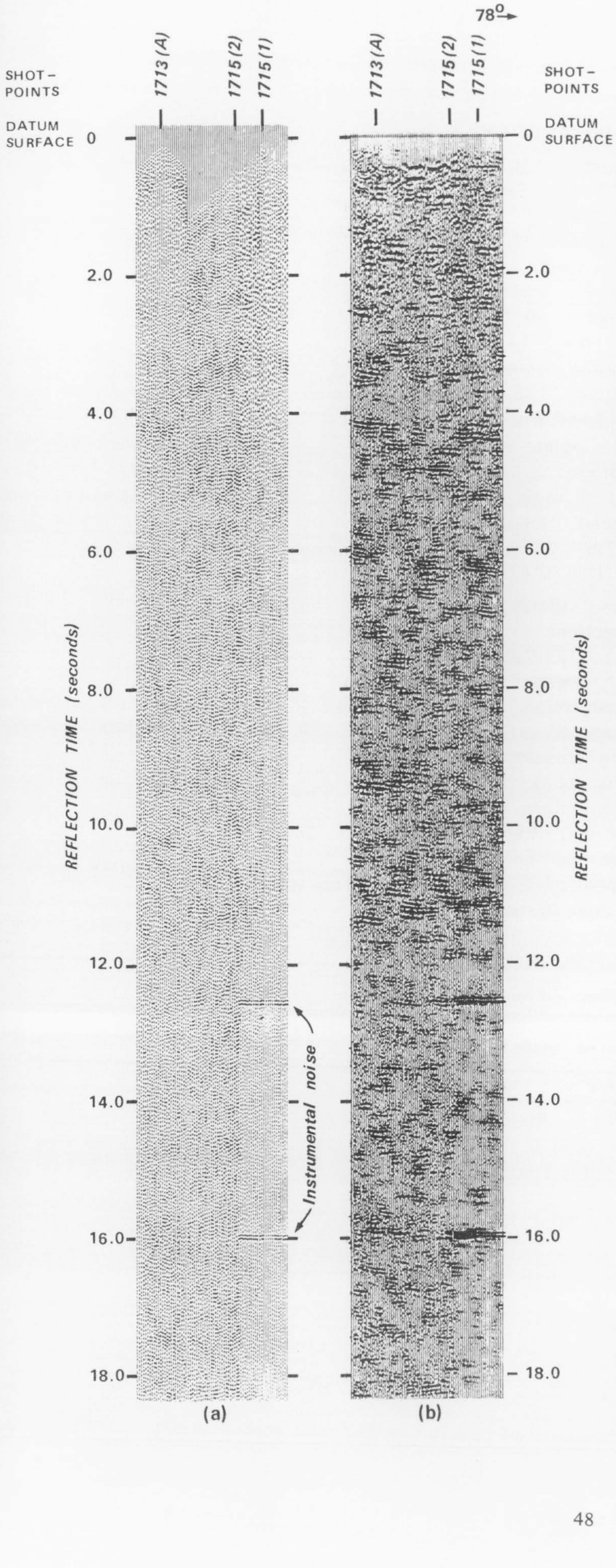
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 23
REFLECTION RECORD SECTION, HINES HILL, TRAVERSE Q EXPANDED SPREAD

WA/B3–52



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : – 6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48/trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
49 – 50 holes in rows of 10 in line
Rows 16 m apart. Holes 15 m apart
Depth 6 – 32 m. Charge 4454 – 7272 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

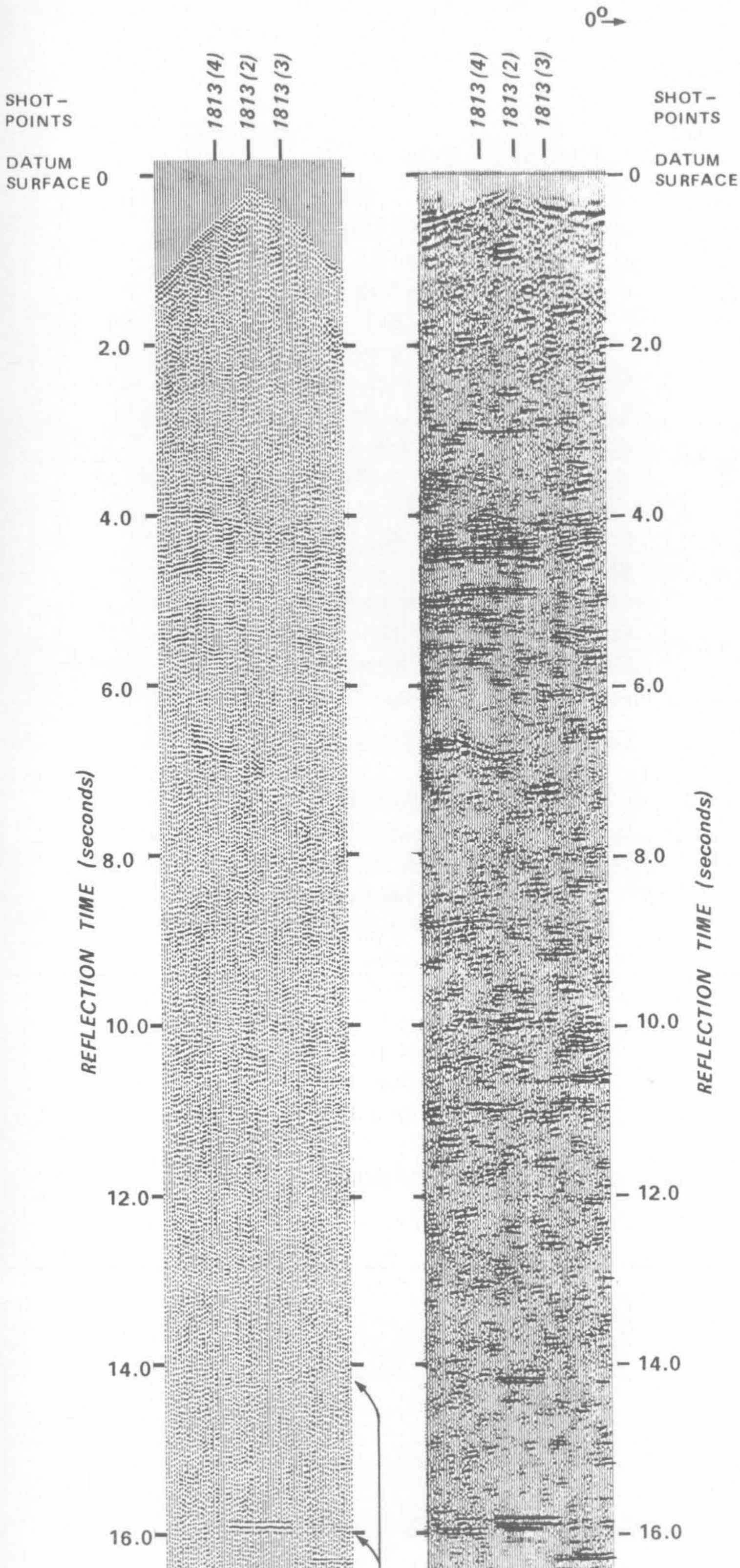
Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 24
REFLECTION RECORD SECTION, HINES HILL, TRAVERSE R

