REPORT 175

Galilee Basin Seismic and Gravity Survey, Queensland 1971

P. L. Harrison, W. Anfiloff, and F. J. Moss

DEPARTMENT OF MINERALS AND ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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SUMMARY

The Bureau of Mineral Resources made a seismic and detailed gravity survey east of the Lake Galilee No. 1 well in the Galilee Basin, central Queensland, between August and November 1971. The aim of the survey was to investigate the structure of the eastern part of the Galilee Basin and its relation to the Drummond Basin.

Single-coverage seismic reflection profiling, and some six-fold CDP multiple-coverage profiling were done on a traverse from the well to outcrops of Drummond Basin sediments. A continuous seismic reflection section from the well to the outcrops was constructed by including previous reflection results obtained in the area. Expanded reflection spreads were shot for velocity control, and some refraction work was done to provide supplementary information at the eastern end of the traverse. Gravity was read on the traverse at seismic shot-points, beyond the eastern end of the traverse over a large gravity high at Mount Donnybrook, and along short cross-traverses.

The quality of the seismic reflection results varied from good to poor. The area was a difficult one in which to record consistently good data. Many of the problems, including low energy penetration and strong multiples resulted from the presence of the 'P' horizon, a strong and fairly shallow reflection associated with the Upper Permian coal measures. Strong random noise and variable ground coupling were also problems along the entire traverse.

The survey defined a sedimentary section thickening from 3800 m at the Lake Galilee No. 1 well to about 6300 m at the eastern end of the seismic traverse. The Galilee Basin sequence is shown to thin and shallow towards the basin edge, and the Upper Permian coal measures apparently subcrop immediately west of the Belyando River. A simple overlap between the Galilee and Drummond basins is indicated, with a narrow wedge of Drummond Basin sediments extending about 20 km west of the Belyando River. The Devonian sequence, entered at 2840 m in the Lake Galilee No. 1 well, is mapped across the basin with fairly uniform thickness, and is shown to shallow eastwards.

From west of the Belyando River across the Galilee Basin edge, the deepest horizon has a reverse dip to the rest of the section. It marks the base of an unidentified, possibly Lower Devonian, sequence which thickens considerably eastwards towards the Drummond Basin.

Immediately east of the Belyando River, the seismic results indicate a highly faulted zone which has been interpreted as a zone of lateral faulting with little or no vertical displacement. This is supporting evidence for the postulated Chinaman Megashear.

The gravity results in conjunction with the seismic results and geological mapping support the postulate of basement uplift in the western part of the Drummond Basin. Model studies indicate that a 37-mgal gravity high over Mount Donnybrook — the 'Donnybrook Gravity High' — may be attributed to a 2-km uplift in basement before deposition of the Drummond Basin sequence. The gravity low west of the Belyando River is considered to be due to a granite pluton at depth. A gentle upward bulge in the two deepest seismic reflection horizons above the position of the postulated granite mass suggests that the mass antedates Drummond Basin deposition and was formed contemporaneously with the basement uplift.

INTRODUCTION

A program of seismic and detailed gravity work was done by the Bureau of Mineral Resources (BMR) in the Galilee Basin east of Lake Galilee, central Queensland, during the period August to December 1971.

The Galilee Basin, an extensive Upper Carboniferous to Upper Triassic basin, trends north and overlies the western margin of the late Upper Devonian to Lower Carboniferous Drummond Basin. A strong gravity gradient east of Lake Galilee appears to be associated with the boundary between the two basins. The Drummond Basin rocks seen in outcrop are not present in Lake Galilee No. 1 well. All available information on the Galilee Basin sediments east of the well indicated that the basin margin was structurally controlled or that the basin sediments thin towards the margin. Knowledge of the basin margin is considered to be important because of an oil show near the base of the Galilee Basin sequence in Lake Galilee No. 1 well and the widespread occurrence of Upper Permian coal measures in the basin.

The area was covered previously by regional aeromagnetic and gravity surveys. Seismic work has been confined mainly to areas west and north of Lake Galilee No. 1 well and has not extended to the eastern margin of the Galilee Basin, east from the well. R. R. Vine (pers. comm.) proposed several alternative structural interpretations of the basin's eastern margin. However, sufficient information was not available from analysis of the previous geophysical data to resolve the nature of the margin.

The seismic and gravity survey that forms the subject of this Report was in the area from Lake Galilee No. 1 well to the Drummond Basin outcrops in the east (Fig. 1). Single-coverage and multiple-coverage continuous seismic reflection profiling techniques were used, and gravity observations were made at close intervals along the main traverse, on several short cross-traverses, and on an extension of the line eastwards beyond the end of the seismic traverse.

Operational reports on the seismic and gravity survey (Harrison & Brown, 1971; Anfiloff, 1972) provide details of staff, equipment, operational statistics, and preliminary results.

GEOLOGY

Regional setting

The regional geology is illustrated in Figure 2. Sediments in the central part of Queensland near GALILEE* occur in several overlapping basins. From oldest to youngest these are the late Upper Devonian to Lower Carboniferous Drummond Basin, the late Upper Carboniferous to Upper Triassic Galilee Basin and the Jurassic-Cretaceous Eromanga Basin. The axes of the Drummond and Galilee Basins are roughly meridional. The three basins are successively displaced to the west in the given order. Outcropping basement in the Anakie High and the Ravenswood Arch forms the eastern and northern limits of the Drummond Basin. Widespread Cainozoic cover makes surface geological data sparse; in particular, the eastern margin of the Galilee Basin is concealed. The western margin of the

* In this Report the names of 1:250 000 Sheet areas are written in capital letters to distinguish them from ordinary place names.

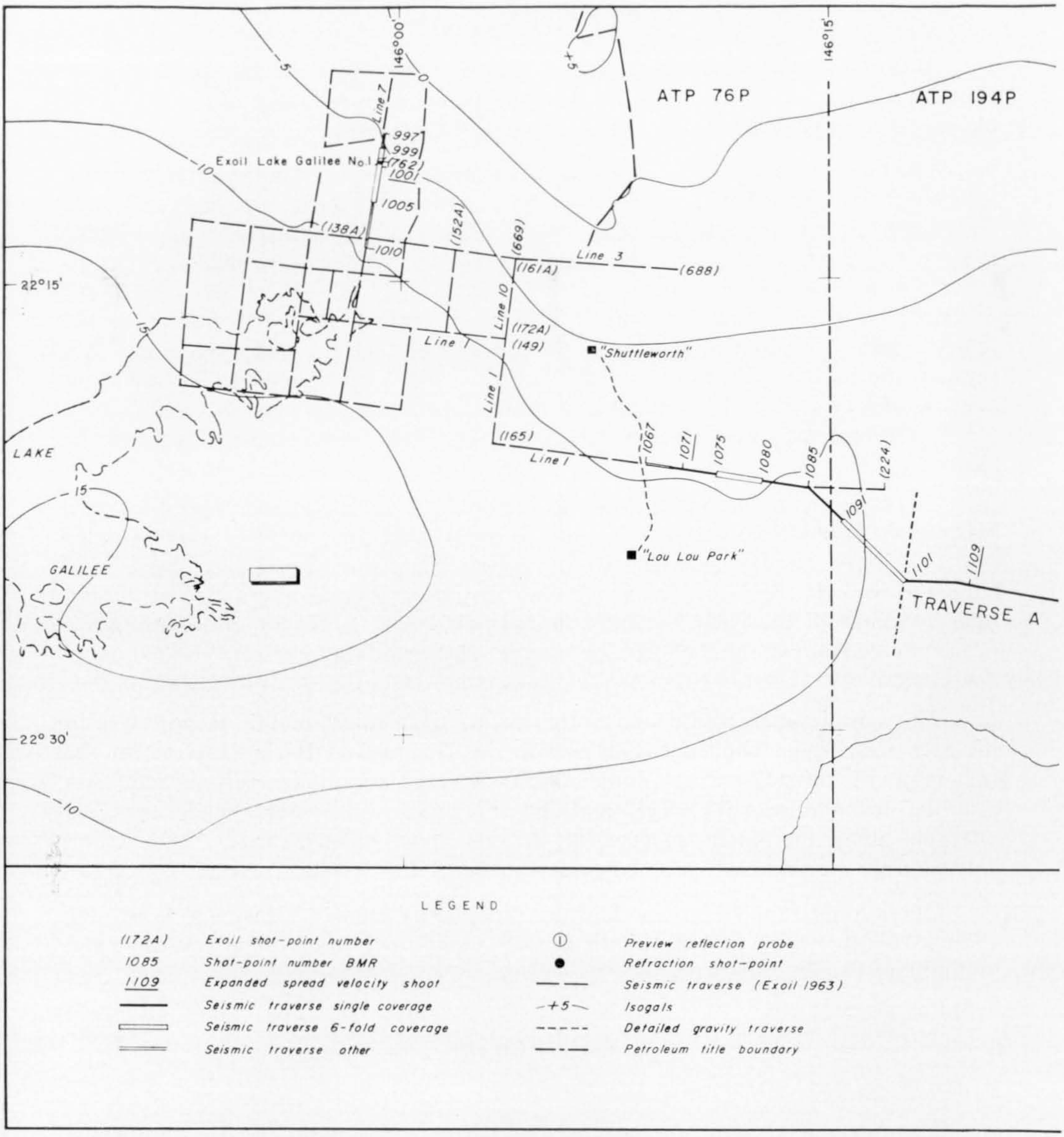


Fig. 1. Locality map.

Drummond Basin is unknown as it is overlain by Galilee Basin sediments. Petroleum exploration wells are widely spaced and provide little evidence of the extent of the basins.

Stratigraphy

The generalized stratigraphy of the three basins in GALILEE is given in Table 1.

The present Drummond Basin outcrop is a structural remnant of a large intermontane basin that resulted from a downwarp in the Tasman geosynclinal zone after the late Middle Devonian Tabberabberan Orogeny (Olgers, 1973). It received

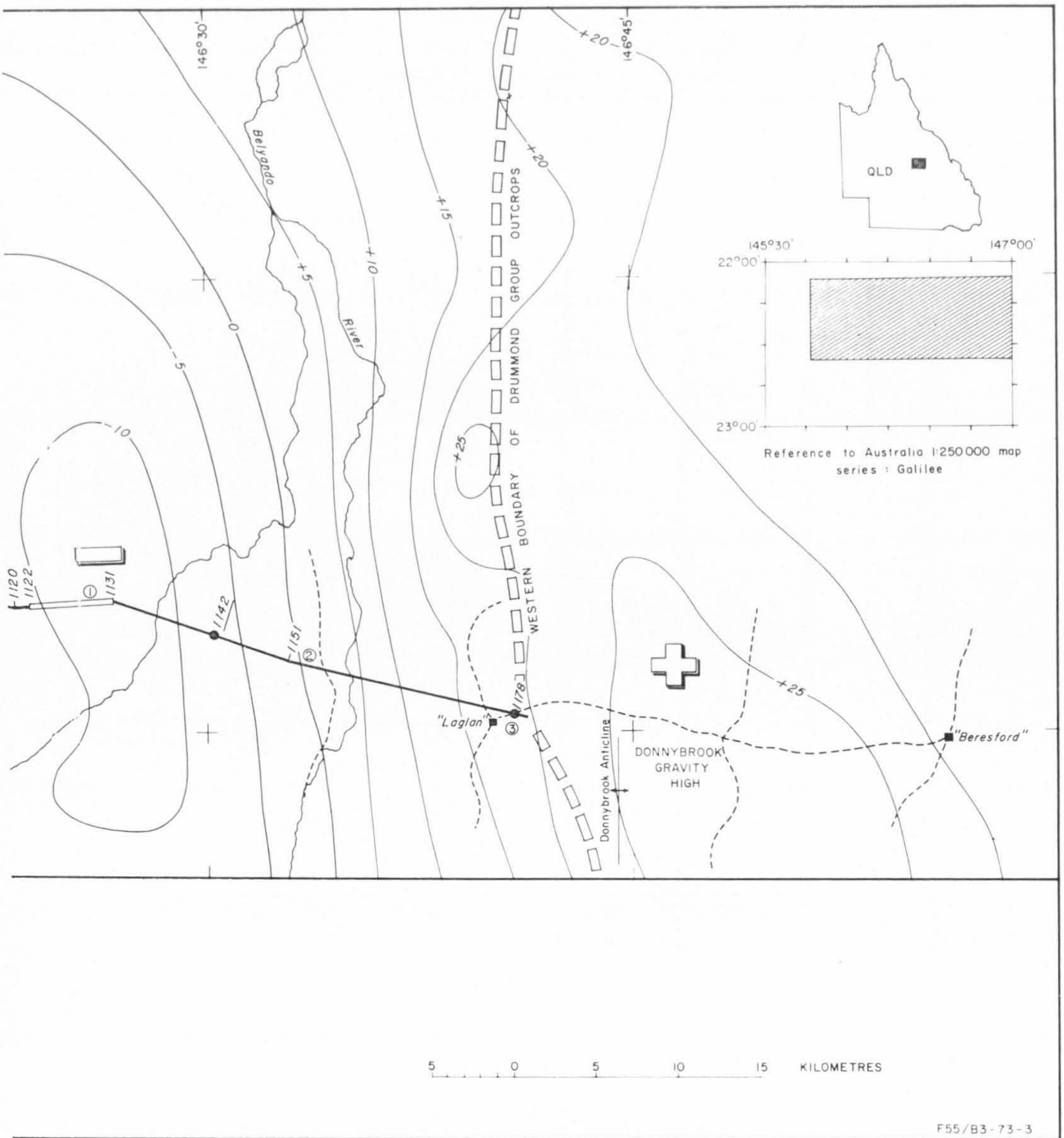


Fig. 1.—Continued.

up to 13 000 m of mainly fluviatile sediments which were carried by generally north-flowing rivers. Sedimentation was terminated by the mid-Carboniferous Kanimblan Orogeny when the sequence was folded and uplifted to form a structural high. This subsequently provided a source of sediment for the Galilee and Bowen Basins.

Sedimentation in the Galilee Basin was also mainly fluviatile, and continued with minor breaks from the Upper Carboniferous until the Upper Triassic. There is evidence of glacial conditions in the Upper Carboniferous and again in the Lower Permian. Mild folding and uplift and some erosion occurred at the end of the Triassic.

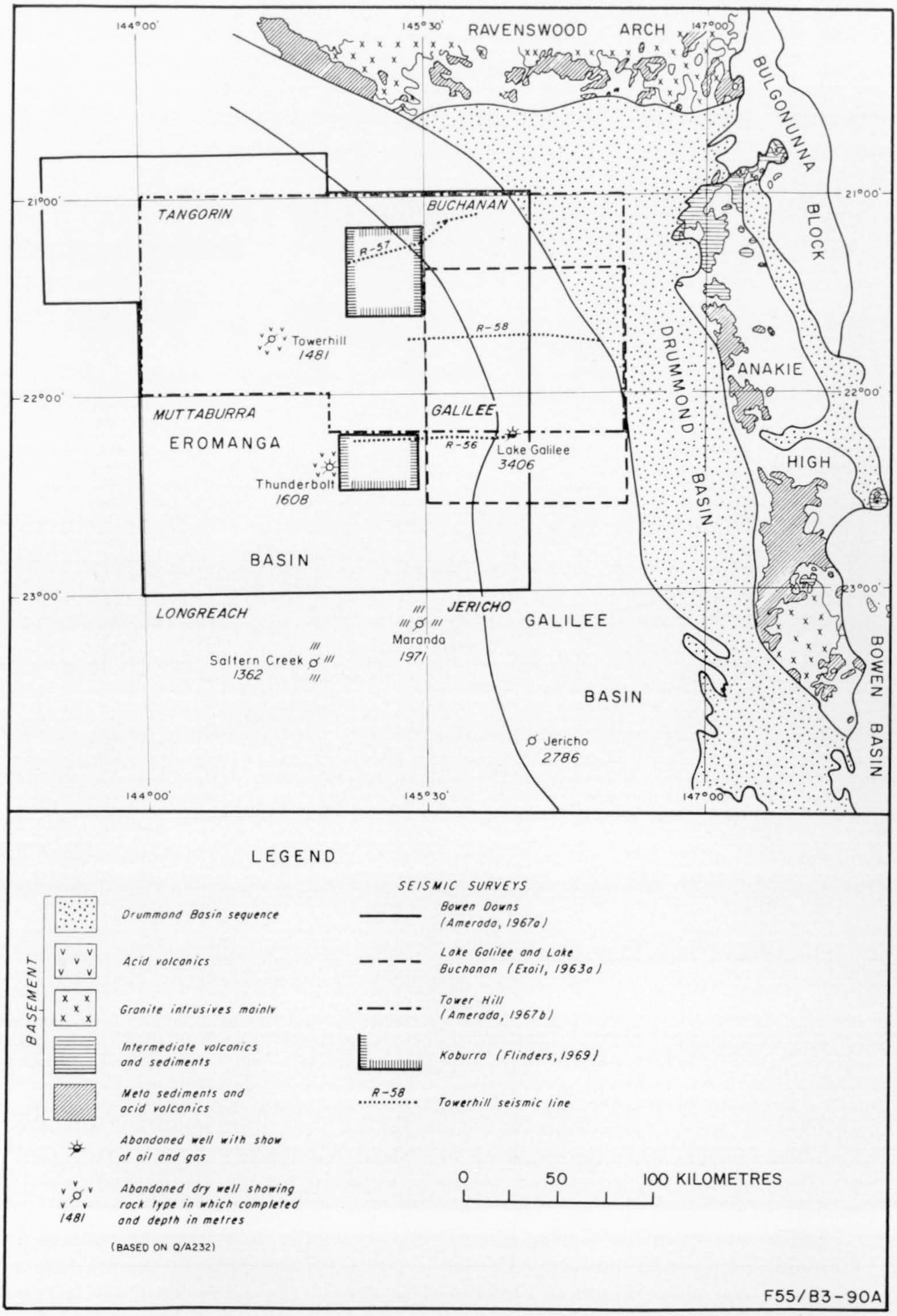


Fig. 2. Regional geology and location of previous seismic surveys.

TABLE 1.

GENERALIZED STRATIGRAPHY

Basin	*Age*	*Group*	*Formation*	*Approximate Thickness (m)*
	QUATERNARY TO ?TERTIARY		Alluvium, soil, sand; duricrust; sandstone, mudstone	superficial; 100 max.; 15 max.
			UNCONFORMITY	
EROMANGA	LOWER CRETACEOUS	ROLLING DOWNS	Doncaster Member of Wallumbilla Formation (mudstone)	60 max.
EROMANGA	JURASSIC TO LOWER CRETACEOUS		Ronlow Beds (sandstone)	130 max.
			UNCONFORMITY	
GALILEE	MIDDLE TO UPPER TRIASSIC		Moolayember Formation (mudstone, siltstone, sandstone)	500 max.
GALILEE	LOWER TO MIDDLE TRIASSIC		Clematis Sandstone	100 - 150
GALILEE			LOCAL DISCONFORMITY	
GALILEE	LOWER TRIASSIC	MIMOSA	Dunda Beds (sandstone, siltstone)	60 - 100
GALILEE			Rewan Formation (mudstone, siltstone)	200 - 330
GALILEE	?LOWER-UPPER PERMIAN		Unnamed shale, coal, sandstone	160 - 200
GALILEE			REGIONAL UNCONFORMITY	
GALILEE	UPPER CARBONIFEROUS TO LOWER PERMIAN		Unnamed shale, coal, sandstone, siltstone	600 - 1800
			UNCONFORMITY	
DRUMMOND	LOWER CARBONIFEROUS	DRUMMOND	Ducabrook Formation (mudstone, sandstone)	1200 +
DRUMMOND			Star of Hope Formation (sandstone, tuff)	1200 max.
DRUMMOND			LOCAL DISCONFORMITY	
DRUMMOND			Mount Hall Formation (pebble conglomerate, mudstone, sandstone)	1000 max.
DRUMMOND			Telemon Formation (sandstone, mudstone, tuff)	1500 +
			RELATION OBSCURE	
	MIDDLE TO UPPER DEVONIAN		Sandstone, shale, siltstone	2000 max.
			UNCONFORMITY	
	?LOWER PALAEOZOIC		Basement, probably low-grade metamorphics, acid intrusives, and related extrusives	

The most valuable source of information on the Galilee Basin sequence is from Exoil Lake Galilee No. 1 petroleum exploration well (Pemberton, 1965) which drilled the thickest known sequence in the basin, almost 3000 m. This sequence includes about 1800 m of Upper Carboniferous to Lower Permian sediments, about 200 m of Upper Permian sediments, and more than 800 m of the Triassic Mimosa Group. The Upper Permian sediments include thick coal seams which provide a strong seismic reflector, the 'P' reflector.

The Eromanga Basin contains more than 2000 m of terrestrial and marine sediments, deposited as a result of regional downwarping which began in the Lower Jurassic and continued to the Upper Cretaceous. Only a thin marginal facies is present in GALILEE.

Lake Galilee No. 1 well drilled 565 m of sediments of late Middle or early Upper Devonian age below the Galilee Basin sequence (Playford, Appendix 1a *in* Pemberton, op. cit.). Drummond Basin sediments were not encountered in the well, and a major unconformity between the Upper Carboniferous and early Upper Devonian sediments represents the time of Drummond Group deposition.

Basement

Basement does not crop out in GALILEE. The nearest exposed basement is the Anakie High, a north-northwest-trending ridge of pre-Devonian Anakie Metamorphics, Middle Devonian volcanics and sediments, and Upper Devonian granite (Olgers, 1973).

The only petroleum exploration well in GALILEE, Exoil Lake Galilee No. 1 well, did not reach basement. A fairly strong seismic horizon recorded at a depth of about 4000 m near the well and interpreted as basement (Amerada, 1967b), may be followed with difficulty westward to the base of Thunderbolt No. 1 well, which bottomed in acid volcanics. The age of the volcanics is uncertain. Other petroleum exploration wells drilled in the area are shown in Figure 2. Maranda No. 1 well and Saltern Creek No. 1 well to the southwest of Lake Galilee No. 1 well bottomed in metasediments which may be equivalent to those in the Anakie High.

Acid volcanics in Towerhill No. 1 and Thunderbolt No. 1 wells to the west may be related to the Lower Palaeozoic Mount Windsor Volcanics in the Ravenswood Arch (Olgers, op. cit.). Jericho No. 1 well to the south intersected a pre-Permian sequence of redbeds with both clastics and volcanics. Vine (1972) suggested a tentative correlation with the Buckabie Formation of the Devonian Adavale Basin.

Structure

The major structural features of the area are illustrated in Figure 3. During the mid-Carboniferous Kanimblan Orogeny the eastern side of the Drummond Basin was uplifted and folded. Olgers (1973) postulated a primary regional compression from the east, with movement along northwest-trending and northeast-trending faults and fault zones with folding around the apex of the moving block. Movement also occurred along at least two major fault zones which formed in the basement parallel to those bounding the moving block. The most prominent of these is the Chinaman Megashear, part of which is the Chinaman Fault.

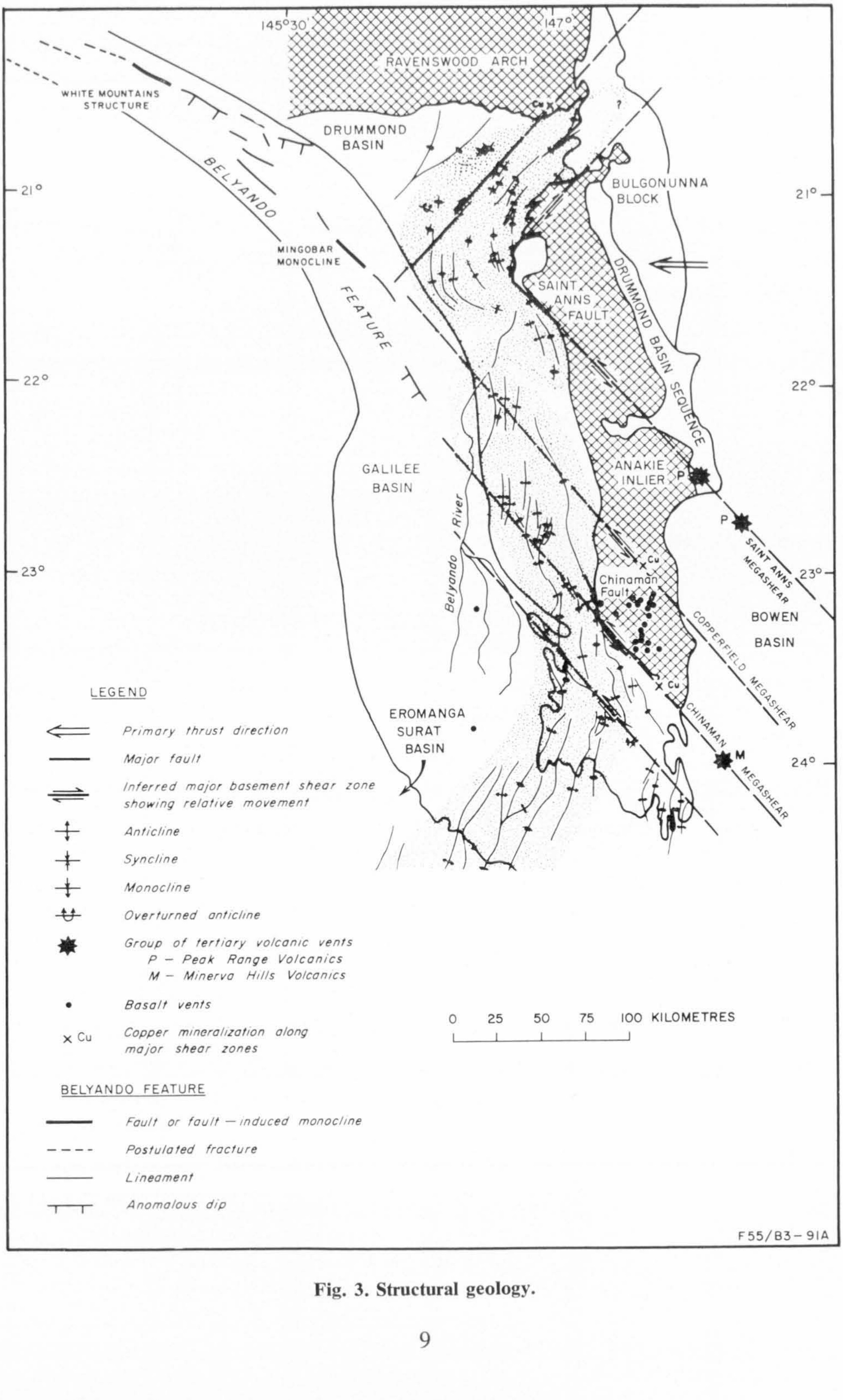


Fig. 3. Structural geology.

Doutch (*in* Vine and Doutch, 1972) considered that the structure in GALILEE can be more simply explained by simple vertical basement movements during and after sedimentation in the Drummond Basin.