WA/B3–53



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1/1 – 20
Gain initial : Varied
final : – 6 to – 12 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart. Geophones 6 m apart
Shot–hole pattern :
50 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 6 – 23 m Charge 5454 – 6545 kg Ammon. Nitrate

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25

(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

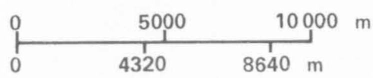
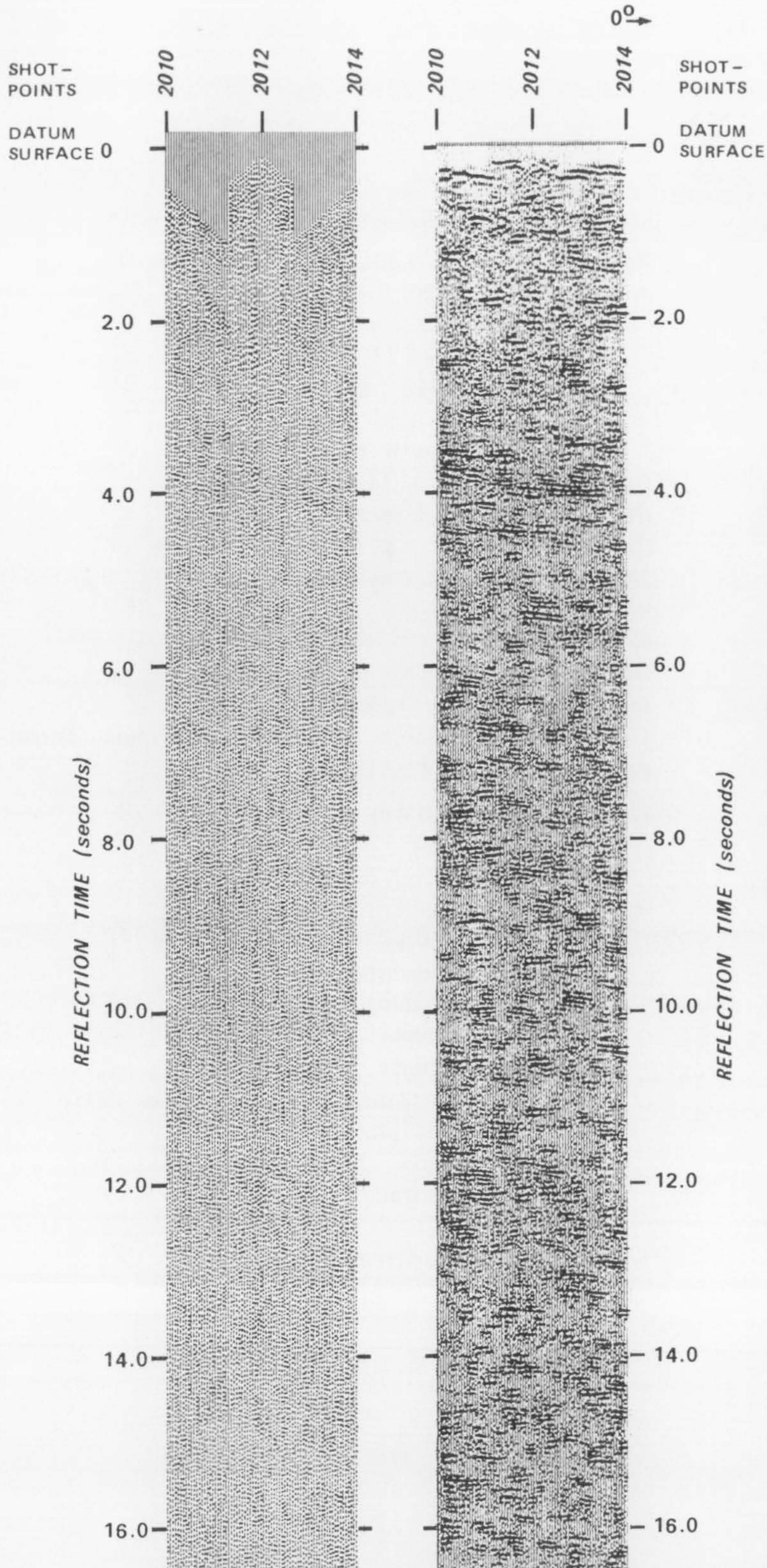


PLATE 25
REFLECTION RECORD SECTION, HINES HILL, TRAVERSE S

WA/B3–54



RECORDING INFORMATION

Magnetic recorder : Electro – Tech DS 7 – 7
Amplifiers : TI 8000 Explorer
Prefilters : Nil
Filters : K 14 – K 72
AGC : 1 / 1 – 20
Gain initial : Varied
final : – 6 dB
Geophones : HS – J 14 Hz
Geophone station interval : 180 m
Geophone pattern : 48 / trace in 2 rows of 24 in line. Rows 6 m apart.
Geophones 6 m apart
Shot–hole pattern :
40 – 52 holes in rows of 10 in line
Rows 15 m apart. Holes 15 m apart
Depth 5 – 14 m. Charge 1818 – 4590 kg Geophex

PROCESSING INFORMATION

(a) Analogue : (BMR)
No corrections
Filters : L 12 – K 25
(b) Digital : (Western Geophysical Co.)
A – D conversion, 8 ms sample rate
Edit, trace demultiplex
2nd zero crossing least – squares minimum phase deconvolution
NMO corrections
Time variant filter, min. 8 Hz, max. 26 Hz
Multi – channel power filter
Radial predictive filter, –5 to +5 ms dip over three traces