Deformation appears to die out westwards away from the Anakie High, and in the central part of the Drummond Basin the wavelength and amplitude of folding decrease to the west.

Unlike the Drummond Basin, the Galilee Basin is structurally little-disturbed Dips are generally less than 1°. Seismic surveys over much of the basin have disclosed only broad structures of low amplitude. Lake Galilee No. 1 well was drilled on the largest known structure, an anticline with amplitude about 50 m in Upper Permian sediments.

Vine (1972) proposed the name Belyando Feature for a major lineament which includes the straight course of the Belyando River where it coincides with a steep gravity gradient in GALILEE, the Mingobar Monocline in BUCHANAN, the White Mountains Structure in HUGHENDEN, and other interpreted fracture zones. The Belyando Feature, illustrated in Figure 3, marks the general division of the Galilee Basin from Drummond Basin or basement outcrops. Vine considered that the lineament may represent a major basement discontinuity, movement along which controlled the westerly extent of the Drummond Basin and initiated the formation of the Galilee Basin.

PREVIOUS GEOPHYSICAL INVESTIGATIONS

Aeromagnetic, regional gravity, and seismic surveys over the northern Eromanga Basin and the Galilee and Drummond Basins include most of the area of interest to the survey. They succeeded in broadly defining the nature and extent of the basins.

Magnetic

Regional aeromagnetic surveys were made in GALILEE by Exoil N.L. (1962), in western JERICHO by Magellan Petroleum Corporation (1963), and in eastern JERICHO and to the east of GALILEE by BMR (unreported). BMR (Jewell, 1960) conducted an aeromagnetic survey of the Great Artesian Basin with widely spaced profiles.

The total magnetic intensity contours are shown in Figure 4. The interpretation of depth to magnetic basement shown by Gibb (1966) generally was not substantiated by subsequent seismic results. A recent interpretation of the magnetic results (H. D. Hsu, pers. comm.) indicates a rise of 2000 m in magnetic basement across the Belyando Feature.

Gravity

BMR reconnaissance gravity surveys from 1959 to 1963 covered the Drummond, Galilee, and Eromanga Basins (Gibb, op. cit.). The regional Bouguer anomaly contours are shown in Figure 5.

The prominent gravity features in GALILEE are the Donnybrook Gravity High (named here) and the steep gradient on its western flank ending in a minor

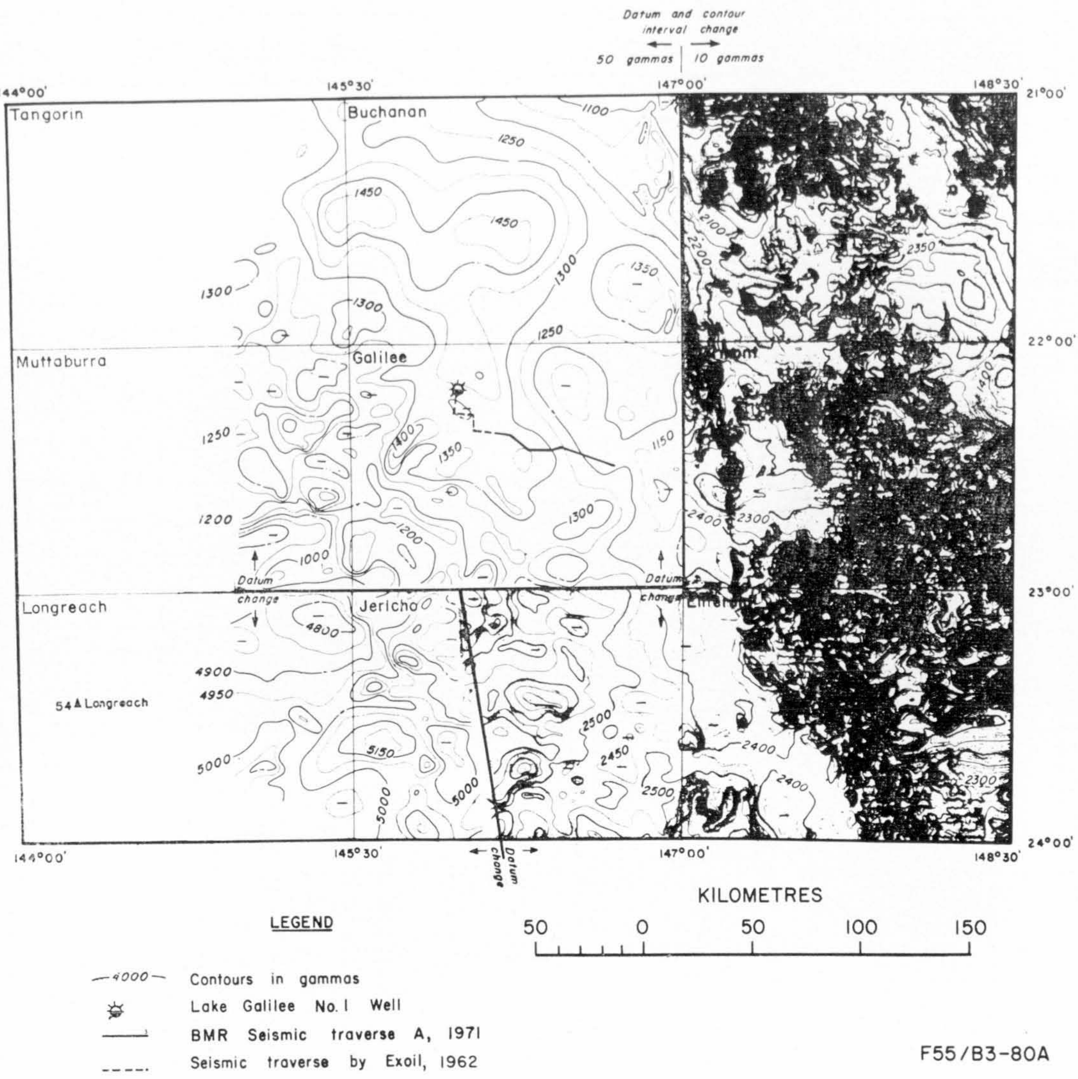


Fig. 4. Total magnetic intensity.

elongated low. The gravity-high peaks over the Drummond Group outcrops near Mount Donnybrook and appears to be part of a chain of gravity maxima trending roughly north-northwest for several hundred kilometres. The association of minor lows similar to that in GALILEE with many of these maxima may be significant and may indicate that the structure at the eastern margin of the Galilee Basin is similar along its entire length.

A semi-detailed gravity survey was made by the BMR in 1967 along seismic lines in the Northern Eromanga Basin (Watts & Brown, in prep.). The area covered included the western halves of GALILEE and BUCHANAN as well as MUTTA-BURRA, TANGORIN, and southern HUGHENDEN. The results of the survey suggested that there is little or no correlation between Bouguer anomalies and sedi-

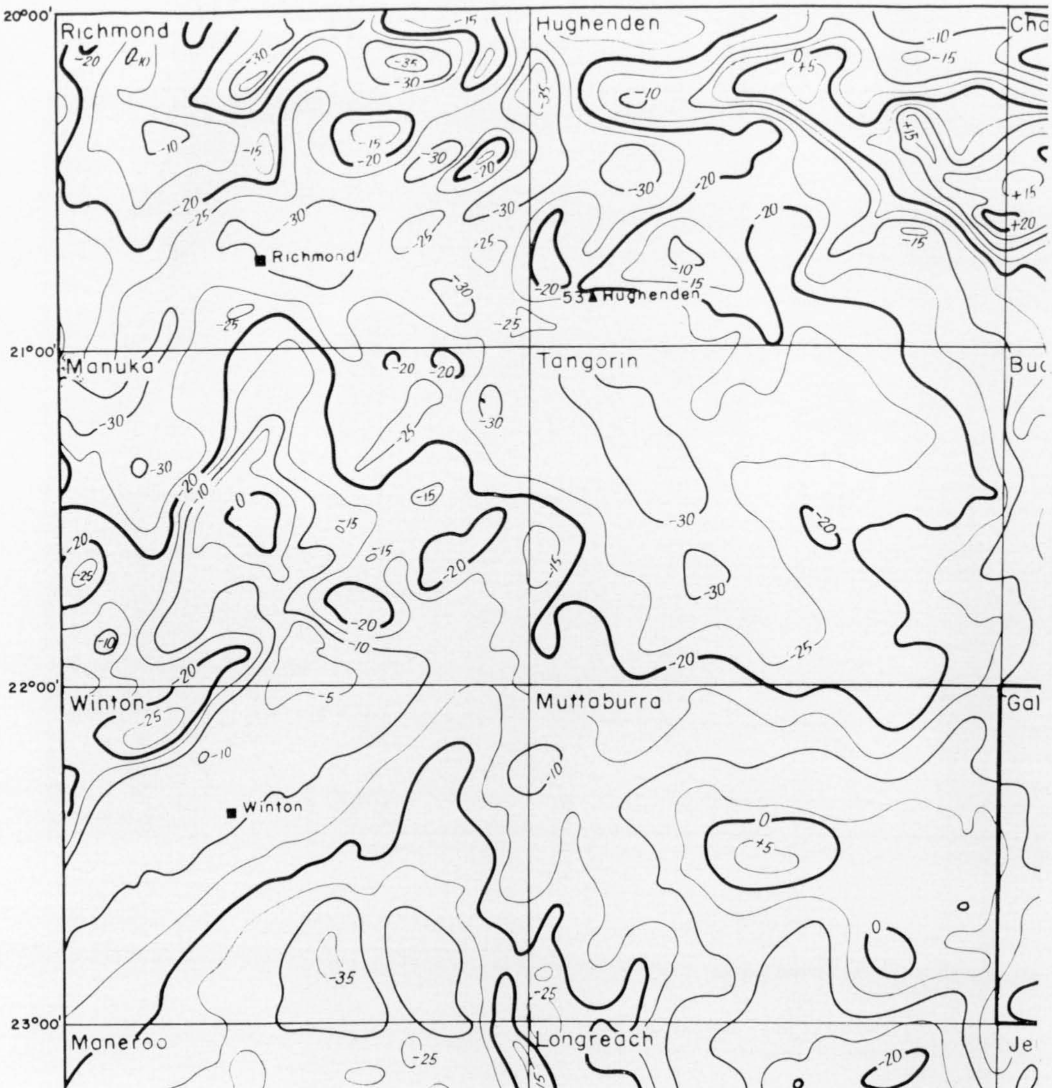


Fig. 5. Regional Bouguer anomaly contours.

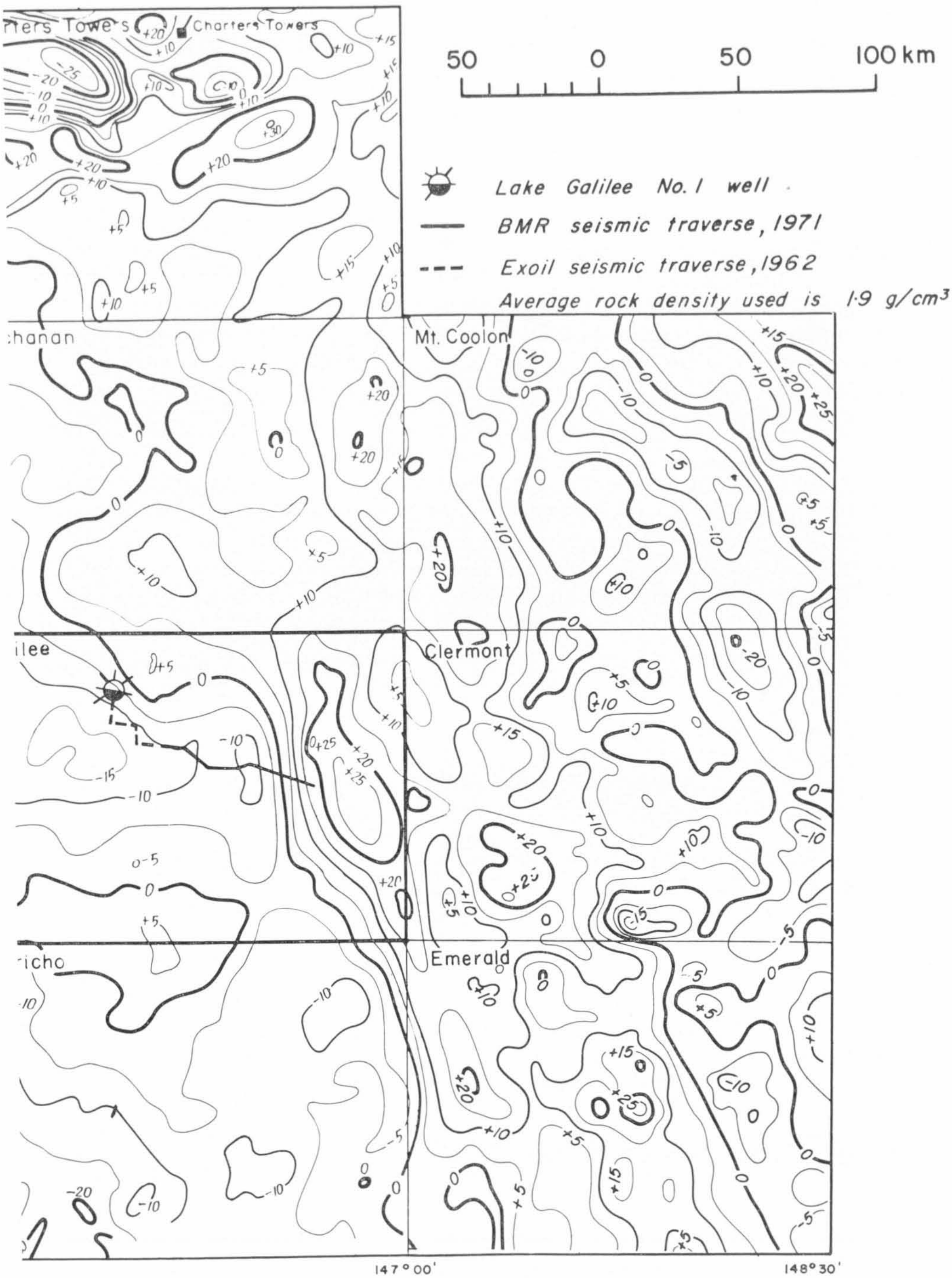


Fig. 5.—Continued.

mentary structure in the area, and that in general Bouguer anomalies are related to intrabasement density variations and basement structure. A possible exception is in the Drummond Basin outcrop area to the east, where only reconnaissance gravity data are available. It was suggested that the Bouguer anomalies there may express the basin structure or underlying, presumably basement, structure.