VELOCITY INFORMATION

Based on refraction analysis

HORIZONTAL SCALE

0 5000 10 000 m
0 4320 8640 m

PLATE 26
REFLECTION RECORD SECTION, WUNDOWIE, TRAVERSE U

WA/B3–55

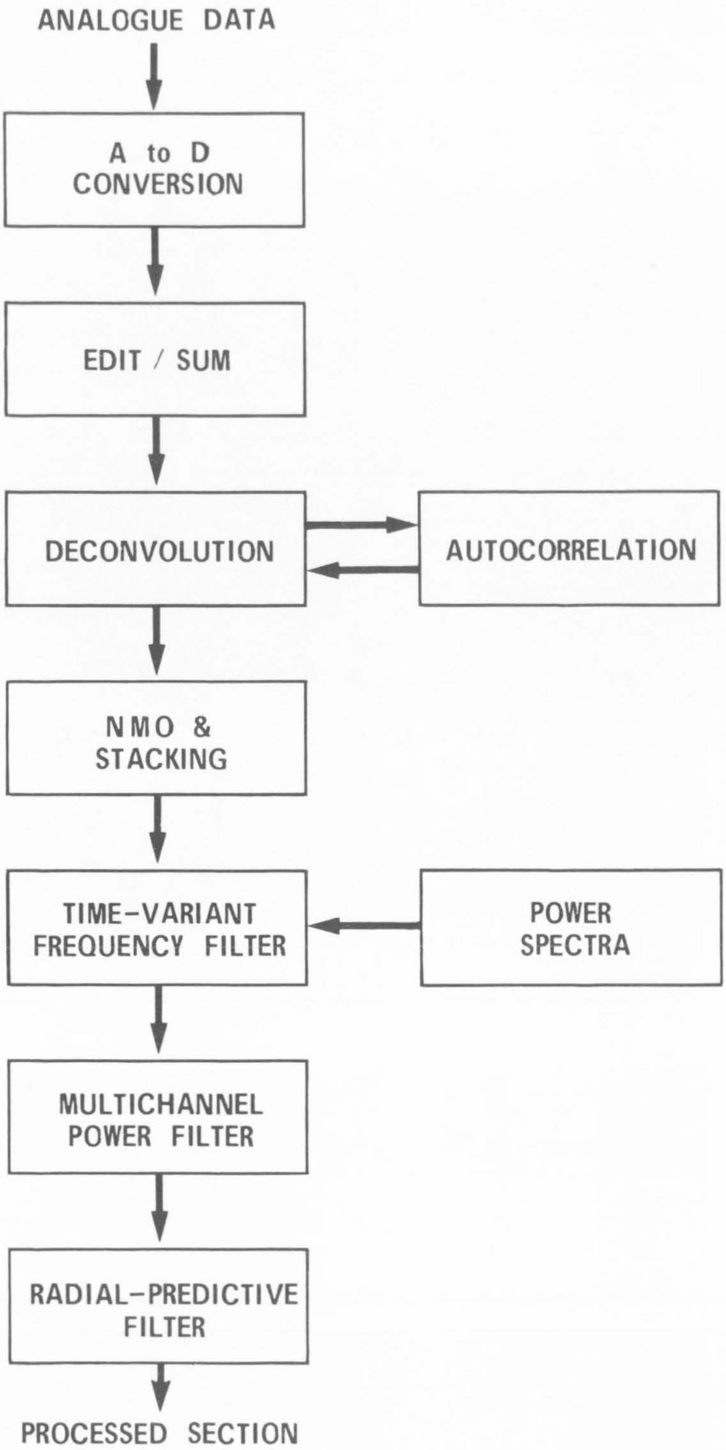
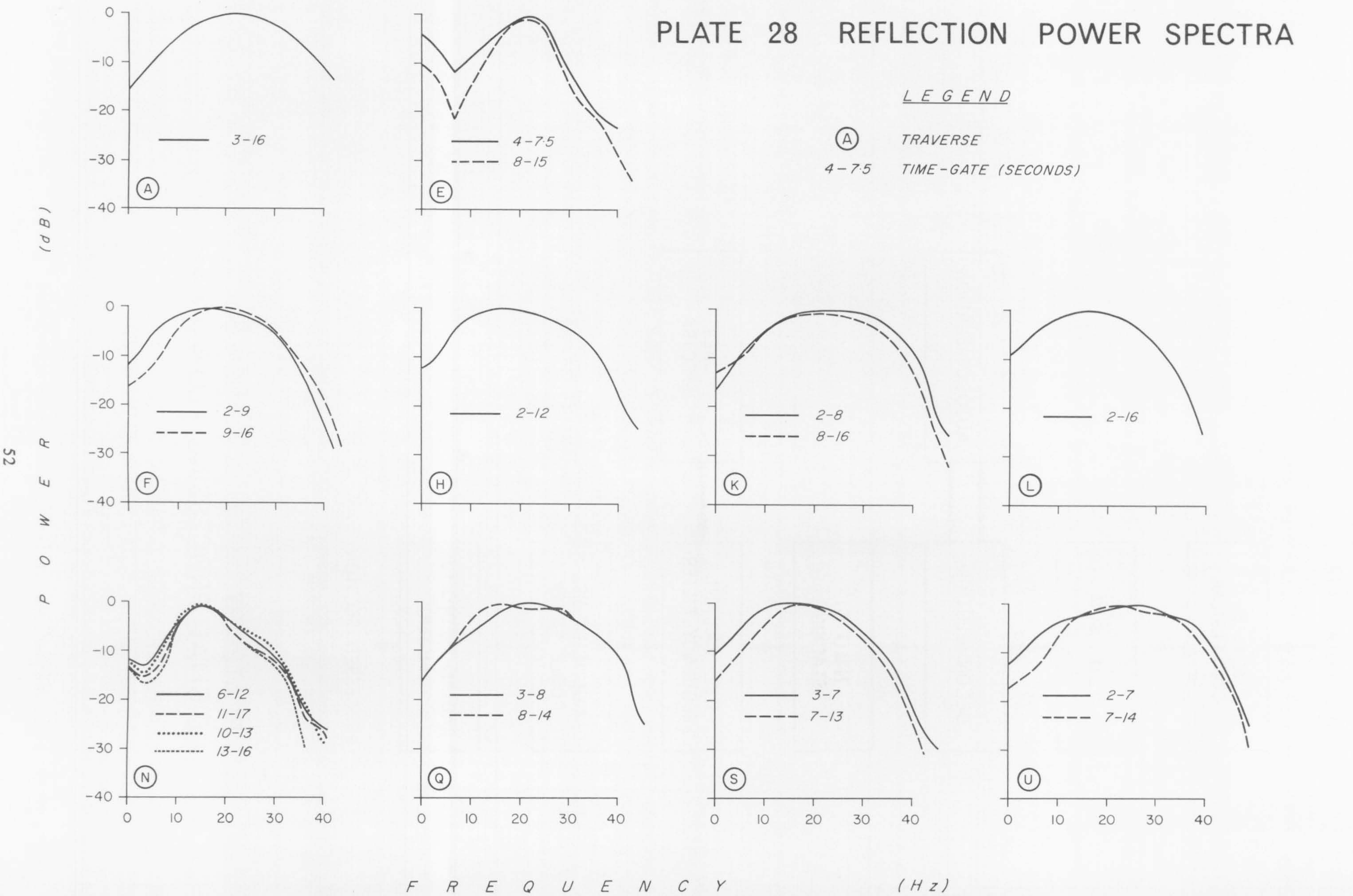


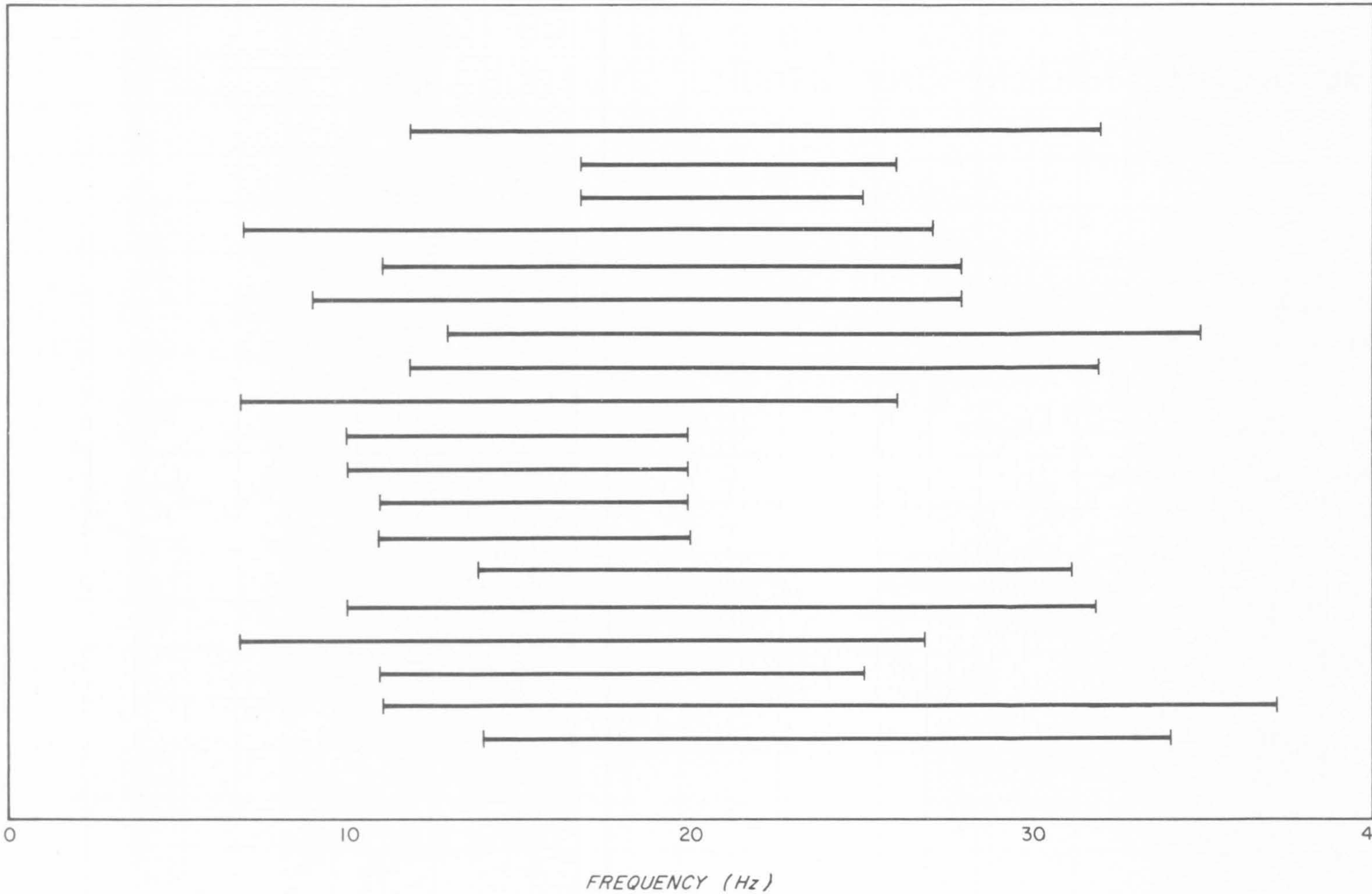
PLATE 27
DIGITAL PROCESSING FLOW CHART

WA/B3-57A

PLATE 28 REFLECTION POWER SPECTRA



WA/83-34

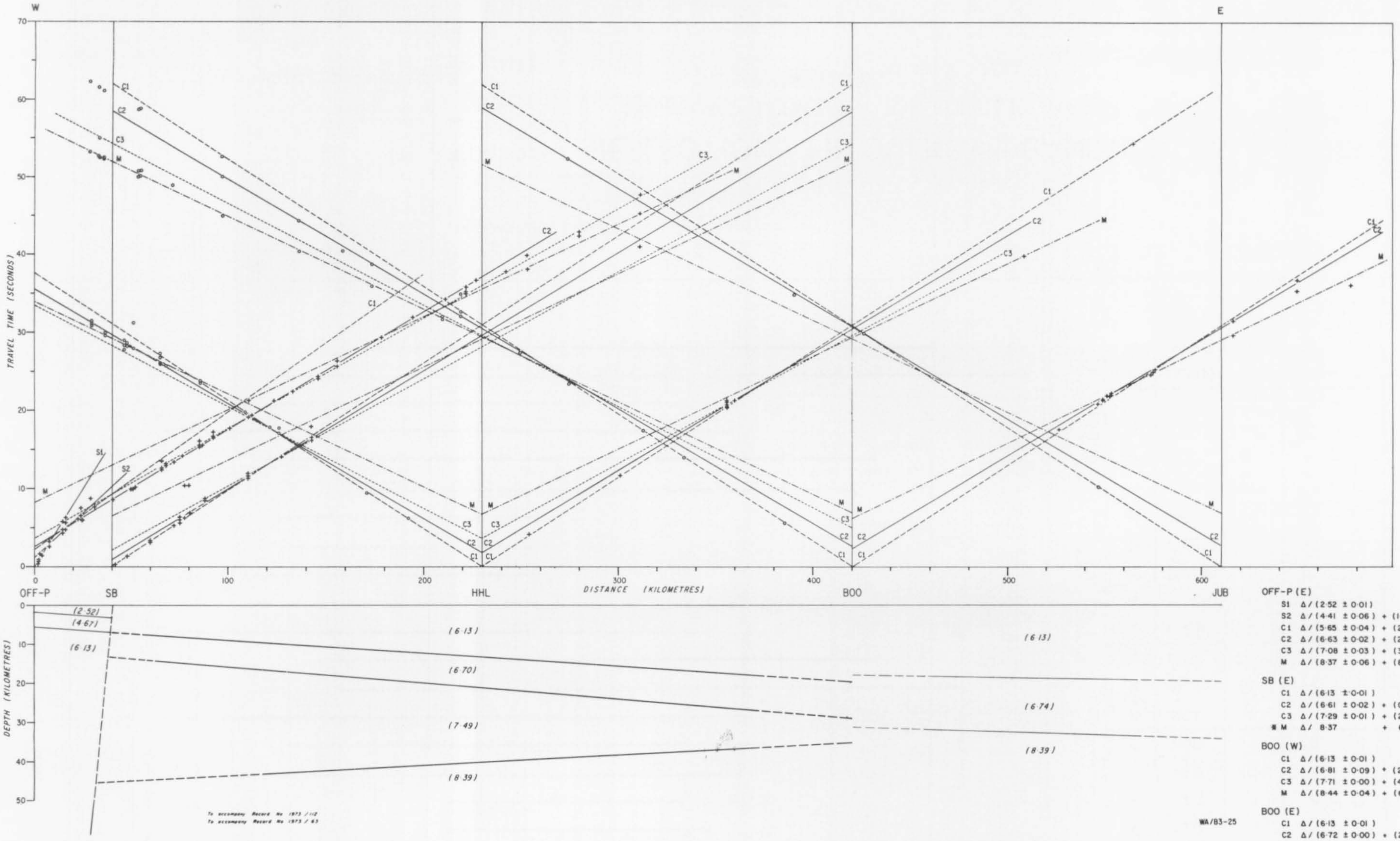


Traverse	Shot-point	Trace No.	Time – gate (s)	AREA
A	509	20	3 – 16	FRASER RANGE
E	122	5	4 – 7·5	
E	122	5	8 – 15	
F	168	10	2 – 9	
F	168	10	9 – 16	
H	805	18	2 – 12	HINES HILL
K	1006	21	2 – 8	
K	1006	21	8 – 16	
L	1106	20	2 – 16	BOORABBIN
N	1303(1)	16	6 – 12	
N	1303(1)	16	10 – 13	
N	1303(1)	16	13 – 16	
N	1303(1)	16	11 – 17	
Q	1614	22	3 – 8	WIDGIEMOOLTHA
Q	1614	22	8 – 14	
S	1813(4)	4	3 – 7	
S	1813(4)	4	7 – 13	
U	2014(1)	4	2 – 7	WUNDOWIE
U	2014(1)	4	7 – 14	

PLATE 29 REFLECTION FREQUENCY BANDWIDTHS

(MEASURED BETWEEN – 3dB POINTS)