Seismic

The location of seismic surveys in the northern Eromanga Basin and the Galilee Basin, particularly within ATP 76P, since 1962 are shown in Figure 2. They were reconnaissance reflection surveys by Exoil N.L. in 1962-63, by Amerada Petroleum Corporation in 1965-66 and again in 1966 using a Geograph ('Thumper') system, and by Flinders Petroleum N.L. in 1969 (literature references are given below). The earlier surveys led to the drilling of Exoil Lake Galilee No. 1 well in 1964 and Amerada Thunderbolt No. 1 and Towerhill No. A-1 wells in 1967.

A considerable, and ever present, problem in seismic work conducted in the Galilee Basin and adjacent areas has been that of recording reliable data from below the 'P' reflector, a strong reflector associated with Upper Permian coal measures. Problems were the low energy penetration of this horizon, and the strong surface multiples associated with it, which interfered with deeper reflections. On most surveys using single coverage and an explosive source, the 'P' reflector was used as a marker to map the basin structure and only occasionally were deeper data obtained.

Lake Galilee and Lake Buchanan seismic survey 1962 (Exoil, 1963). This single-coverage reflection and refraction survey was conducted by Austral Geo-Prospectors Pty Ltd for Exoil N.L. A closed north-trending anticline in the south of the area and an east-west dip reversal in the northeast were mapped on the 'P' reflector. A long, reversed refraction profile indicated a sedimentary sequence greater than 5700 m thick near the centre of the surveyed area.

Bowen Downs seismic survey 1965-66 (Amerada, 1967a). This survey was conducted by Petty Geophysical Engineering Co. and Namco Geophysical Co. for Amerada Petroleum Corporation. It covered a large area west of the Lake Galilee and Lake Buchanan survey area, and 2460 km of line was traversed. Data quality was generally fair, but was poor on Cretaceous sandstone outcrops. 'P' reflection contours indicated gentle relief. Two major structures found were a marked northeast-trending ridge and a less marked northwest-trending ridge. The structural trends indicated by the seismic work generally conform to those of the regional structure in the southwest, and not to the younger northwest-trending fold belt of the Drummond Basin.

Koburra seismic survey 1969 (Flinders, 1970). This survey was conducted by United Geophysical Corporation for Flinders Petroleum N.L. Several structures found on previous surveys by Amerada were detailed. Single-coverage seismic reflection techniques were used to map the 'P' reflector over selected structures. No deeper data were obtained.

Towerhill seismic survey (Amerada, 1967b). This survey was conducted by Ray Geophysics Pty Ltd for Amerada Petroleum Corporation. A surface source, the Geograph 'Thumper', was used and up to 12-fold common depth point profiling was done. The objective of obtaining reflection data from below the 'P' reflector was achieved. Two horizons, I and II, interpreted as the 'P' horizon and basement and in places an intermediate horizon III were mapped. Data quality was generally good with data recorded to 3.5 s record time, corresponding to a depth of about 9500 m.

An exception was in BUCHANAN, where record quality was poor in the area of Permian outcrops at the eastern margin of the Galilee Basin. The survey verified previously mapped anticlines at the 'P' horizon level.

Reflection horizons identified near Exoil Lake Galilee No. 1 well were correlated along the traverses north from the well and indicated the area of maximum thickness of sediments.

East-west line R-56 intersects Lake Galilee No. 1 well. This line and line P-35 from the Bowen Downs seismic survey provide continuous reflection coverage from this well to Thunderbolt No. 1 well. Horizon II, tentatively followed from Lake Galilee No. 1 well, correlated with a horizon near the base of Thunderbolt No. 1 well, which bottomed in acid volcanics. However, the correlation is uncertain because the record quality is poor on the western part of line R-56.

Lines R-57 and R-58 (Plate 1) were recorded towards the eastern margin of the Galilee Basin in BUCHANAN. They both indicate the same features: a thick sedimentary sequence and general uplift of the sediments on the eastern ends of the lines. The structure crossed by both lines is probably the geologically-mapped Mingobar Monocline (Fig. 3) which is a component of the Belyando Feature (Vine et al., 1965).

OBJECTIVES AND PROGRAM

Objectives

The main objective of the seismic and gravity survey was to define the structural configuration of the eastern margin of the Galilee Basin and its relation to the western margin of the Drummond Basin.

A further objective of the gravity survey was to investigate the nature of the Donnybrook Gravity High, which is centred over an area of Drummond Basin outcrops at Mount Donnybrook and extends over the eastern margin of the Galilee Basin.

Seismic program

The details of the seismic program proposed and the program carried out are given in the operational report on the survey by Harrison & Brown (1971). A summary of operational statistics is included in that report.

The location of the traverse surveyed and the main types of recording employed are shown in Figure 1. During the survey the success of the shooting and recording techniques was continuously assessed, and modifications were made as necessary. The seismic program was planned to record reflection seismic data along a traverse from Lake Galilee No. 1 well eastwards as far as the Drummond Group outcrops (Fig. 1), starting with experiments near the well to establish shooting and recording parameters. The traverse was designed to cross the maximum gravity gradient, taking advantage of previous seismic lines recorded by Exoil (1963a) and convenient access eastwards. The following is a summary of the program carried out.

Initial experiments. The following tests were carried out on a north-south traverse through Lake Galilee No. 1 well:

— Uphole Shoot to establish the best shooting depth and to obtain near-surface velocity information.

— Noise Test to establish the characteristics of longitudinal and transverse coherent noise to determine effective frequency filters and suitable shot-hole and geophone arrays.

— Expanded Spread to obtain vertical velocity information, to identify primary and multiple reflections, and to assess the effectiveness of the chosen recording parameters in cancelling coherent noise.

— 6-fold CDP coverage to determine the effort required to obtain reflections and to assess the effectiveness of the chosen recording parameters in cancelling coherent noise.

— 6-fold CDP coverage to determine the effort required to obtain reflection information from below the 'P' horizon and to compare the results of two different shot-to-geophone offsets in cancelling multiples.

Some 33 km of the proposed traverse was then omitted, as acceptable data existed from Exoil's earlier work. Recording was recommenced where the Exoil data deteriorated in quality.

Limited experiments, including a further expanded spread, were conducted initially to check that the selected shooting and recording parameters were applicable in the new area. Several shot-points of single coverage were shot at two depths for uphole stacking; the stacked section showed a reduction in random noise but little attenuation of ghost reflections. As ghosting was much less serious than near the well, no further attention was devoted to this problem.

Production reflection shooting. The traverse was shot using single coverage split-spreads between four 6-fold CDP probes at selected places. On the easternmost two probes the geophone station interval was increased from 45 to 90 m so that longer geophone groups could be used to attenuate longitudinal coherent noise without incurring ground mixing.

Velocity investigations and recording control. Vertical velocity information from Lake Galilee No. 1 well, from the previous seismic survey results, and from the expanded spreads was reassessed as the survey progressed. The best shooting depth and the near-surface velocity and weathering information were checked with three full-scale uphole shoots and two limited uphole shoots at intervals along the traverse. Three single coverage probes were recorded ahead of the main operation to preview recording conditions on the proposed line. This facilitated planning of the program.

Additional detailed reflection shooting. As the recording proceeded eastwards the 'P' horizon became shallower until it was not recorded on the normal geophone spreads. Short reflection and refraction spreads were recorded in an attempt to follow the coal measures to where they subcrop under the recent sedimentary cover. Shot-points 1156 to 1169 were reshot using deeper holes after completion of single-coverage shooting to the eastern end of the traverse. This was in a region of confused reflection quality where an uphole shoot at SP 1155 and other investigations had indicated deeper than usual weathering. The results of the shots from the two depths were uphole-stacked.

Refraction and deep crustal reflection. A refraction probe about 20 km long was shot at the eastern end of the traverse in an attempt to determine the refraction velocities of reflectors. The probe was not fully reversed; only the near spreads were recorded from the easternmost shot-point. Reflection data provided dip control.

A second seismic recorder was used to obtain deep crustal reflection data at SP 1142 at the same time as the shots there were recorded on the refraction probe. Also mobile recording stations were set up to record deep crustal refraction information along a line northwards towards Charters Towers. The deep crustal refraction and reflection results have been reported by Cull & Riesz (1972).

Gravity program

Operational details of the gravity survey are given by Anfiloff (1972). Gravity was measured along the seismic traverse from SP 1067 to 1173 at 540 m intervals, and farther east to Beresford homestead at approximately 500 m intervals (Fig. 1). Measurements were also taken at 800 m intervals along six cross-traverses to define the gravity field in the area more accurately.

SEISMIC DATA RECORDING, PROCESSING, AND ANALYSIS

Data recording

The main recorder was a PT-700, PMR-20 analogue FM system. A TI8000, DS7-7 analogue direct recorder was used to obtain supplementary information and to train personnel.

Recording techniques used along the traverse are indicated in Plate 2. Programmed Gain was initially used in recording, but over most of the traverse AGC was used because of variable coupling of shot energy. Daily, weekly, and monthly equipment tests were conducted according to established testing procedures described by Hemphill & Brown (1972).

Uphole shoot and attenuation of ghost reflections. The first experiment near Lake Galilee No. 1 well was an Uphole Shoot in an 80-m hole to establish the optimum shooting depth and to determine near-surface velocities. An event recorded at about 200 milliseconds below the 'P' horizon showed variation in this time-difference from the 'P' horizon with shot depth, suggesting that it might be a ghost reflection. Stacking of pairs of records from different shot depths did not effectively attenuate the probable ghost reflections. Farther eastwards along the traverse ghosting became, and remained, a less serious problem, as shown by the reflection records from SP 1071 to 1076.

Noise test and determination of geophone and shot-hole patterns. A Noise Test was recorded at SP 1000 as part of the initial experimentation. Plate 3 shows the unfiltered record section, indicating the main noise and signal events, together with a frequency wave-number diagram. The filtered record sections are shown in Plate 4. A 16 Hz, 12 dB/octave low-cut filter and a 100 Hz high-cut filter were selected and used throughout the survey. Playback filters found to be most suitable, and a low-cut filter of 20 Hz and a high-cut filter of 78 Hz were used throughout the survey.

A geophone pattern of eight geophones 6 m apart in line along the traverse was selected to attenuate longitudinal coherent noise. The cut-off wavenumber of this group for in-line noise was 10 cycles per 1000 m. Several events had wavenumbers below this cut-off, but they were attenuated effectively by the low-cut frequency filter. The transverse noise test (Plate 3) indicated that transverse noise was a problem. Two strong transverse noise events, T1 and T2, had apparent frequencies below 15 Hz and wavenumbers ranging from 6 to 27 cycles per 1000 m. A low-cut frequency filter of 16 Hz and a wavenumber cut-off of 16 cycles per 1000 m together were found to be necessary to effectively attenuate these events. A pattern of 32 geophones in 4 rows of 8 geophones in line with rows 8 m apart and geophones 6 m apart was selected to attenuate the longitudinal and the transverse coherent noise.

The characteristics of the coherent noise changed near SP 1071. One noise event in particular, of wavenumber 13-20 cycles per 1000 m and frequency 25-33 Hz interfered seriously with signal, as seen on the expanded spread at SP 1071 (Fig. 7). This noise did not seriously affect the quality of reflections on single-coverage spreads with a maximum geophone offset of 540 m. However, for offsets over 1000 m used in CDP profiling the 'P' horizon event was affected. The cut-off wavenumber for in-line noise was decreased to 5 cycles per 1000 m by changing the geophone pattern from 4 rows of 8 geophones to 2 rows of 16 at the same spacing. This satisfactorily attenuated the noise. This pattern had a cut-off wavenumber for transverse noise of 30 cycles per 1000 m. However, transverse noise was not troublesome in this area and was not increased by the change of pattern. The geophone station interval was increased to 90 m to avoid ground mixing.

Later in the survey the pattern was reduced to 2 rows of 8 geophones towards the eastern end of the traverse, and this proved to be satisfactory.

The number of holes drilled for each shot was determined largely by the drilling and recording rates, as many as possible being drilled in a pattern for noise cancellation. Three to five holes per shot were used generally; where possible, however, 10 holes were drilled in 2 rows of 5 in a pattern of similar dimensions to the geophone pattern used.

Expanded spread and attenuation of multiple reflections. An expanded spread was recorded centred on SP 1001 near Lake Galilee No. 1 well (Fig. 6), and results indicated that coherent noise events were effectively attenuated. However, multiple reflections were a problem. The primary and multiple reflection events were clearly identified on the analysis of the reflection data on the expanded spread. The moveout differences between multiples and primaries at the same effective reflection times were used to design CDP spreads to attenuate the multiples, as described by Mayne (1962).