WA/B3-33A



OFF-P (E)
S1 Δ/(2·52 ± 0·01)
S2 Δ/(4·41 ± 0·06) + (1·15 ± 0·06)
C1 Δ/(5·65 ± 0·04) + (2·23 ± 0·03)
C2 Δ/(6·63 ± 0·02) + (2·53 ± 0·05)
C3 Δ/(7·08 ± 0·03) + (3·67 ± 0·10)
M Δ/(8·37 ± 0·06) + (8·16 ± 0·17)

SB (E)
C1 Δ/(6·13 ± 0·01)
C2 Δ/(6·61 ± 0·02) + (0·92 ± 0·07)
C3 Δ/(7·29 ± 0·01) + (2·14 ± 0·05)
* M Δ/ 8·37 + 6·51

BOO (W)
C1 Δ/(6·13 ± 0·01)
C2 Δ/(6·81 ± 0·09) + (2·61 ± 0·46)
C3 Δ/(7·71 ± 0·00) + (4·95 ± 0·00)
M Δ/(8·44 ± 0·04) + (6·87 ± 0·18)

BOO (E)
C1 Δ/(6·13 ± 0·01)
C2 Δ/(6·72 ± 0·00) + (2·44 ± 0·00)
M Δ/(8·29 ± 0·39) + (6·32 ± 0·86)

JUB (W)
C1 Δ/(6·13 ± 0·01)
C2 Δ/(6·76 ± 0·12) + (2·67 ± 0·60)
* M Δ/ 8·50 + 6·92

* ASSUMED VELOCITY

PLATE 30 TIME-DISTANCE CURVES AND INTERPRETATION BETWEEN PERTH AND THE JUBILEE MINE

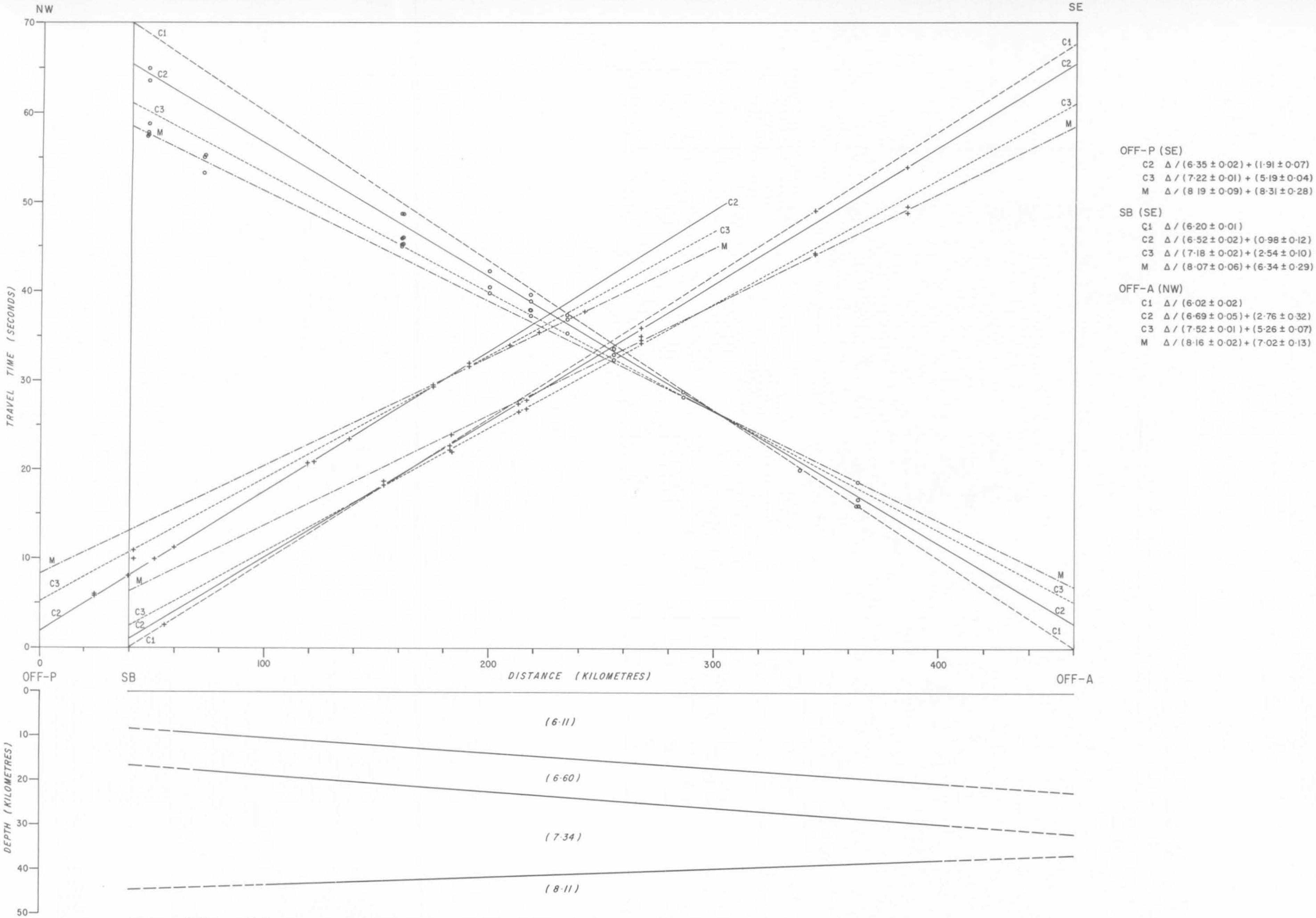


PLATE 31 TIME-DISTANCE CURVES AND INTERPRETATION BETWEEN PERTH AND ALBANY

WA/B3-27