6-fold CDP profiling was recorded near the well using shot-to-nearest-geophone offsets of 45 and 585 m. Multiples were not much attenuated by using the shorter offset and although multiples were attenuated considerably by using the longer offset, the 'P' horizon was degraded on the distant seismic traces after stacking. Thus an intermediate offset of 225 m was used for production CDP recording.

Production recording. The shot-hole and spread locations for the production reflection recording are illustrated on the operational plan in Plate 2.

30 km of Exoil single coverage data from the end of the 6-fold CDP coverage above Lake Galilee No. 1 well was considered to be of sufficiently good quality, and this part of the traverse was not reshot. A 6-fold CDP probe was recorded commencing at SP 1076$^{2}/_{12}$ using a 45 m geophone station interval and an offset of 225 m.

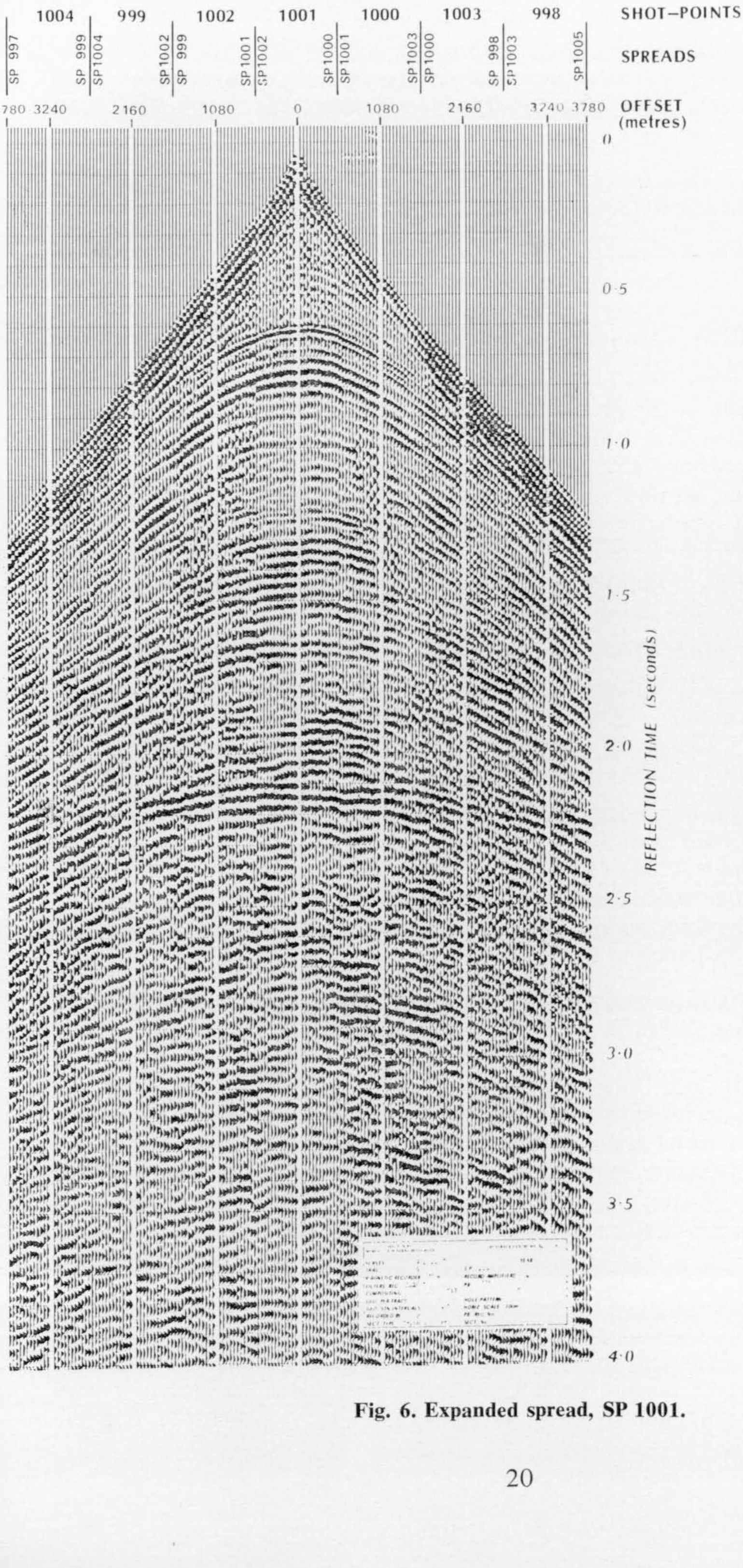
A minimum offset of 90 m and a geophone station interval of 90 m were used on the easternmost two 6-fold CDP probes. The 'P' horizon was degraded because the longer geophone group with its lower cut-off wavenumber attenuated the reflection for offsets beyond 500 m. At long offsets, the application of normal moveout resulted in a significant stretching of the most distant traces and a lower apparent frequency for the 'P' horizon reflection; this degraded the 'P' event after stacking. The advantages of improved multiple and coherent noise attenuation were considered to outweigh the disadvantage of this effect on the 'P' horizon event.

Vertical stacking, SP 1156–1169. Record quality was poor near SP 1156–1169. This was believed to result from shooting in a low-velocity layer below the weathered layer. The geological section here appeared to be disturbed. The records from reshooting with 7 kg charges at depths of 50 m were stacked with the original records.

Expanded spreads. Four expanded spreads were recorded during the survey (Figs. 6-9). They were recorded with a 7-spread arrangement along Traverse A, using the method of Musgrave (1962), in places where the single-coverage reflection sections indicated better reflection quality than elsewhere. Their purpose was to provide vertical velocity information, to allow primary and multiple reflections to be identified, and to aid in planning CDP work.

Refraction probe. A refraction probe was recorded between SP 1142 and 1178. The record sections are shown in Plate 10. The probe was recorded to determine the refraction velocities of the reflecting horizons as well as to provide more information on the structure in the zone of poor reflections between SP 1150 and 1168. SP 1142 was used for refraction shots because of the availability of shallow refraction information from first breaks on the expanded spread centred there. Shot-coupling was good and drilling was easy. A geophone station interval of 90 m was used. A maximum offset of 19 km was required for penetration to a depth of 3000 m. The probe was not completely reversed, only three spreads being recorded from SP 1178. It was considered, however, that the already completed reflection recording provided adequate dip control. Shot coupling at SP 1178 was rather poor; the charges used ranged from 500 to 4000 kg.

Shallow 'P' horizon. From about SP 1135, where the 'P' horizon became too shallow to record on the normal spread, attempts were made to record it with short reflection and refraction spreads at SP 1139, 1155, and 1164. For the



RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters: Out

Filters : LL 16 – KK 100

Programmed Gain:

Function: A

Geophones: HS – J, 14 Hz

Geophone Station Interval: 45 m

Geophone Pattern:

24/trace, in 3 rows of 8 in line

Rows 8 m apart, geophones 6 m apart

Shot Hole Pattern:

3 holes, 15 m apart in line

Depth 23 – 25 m

Average charge 3 x 14 kg

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

AGC : SS

Compositing: Nil

VELOCITY INFORMATION

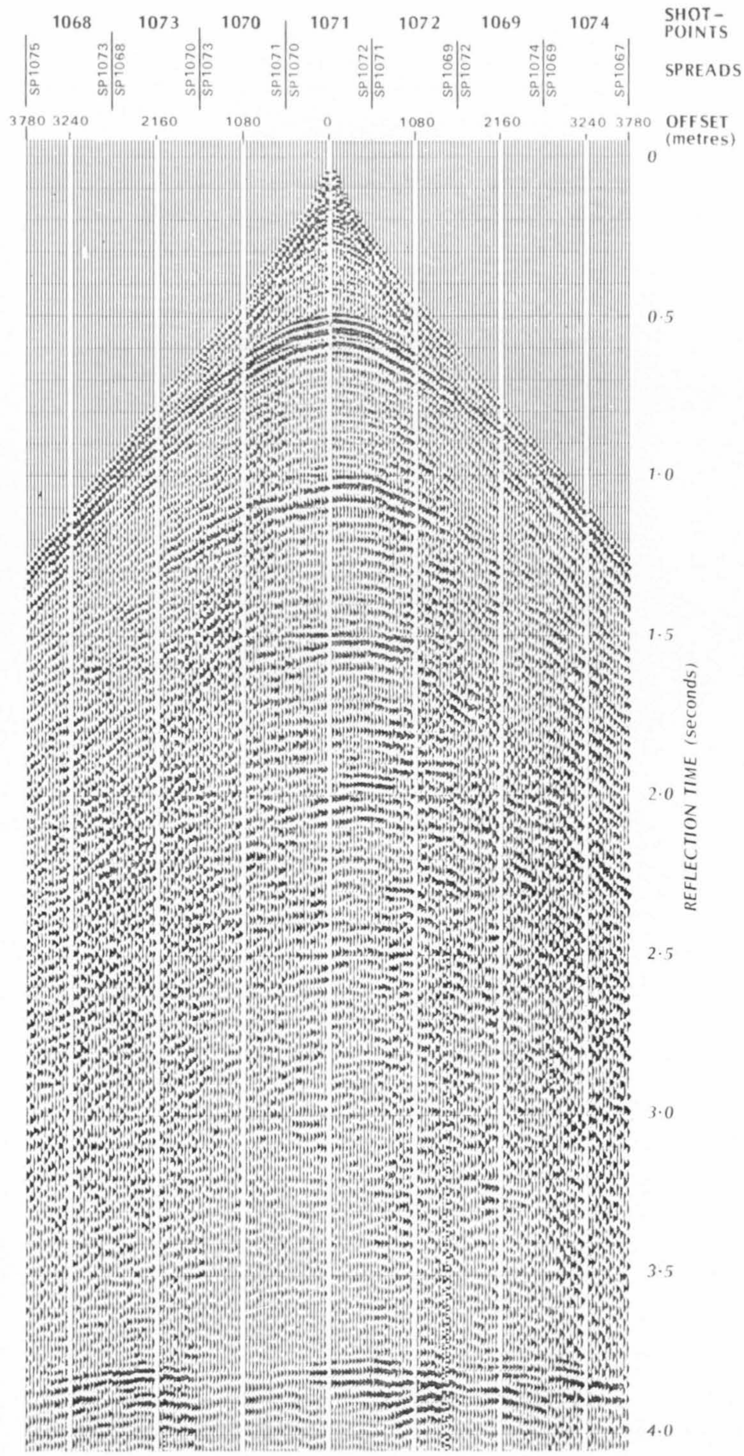
Nil

HORIZONTAL SCALE

As indicated

F55/B3-86A

Fig. 6. Expanded spread, SP 1001.



RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers: PT – 700

Prefilters: Out

Filters : LL 20 – KK 100

Programmed Gain:

Function: A

Geophones: HS – J, 14 Hz

Geophone Station Interval: 45 m

Geophone Pattern:

32/trace, in 4 rows of 8 in line

Rows 8 m apart, geophones 6 m apart

Shot Hole Pattern:

3 holes, 15 m apart

Depth 23 – 25 m

Average charge 3 x 25 kg

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

AGC : SS

Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

As indicated

F55/B3-85A

Fig. 7. Expanded spread, SP 1071.