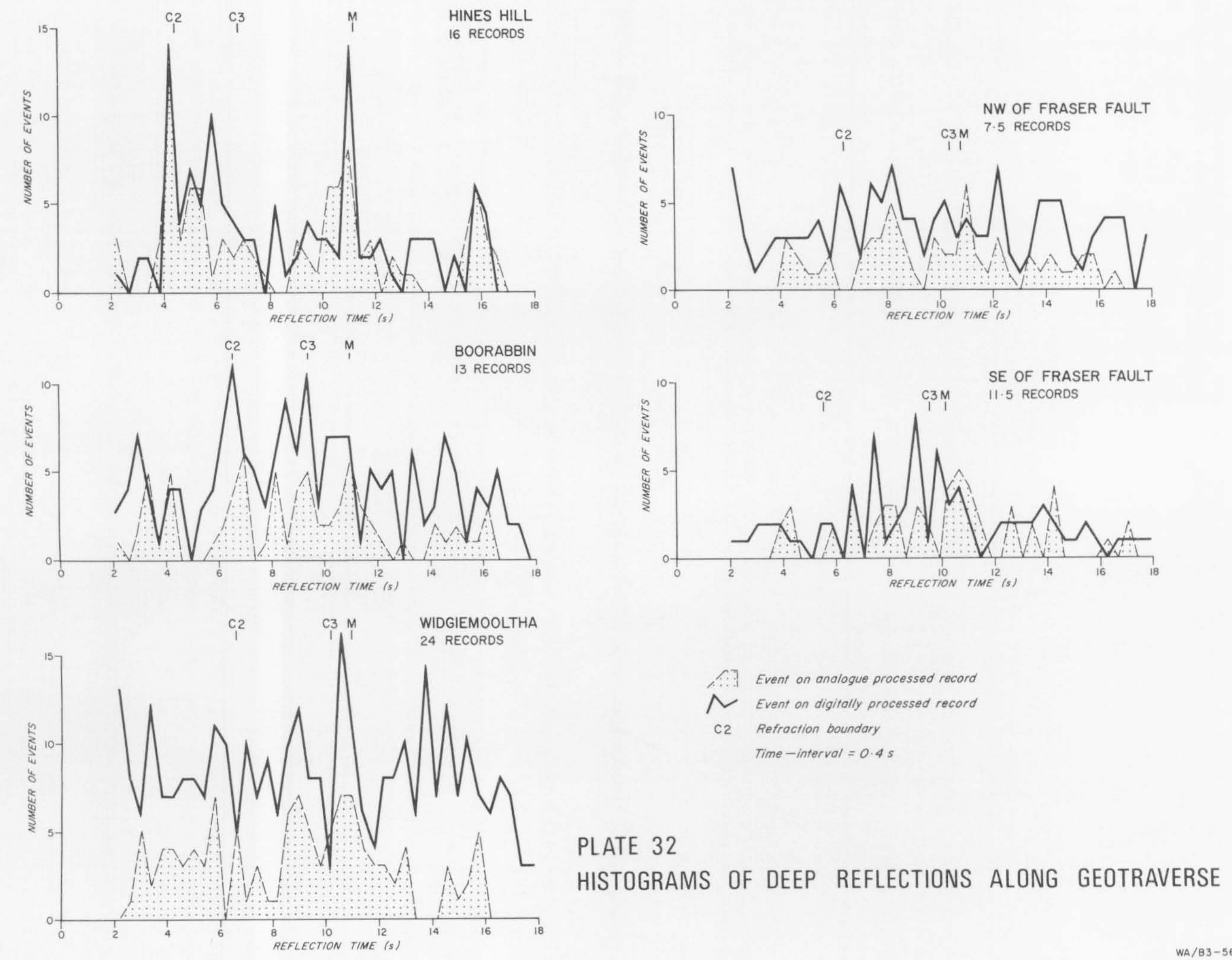


PLATE 32
HISTOGRAMS OF DEEP REFLECTIONS ALONG GEOTRAVERSE

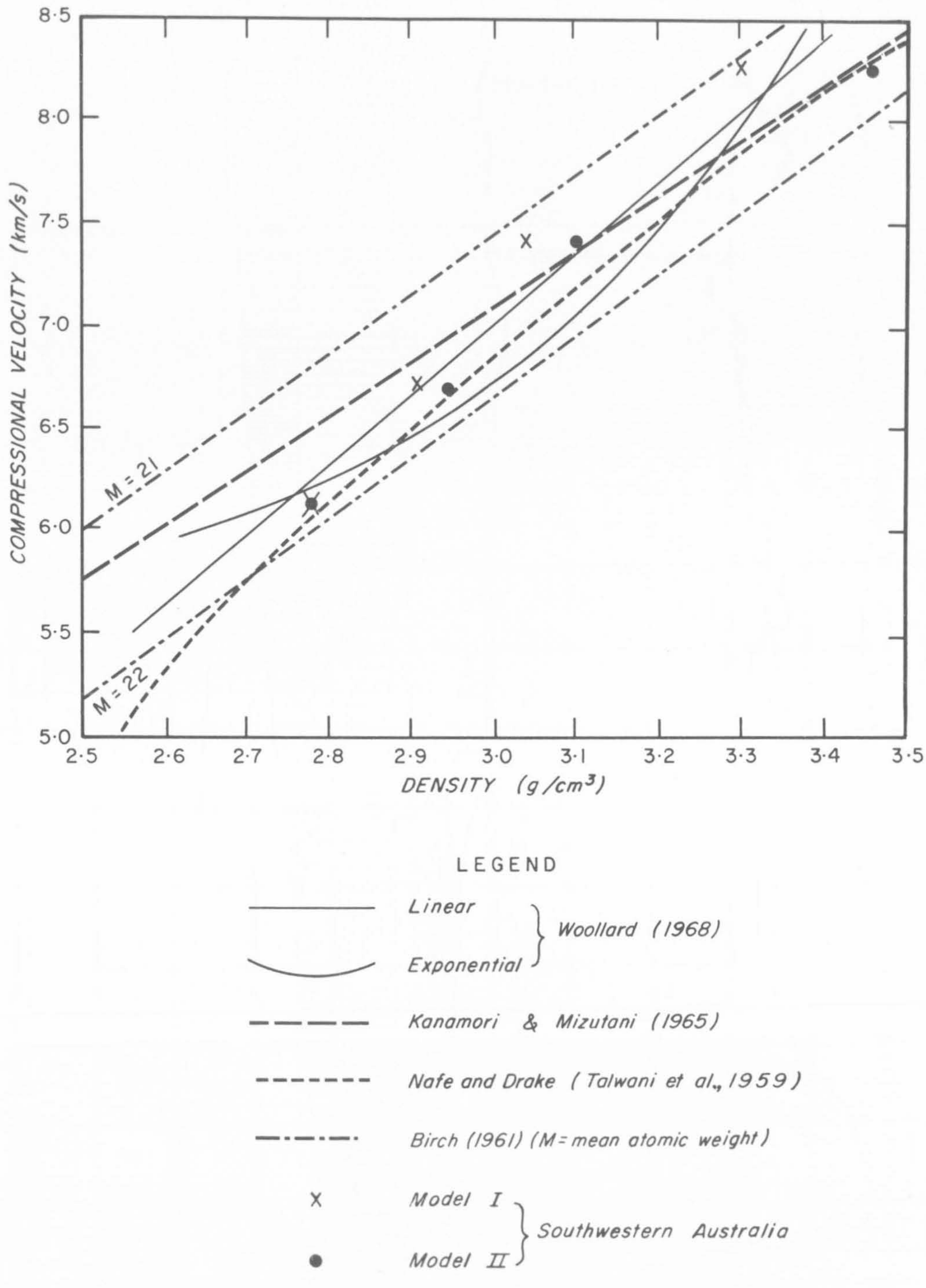


PLATE 34 DENSITY-VELOCITY RELATIONS

WA/B3–26A

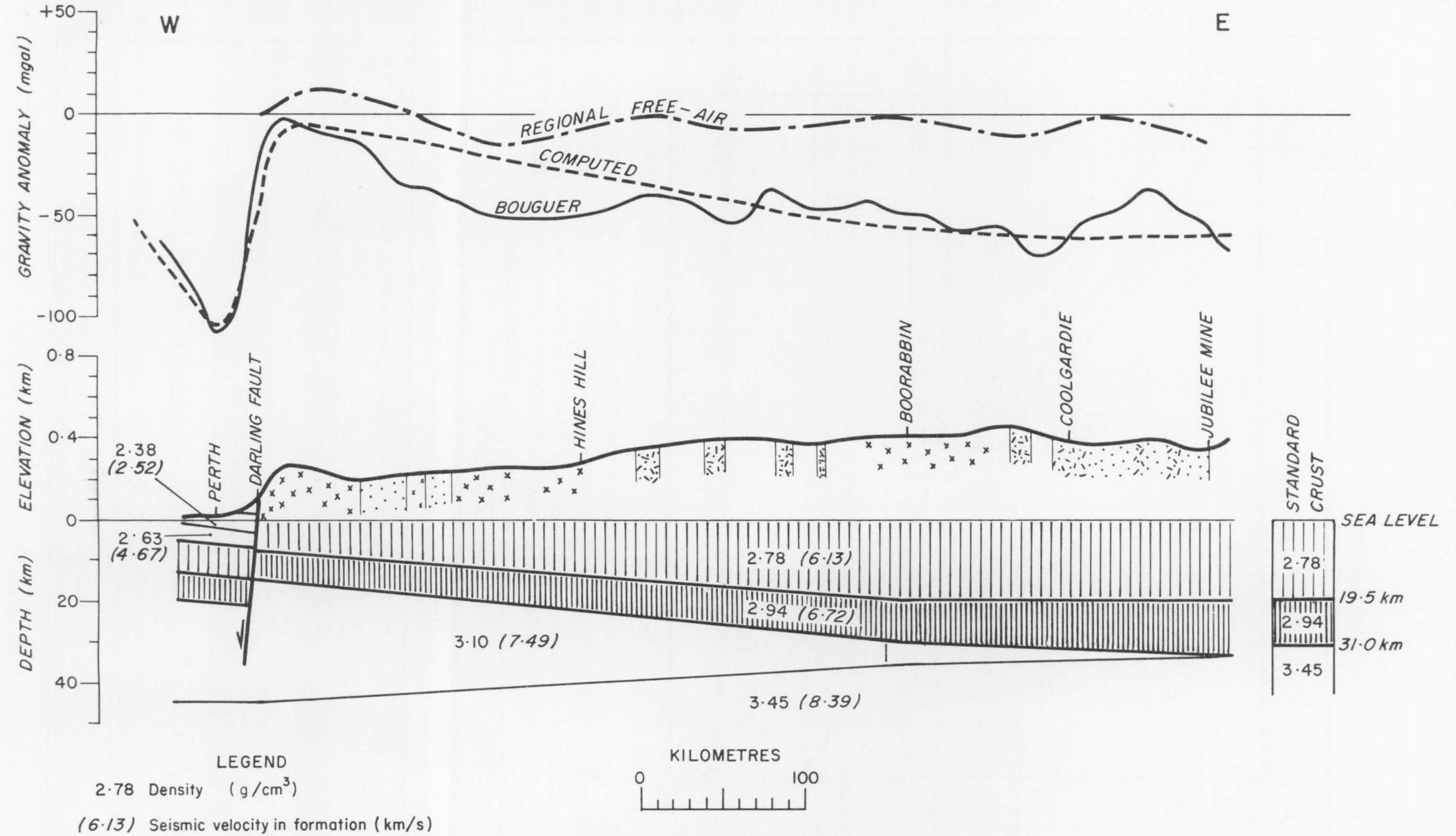


PLATE 35 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN PERTH AND THE JUBILEE MINE