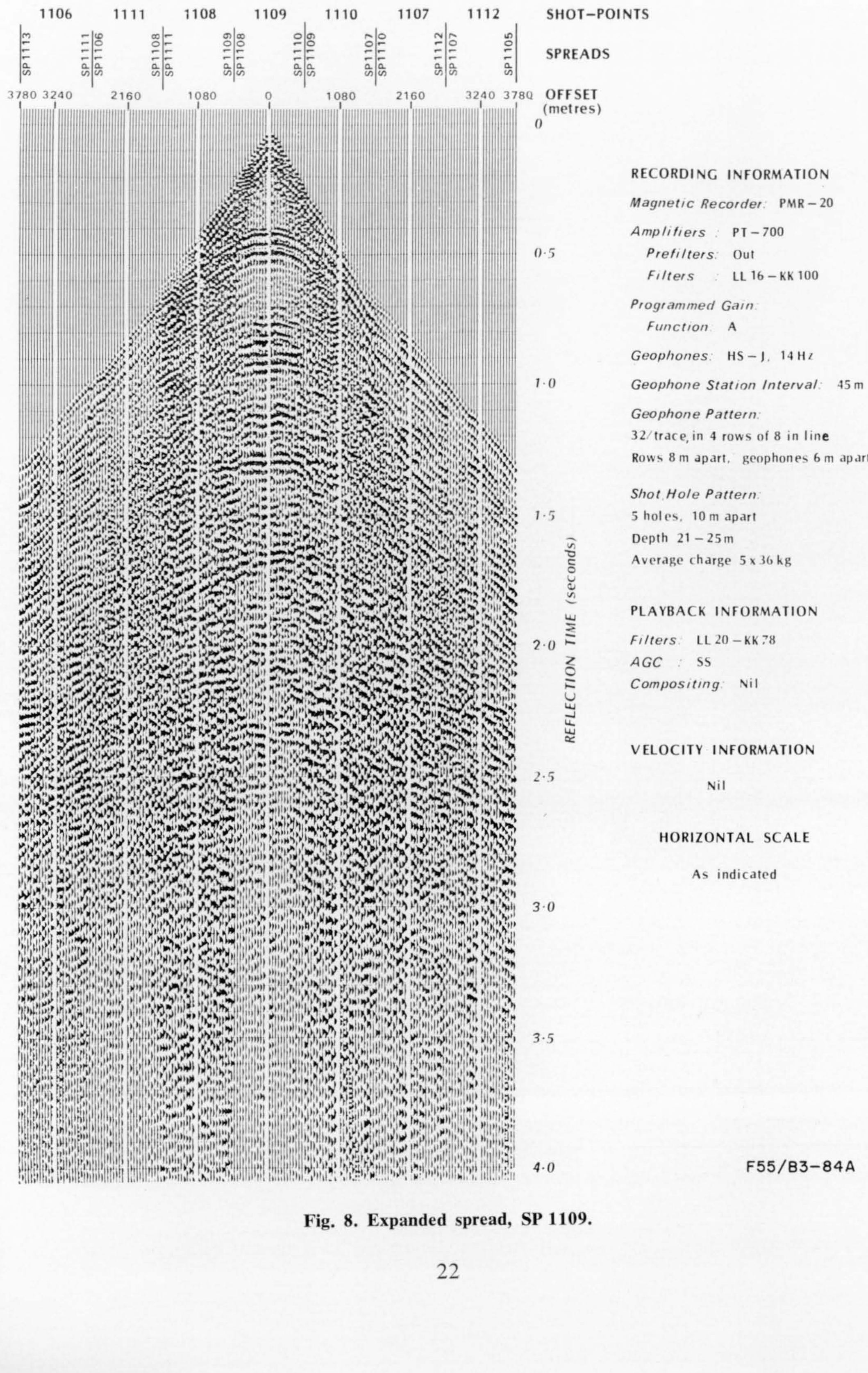
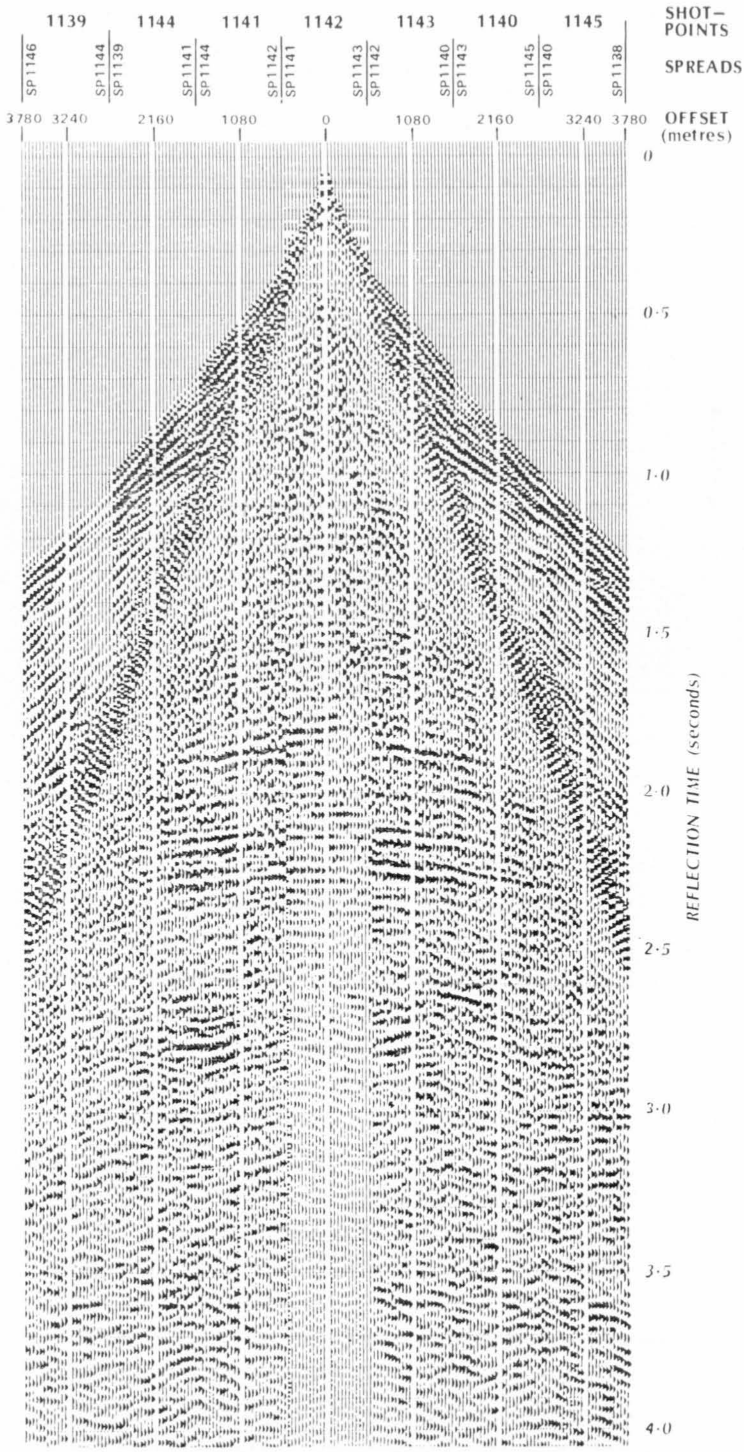


Fig. 8. Expanded spread, SP 1109.



RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters: Out

Filters : LL 16 – KK 100

Programmed Gain:

Function: A

Geophones: HS – J, 14 Hz

Geophone Station Interval: 45 m

Geophone Pattern:
16/trace, in 2 rows of 8 in line
Rows 8 m apart, geophones 6 m apart

Shot Hole Pattern:
Single
Depth 25 m
Average charge 70 kg

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

AGC : SS

Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

As indicated

F55/B3-83A

Fig. 9. Expanded spread, SP 1142.

reflection spreads the charges used were as small as 2.5 kg and geophone station intervals as short as 7 m.

Processing techniques

Analogue processing. Analogue processing of the magnetic tapes was done in the BMR Playback Centre in Canberra, and record sections for the reflection profiles are presented in Plates 5-8. The normal moveout (NMO) used for all final sections was derived from the composite velocity illustrated in Figure 10. This average function was selected as no systematic velocity changes were observed from velocity information along the traverse. A residual moveout correction was applied to long-offset CDP data, because the required NMO for the most distant traces from the shot exceeded the maximum NMO applied on the machine, on its first run. This was most important for correcting the 'P' reflection.

Weathering and elevation effects were not a serious problem. The topography along the traverse was generally flat and the weathered layers were fairly uniform. Corrections obtained using the uphole correction method (Vale, 1960) were adequate for the 6-fold CDP probes and for most of the single coverage. However, for the single-coverage spreads SP 1101–1122, the static correlations were further refined by applying additional corrections obtained by analysing the minor irregularities on the good quality 'P' reflection event. Empirical adjustments were occasionally made to the static corrections.

A 20-78 Hz bandpass filter was found to be optimum for playback and was adopted for all sections. The effectiveness of this bandpass on the noise test records is shown in Plate 4.

Digital processing. In addition to the analogue processing, digital processing was done on the data from the eastern end of the traverse in an attempt to improve the record quality within the zone of poor reflection continuity. This processing was done under contract by Western Geophysical Co. The data from the 6-fold CDP probe at SP 1124 to 1131 and the single coverage at SP 1131 to 1177 were digitally processed, and the results are presented in Plate 8.

Magnetic tapes were transcribed with a 2-millisecond sampling rate. The main processes applied were deconvolution, stacking (for the CDP data), and time-variant filtering. Deconvolution removed later legs of extended reflection wave-trains. The improvement obtained is illustrated by comparison of analogue and digital sections in Plate 9.

Many records had low-level traces towards the end of the record, for which AGC on analogue playback was unable to compensate. The digitally processed sections exhibit a more uniform level. On the single-coverage records at SP 1156 to 1169, the output level of the seismic traces was lower for the deeper shots than for the shallower shots. The later events from the deeper shots had a higher frequency content than those from the shallower shots.

Vertical stacking of the two tapes gave no improvement. Even the Digital Coherency Stack of Western Geophysical Co. failed to improve the quality of vertically stacked records compared with that of the records from shallow shots. The records from the shallow shots were used in the digitally processed section (Plate 8).

Optical processing. Optical processing, using the BMR LaserScan, was done on the reflection sections at the eastern end of the traverse, including the section from the zone of poor reflection quality in which a confusion of dipping events occurs.

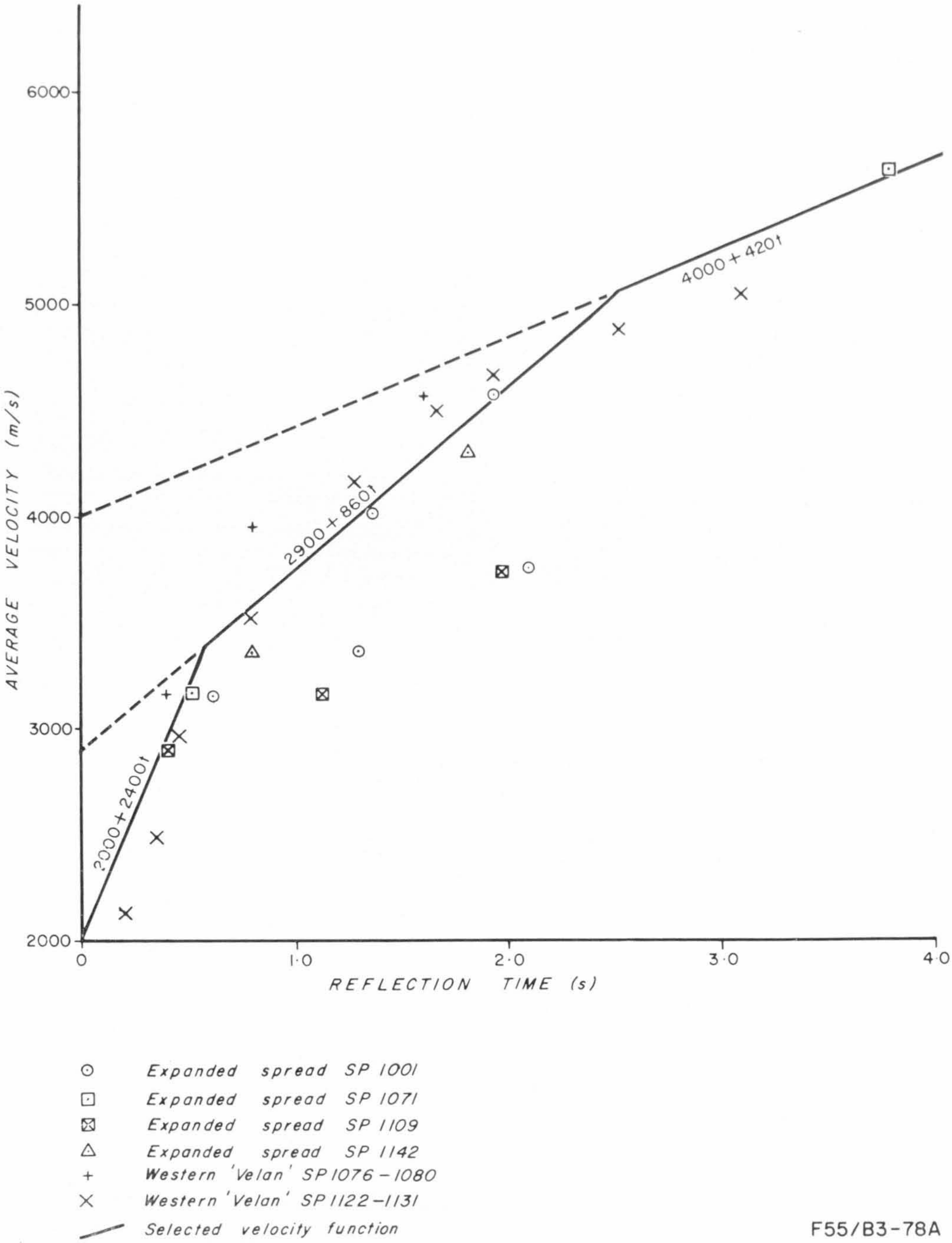


Fig. 10. Composite velocity plot.

Two-dimensional Fourier transforms of the seismic sections were photographed so that the frequency content of the sections, and the signal-to-noise ratio could be studied in order to choose spatial filters. The main filter used was a wedge cancelling easterly dips in the range 0-50°. The processing effectively removed unwanted dipping events, but it did not improve the continuity of westerly-dipping events through the zone.

Analysis

Velocity analysis. The expanded spreads (Figs. 6-9) were analysed by the t^2–x^2 method using the computer program VELSPRED (Pettifer, 1972). Further velocity information was obtained by digitally processing CDP data from SP 1124 to 1131 and SP 1080 to 1093, using the 'Velan' process of Western Geophysical Co. This is a process in which for a succession of reflection times the members of a CDP family are compared for each of many velocities. For each velocity, all possible pairs of traces in a CDP family are cross-correlated. The sums of the cross-correlations are used for comparison. The average velocities deduced from the four expanded spreads and two 'Velans', are plotted against record time in Figure 10. No systematic velocity changes were observed along the traverse. Only one velocity function, indicated by a heavy line in the figure, was used in the processing and interpretation. This function is consistent with functions used in the area on previous seismic operations (Exoil, 1963, Amerada, 1967a) and velocity information from the sonic log in Lake Galilee No. 1 well.

Anomalous events. In the zone of poor reflections between SP 1150 and 1178, numerous curved, steeply-dipping events and some linear events were recorded over many shot-points. Some of the more prominent events are indicated in Plate 11. The curved events were analysed by comparing them with theoretical diffraction curves. To explain the curves as diffractions from discontinuities normal to the traverse requires an unrealistically high velocity function in the sediments. They can be explained, however, if it is assumed that the traverse intersects a possible fault plane at about 40° (Fig. 16). The long, straight events were analysed assuming them to be reflected refractions. A fault from which such refractions would be reflected would cross the traverse also at about 40°. The traverse intersects possible faults in a band from about SP 1140 to 1169.

Refraction results. Plate 10 shows the refraction records, a time-distance plot, and the deduced interpretative model. First arrivals obtained were of fair to poor quality. Generally the first trough following the break was timed. The profiles of the refractors were computed from the time-distance information using the depths of the refractors calculated at the shot-points and dip information from reflection records. The points on part of the time-distance curve were widely scattered about the best fitting line. The scatter does not appear to be affected significantly by the application of static corrections and may be due in part to lenses of low-velocity material deep in the section.

Shallow refraction analysis. First breaks from single-coverage split-spread reflection records from SP 1131 to 1178 were analysed to obtain depth and velocity information from shallow layers. Uphole times generally, and the results of several uphole shoots were incorporated in the interpretation of the near-surface structure illustrated in Figure 14.

The purpose of the analysis was to define the shallow structure under recent sediments to determine whether it would throw light on the nature of the deeper structure across the basin margin. In particular it was done to determine whether faulting could be observed in the shallow layers.

GRAVITY DATA PROCESSING AND ANALYSIS

Processing

The gravity survey data were processed to obtain Bouguer gravity data suitable for interpretation. The processing involved two data passes through the computer using the BMR computer program GRAVHTO5.

In the first pass, meter drift was removed from the results from each loop, the meter scale factor was applied to each reading, and ties were established between loops to obtain observed gravity values on a common datum. This datum was then adjusted using the tie to an isogal station, to give absolute observed gravity values.

In the second pass, the absolute gravity values were reduced to Bouguer gravity values by incorporating the station elevations, latitudes, and the Bouguer slab correction density. The density was determined using the Density Profiling Method (Nettleton, 1939).

Analysis

The analysis of the gravity data and associated data necessary for interpretation purposes involved the following procedures:

Rock density analysis. Densities were obtained for rock samples collected at several places during the survey (Anfiloff, 1972), and also from tables of core analyses for the Lake Galilee No. 1 and Thunderbolt No. 1 wells. This information is summarized in Table 2.

TABLE 2

ROCK DENSITY INFORMATION

Source and depth (m)	*No. of specimens*	*Sequence or formation*	*Rock type*	*Age*	*Density range (g/cm^3)*
Surface	8	Mount Hall	Quartz, sandstone, conglomerate	L. Carboniferous	2.37 - 2.74
Lake Galilee No. 1					
0–2830	34	Galilee	Sandstone, shale	Permian	2.00 - 2.69
2830–3380	8	Adavale?	Sandstone, shale	Devonian	2.55 - 2.69
Thunderbolt No. 1					
1680	2	(?)	Dacite, acid volcanics	?Pre-Devonian	2.44 - 2.62

The table shows a large variation in density for each group of specimens. Since insufficient information is available to obtain average densities by weighted means, the above densities have been used only as a guide for gravity modelling.

Multiple density profiling. The Density Profiling Method was applied to the gravity data to determine the optimum Bouguer correction density. The elevation profile for the main traverse was superimposed on the Bouguer gravity profiles for five

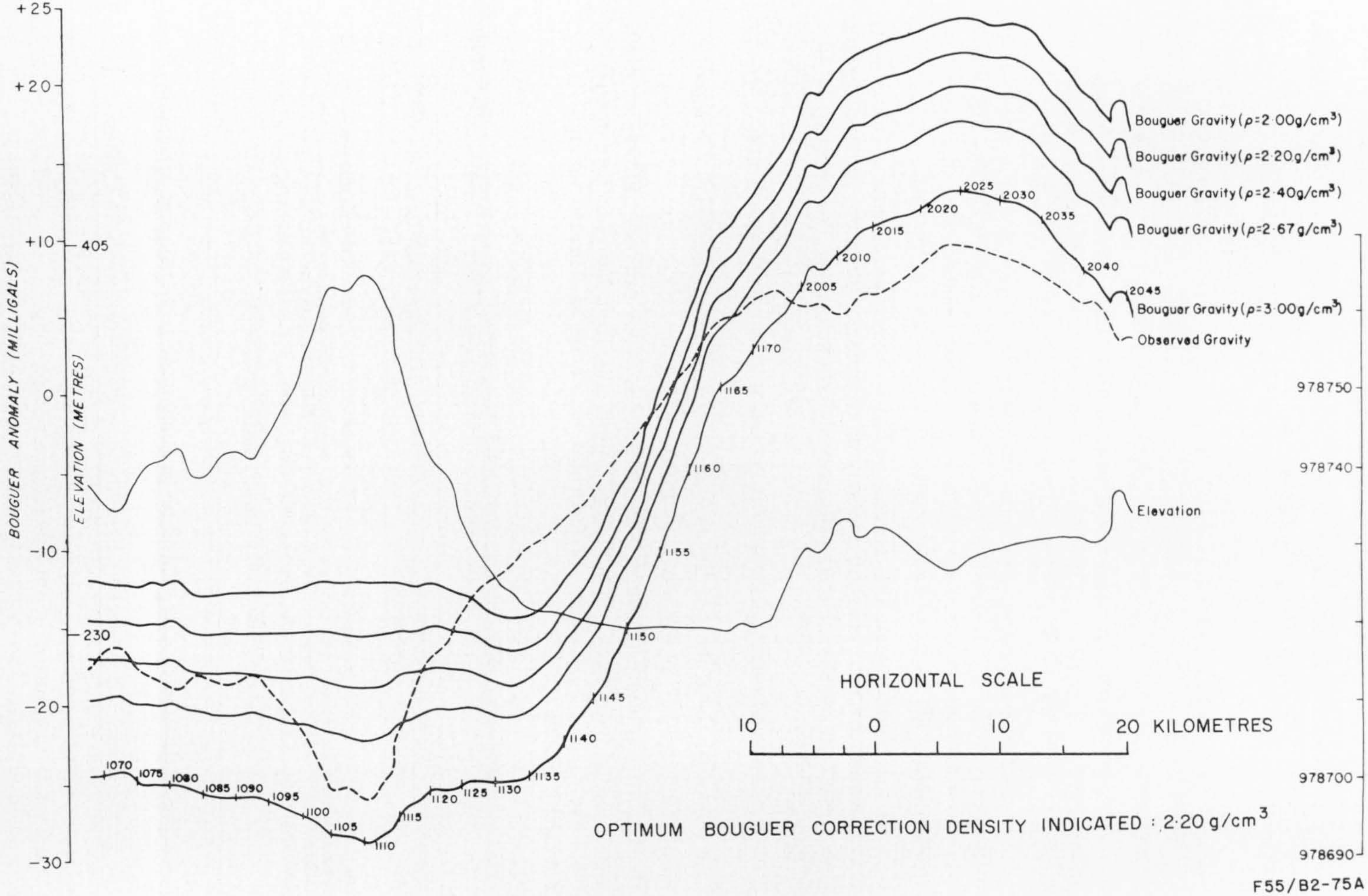


Fig. 11. Multiple density profiles.

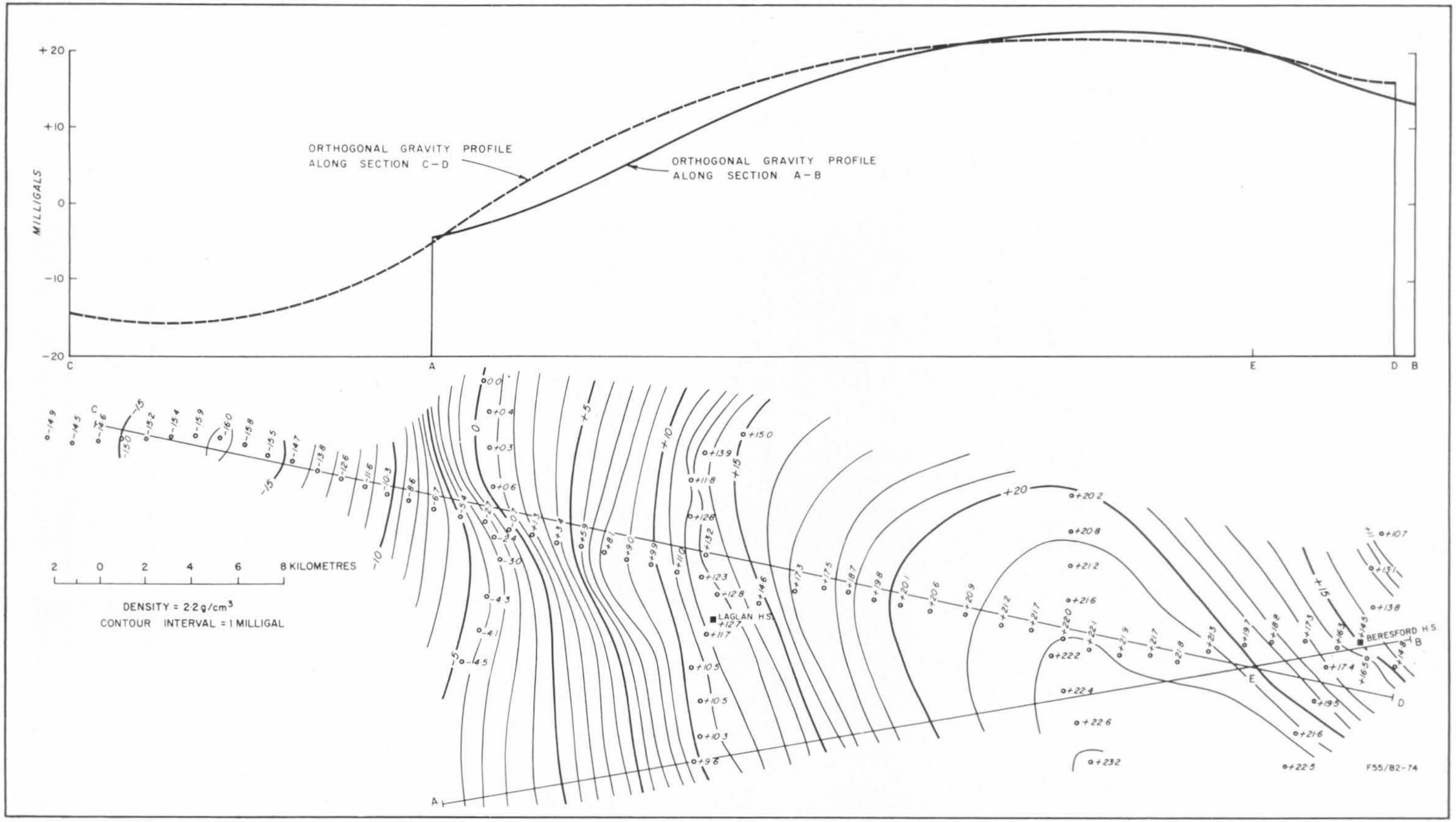


Fig. 12. Donnybrook Gravity High Bouguer anomaly contours and profiles.

densities between 2.0 and 3.0 g/cm³ (Fig. 11), and the correlation between elevation and gravity was noted in each case. Between Stations 1075 and 1150, a good correspondence is observed; the gravity profile for 2.20 g/cm^3 density has a minimal correlation with the elevation profile, and hence a minimum residual topographic error over this span. Since the Bouguer gravity profile is more density-dependent over this span than elsewhere in the profile, it is feasible to accept the value of 2.20 g/cm^3 as the Bouguer correction density applicable to all the gravity stations of the survey. This density may also be assigned to the top layers of the Galilee Basin sequence for gravity modelling as these sediments crop out over the segment of the profile in question. The density obtained by this method agrees with values measured on specimens from the top of the Galilee Basin sequence in Lake Galilee No. 1 well.

Contouring Bouguer gravity. Data from the traverses were contoured in order to determine the trends of anomalies. Figure 12 shows the gravity contours of the Donnybrook Gravity High, an elongate northwest-trending high with a peak value greater than 23 mgal, extending over the eastern half of the traverse and intersecting it at an angle of about 60°.

The A-B and C-D profiles on the same plate indicate that the profile of the anomaly measured along the traverse is 13 percent wider and 5 percent lower in amplitude than the profile taken through the peak of the anomaly at right angles to its trend.

Gravity modelling. Modelling was done using the BMR 2-dimensional simulation program GRAV2D. This program processes two-dimensional models comprising up to 10 bodies, and is capable of simulating in one pass the gravity effects of a model for various combinations of densities.

Simulated gravity profiles were matched to the 2.20 g/cm^3 Bouguer anomaly profile along the main traverse in order to establish the cause of the Donnybrook Gravity High. The orthogonal profile taken from contour values along A-B at right angles to the trend (Fig. 12) could not be used as the simulation objective because it does not contain sufficient detail. Therefore three sources of errors are present in the modelling process:

(1) The traverse cuts the anomaly obliquely, and the apparent anomaly is therefore 13 percent wider than the actual one.
(2) The traverse does not cut the anomaly at its peak value, and the apparent anomaly is therefore 5 percent lower in amplitude than the actual one.
(3) The anomaly has a finite length-to-breadth ratio, and cannot therefore be simulated in two dimensions with complete accuracy.

These three errors are cumulative, and a narrower but larger overall mass anomaly than the models depict must therefore exist at Mount Donnybrook. However, it is considered that this does not seriously affect the major structural elements proposed in the models.

SEISMIC RESULTS

Reflection data quality

The processed record sections are presented in Plates 5-8. For the 6-fold CDP probes with a geophone station interval of 90 m, traces have been played out twice continuously to maintain a uniform trace spacing on the sections.

The quality of the data varies generally from good to poor. The 6-fold CDP data were of good to fair quality near Lake Galilee No. 1 well. Three primary events were recorded there: the 'P' reflector at 0.6, possible basement at 2.1, and an intermediate reflector at 1.3 s. The first two events were recorded near the well on previous seismic surveys (Amerada, 1967b).