WA/B3-29-1A

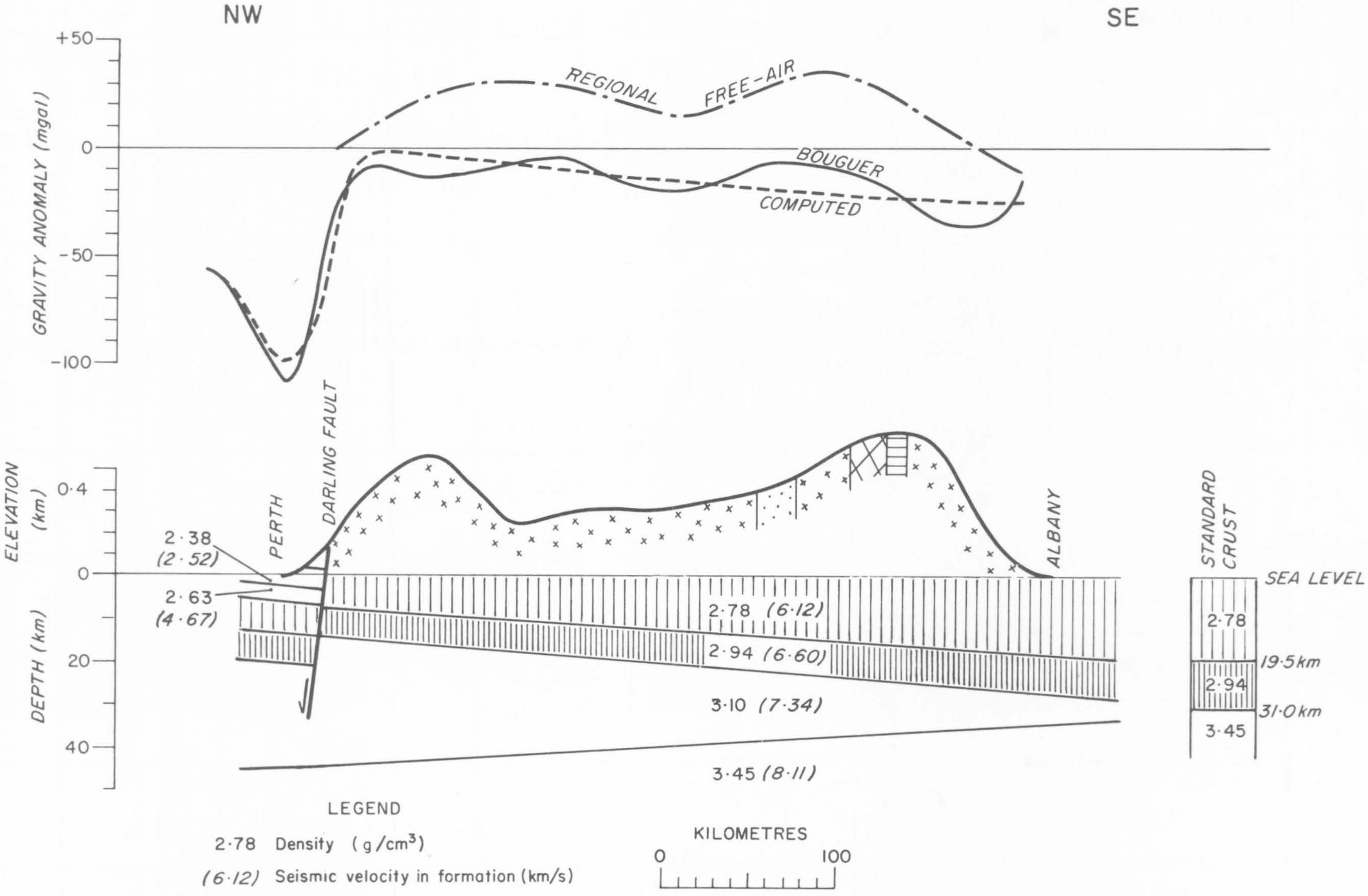


PLATE 36 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN PERTH AND ALBANY

WA/B3-31-1A

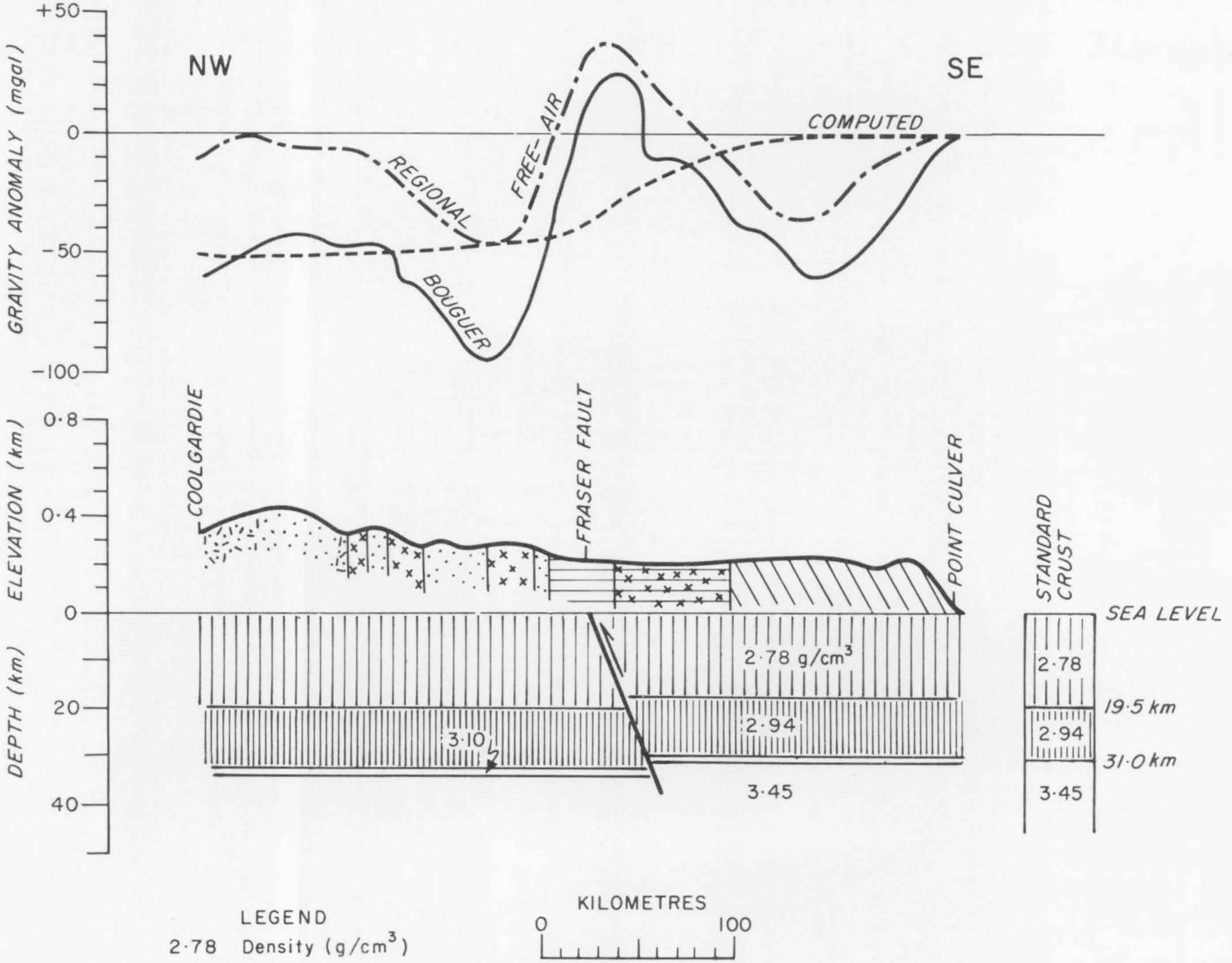


PLATE 37 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN COOLGARDIE AND POINT CULVER

WA/B3-30-1A

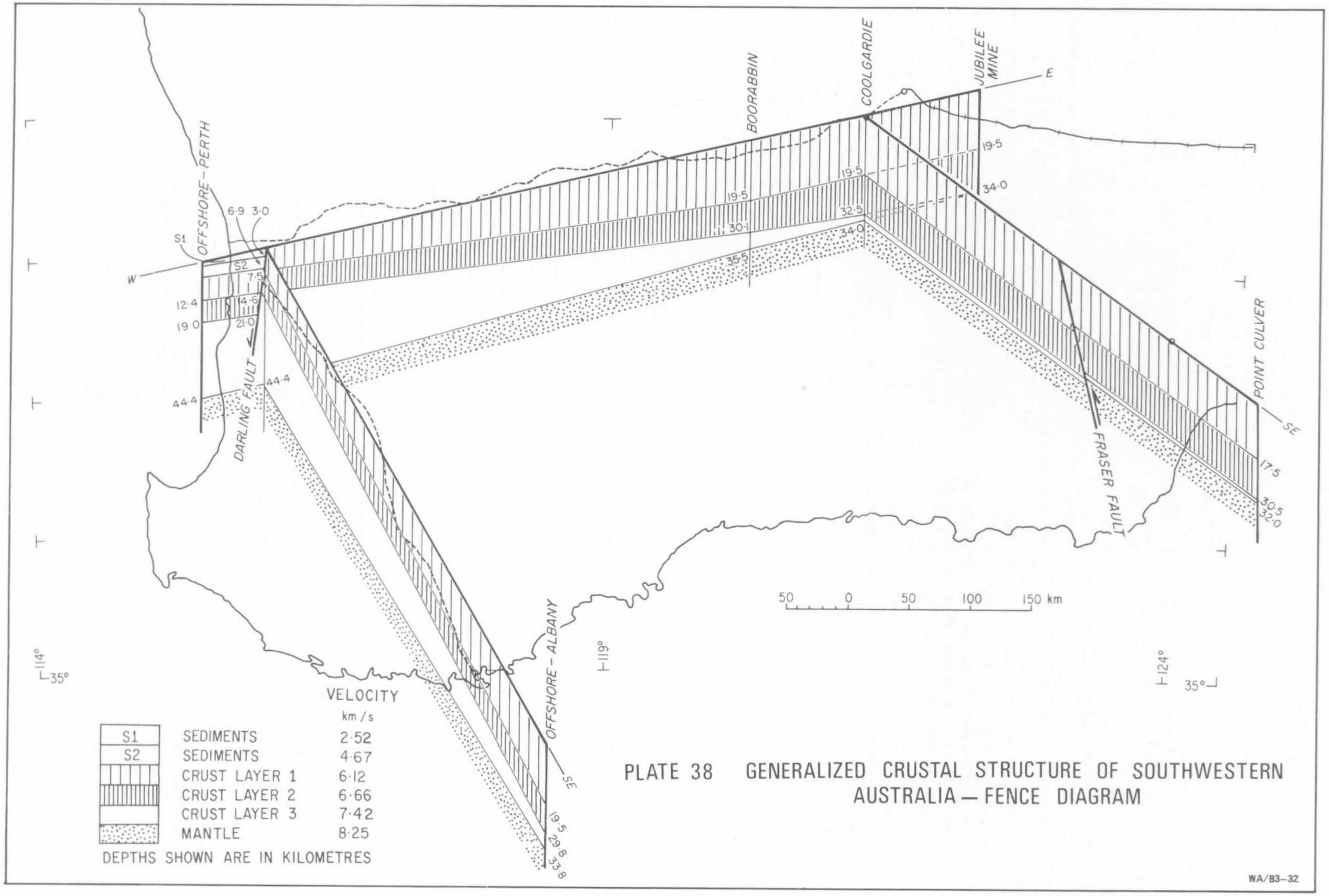


PLATE 38 GENERALIZED CRUSTAL STRUCTURE OF SOUTHWESTERN AUSTRALIA — FENCE DIAGRAM

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PLATE 33 REFLECTION RESULTS AND STRUCTURE ALONG GEOTRAVERSE