The 'P' reflector recorded as a strong event over most of the traverse became steadily shallower eastwards until it was not recorded with the normal spread at about SP 1135. The other main reflection events remained almost horizontal and could be followed, though with some difficulty, as far as SP 1153. Between SP 1154 and 1167 the record quality deteriorated, and only one reflection could be followed. This was a disturbed, though continuous, event below 2.0 s which had not been recorded previously. From SP 1168 to 1178 the record quality improved markedly, and many shallow reflections of fair quality were recorded.

The reprocessed Exoil data included in the results were of sufficient quality to allow the primary events below the 'P' reflector to be followed. The primary events were of higher frequency than the multiples in the section, thereby considerably aiding their identification.

Generally the 6-fold CDP probes gave data of better quality. Attenuation of multiples and random noise was good and resulted in a higher signal-to-noise ratio for the deeper primaries. The CDP work with long spreads gave improved multiple attenuation but a somewhat degraded 'P' reflection event.

In the region of SP 1071, random noise was a more serious problem than it was close to the well, and coherent noise events, not previously identified, affected the quality of the CDP data. A reflection of fair quality was recorded at about 3.8 s over several shot-points in this area. Analysis of the expanded spread centred at SP 1071 suggested that it is a primary event.

The single-coverage data from SP 1101 to 1122 were recorded over outcropping Tertiary sandstone in the area of greatest relief along the traverse. The record quality was particularly poor here, and primaries below the 'P' reflection were difficult to follow although patterns of 10 shot-holes were used. Many high-angle interference events, which may be off-side reflections or reflected refractions, were recorded.

Factors influencing data quality

The good to poor quality of the recorded data resulted from a combination of the following problems encountered in the area:

- Low energy penetration of the 'P' horizon. Most of the seismic energy was reflected by this horizon and little energy penetrated to deeper horizons.
- Multiples of the 'P' reflection event were at times very strong, and interfered with deeper reflection events. As the 'P' horizon became shallower towards the east, the multiples became progressively less troublesome.
- Random noise was a problem over the entire traverse.
- Strong coherent noise trains, with varying characteristics, were propagated along the traverse.

— Ghost reflections were pronounced close to the well, but were not a serious problem over most of the traverse.
— Energy coupling in the shot-holes and the ground response measured at the geophones varied, with the result that Automatic Gain Control rather than Programmed Gain Control had to be used in most of the recording.

Synthetic seismograms

Synthetic seismograms were produced from sonic log data from Lake Galilee No. 1 well, using BMR computer program SEISYN, to investigate the characteristics of primary and multiple reflections. The synthetic seismograms computed with a Ricker Wavelet of centre frequency 30 Hz were found to match the field traces most closely. Field seismic traces and synthetic seismograms are compared in Figure 13.

Primaries at 0.6 to 1.3 s were identified on the synthetic seismograms. These events agree with the field results, but the latter event is very weak on the field traces. There is evidence of two further primaries at about 0.8 and 1.1 s. The event at about 0.8 s was considered in the field to be probably a ghost reflection associated with the 'P' reflection. The surface multiples and ghosted primaries synthetic seismograms are substantially the same as the simple primaries one, whereas on the complete multiples seismogram, primary reflections are of much poorer quality. This suggests that surface multiples and ghost reflections are of much poorer quality. This suggests that surface multiples and ghost reflections were not as serious a problem as other multiples near Lake Galilee No. 1 well.

Refraction

The refraction records, time-distance plot, and deduced model are shown in Plate 10. The quality of the first-arrival data was not good generally. However, it is considered to be sufficiently good to justify the continuity of the deeper refractors through the zone where shallow reflection information is lacking, as is presented in Plate 10. The refraction results indicate that the refractors are relatively undisturbed over the subsurface covered.

GRAVITY RESULTS

The gravity contours (Fig. 12) delineate a large positive anomaly in the eastern part of the survey area, centred over Drummond sequence outcrops at Mount Donnybrook. The anomaly extends westwards into a shallow low. Farther west, over the Galilee Basin, the gravity profile is mainly flat and featureless.

The final (2.20 g/cm^3) Bouguer gravity profile (Fig. 15), constructed from values at stations along the traverse, shows a positive anomaly of amplitude 37 mgal and width 70 km. On its western edge is a small negative anomaly of amplitude 2 mgal. To aid the interpretation of the gravity results, the profile was extended 35 km eastwards to the Anakie Metamorphics outcrops, using values taken from reconnaissance gravity contours (Gibb, 1968). This permitted two-dimensional modelling to the Anakie outcrops, thus minimizing end effects near the survey area.

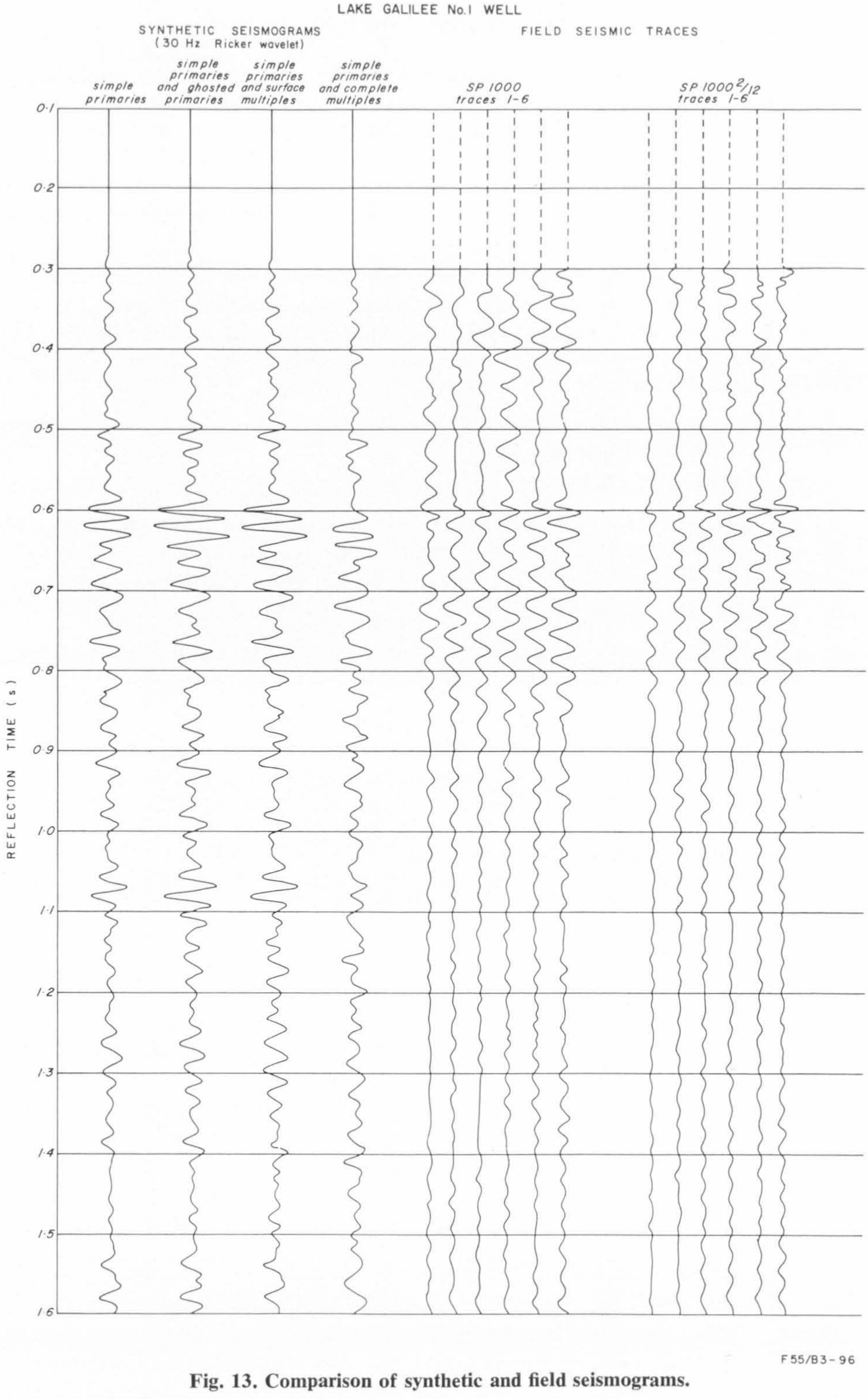


Fig. 13. Comparison of synthetic and field seismograms.

INTERPRETATION

The seismic results provide information on the thickness of the sedimentary section and the structure at the eastern margin of the Galilee Basin. The gravity results over the basin are in reasonable agreement with the reconnaissance helicopter gravity results and fully support the seismic interpretation. A structural model of the eastern margin of the Galilee Basin and across the Drummond Basin to the Anakie Metamorphics in the east is proposed from the seismic and gravity results.

The principal reflection events have been labelled on the record sections (Plate 10). A model of the eastern part of the line, shown in Figure 17, was deduced from the seismic results using the generalized velocity function determined for the survey. The zones between the labelled events have been tentatively identified. The labelled events are as follows:

A — 'P' horizon associated with the Upper Permian coal measures which were penetrated in Lake Galilee No. 1 well.

B — base of Galilee Basin sequence, in Lake Galilee No. 1 well.

C — non-prospective basement, tentatively interpreted from the results of previous seismic work (Amerada, 1967b).

D — unconformity between Galilee Basin and Drummond Basin sediments.

A continuous event E, below the zone of poor reflection quality at the eastern end of the traverse, was only tentatively identified. A fair-quality event recorded over several shot-points about SP 1126, at a record time of about 3.0 s, was not labelled.

Reflection events A, B, and C identified near the well were followed over most of the traverse, and phantom horizons were drawn through zones of poor-quality discontinuous data. Correlations of events A, B, and C across the zone of poor reflection quality between SP 1154 and 1168 were aided by the recognition of unconformities on either side of the zone.

The geological sections between the principal reflection events indicated on the model (Fig. 17) are interpreted as follows:

–A R: Recent sediments dipping gently westwards from about SP 1152 and penetrated at the top of Lake Galilee No. 1 well.

A–D Cu-P: Galilee Basin sequence identified in Lake Galilee No. 1 well. Horizon A, associated with the Upper Permian Coal measures at the top of the sequence in the well, was followed to about SP 1135 and has been extrapolated eastwards to SP 1152.

D–B Cl: Drummond Basin sediments, unconformably overlain by the Galilee Basin sequence, pinch out in the west at about SP 1110. The tentative identification of this zone with the Drummond Group was made by extrapolation at the eastern end of the traverse. Drummond Basin sediments are absent in Lake Galilee No. 1 well, there being a time-gap in the well sequence from the Upper Devonian to Upper Carboniferous, the time of Drummond Basin deposition.

B–C Du: ?Adavale Basin sediments. The top of a sequence, about 1800 m thick along the entire traverse, was penetrated in Lake Galilee

No. 1 well and dated as Middle to Upper Devonian. The sequence is of the same age as Adavale Basin sediments. The tentative identification of the sequence as Adavale Basin sediments is based on the age determination and the postulate by Vine (1972) of widespread sedimentation during the Devonian.

C–E Dl: This unit is mapped eastwards from SP 1112 and thickens considerably towards the Drummond Basin. Its age and composition are unknown and it may only be inferred to be part of the Adavale sequence, or low-grade metamorphics of the Anakie Metamorphics (Olgers, 1973) and acid volcanics.

–E Pzl: The seismic results indicate a somewhat discontinuous reflection event E. The unit Pzl may be Anakie Metamorphics or crystalline basement. Since reflections were recorded from deeper than the horizon labelled E, the former interpretation is considered to be the more probable.

Seismic results indicate considerable faulting at the eastern margin of the Galilee Basin (Fig. 17). The interpreted throws of the faults have generally been small; some faults appear to be confined to the uppermost part of the section while others extend through the entire section. The interpretation of first-break, near-surface, refraction data shown in Figure 14 indicates very low-angle faults which may extend into the deeper parts of the section. Diffraction and reflected refraction events within the zone of poor reflection continuity (Plate 10) were analysed. Families of diffraction events were interpreted as originating from deep-seated faults about SP 1162 and 1168. The results of the refraction probe indicate no major disturbance of refracting horizons shallower than about 2000 m.

The seismic traverse appears to cross a fracture zone between SP 1154 and 1168. Analysis of diffractions and reflected refractions in this zone indicates that the fault orientation is roughly northwest (Fig. 16). Olgers (1973) has attributed mid-Carboniferous folding and faulting in the Drummond Basin to a primary compression during the Kanimblan Orogeny and has postulated a series of megashears in the basement (Fig. 3). The postulated Chinaman Megashear, crossing the seismic traverse in a northwesterly direction, and the position of a possible fault interpreted from aeromagnetic results (Exoil, 1962) shown in Figure 16 are supported by the seismic interpretation.

Two alternative interpretations of the detailed gravity results were considered for the structural section over the eastern Galilee Basin and the Drummond Basin. They have similar configurations for the uppermost units, defined by the seismic results in the Galilee Basin and geological mapping in the Drummond Basin, but differ markedly in the interpretation of the structure of the deeper units and the basement.

One interpretation associates the Donnybrook Gravity High with a basement rise of 2 km within the Drummond Basin. This is consistent with the hypothesis of vertical uplift across the Belyando Feature culminating in the mid-Carboniferous Kanimblan Orogeny (Vine, 1972). It is also supported by aeromagnetic depth estimates (H.D. Hsu, pers. comm.) which show a 2-km rise in magnetic basement east of the Belyando Feature. The second alternative is based on a reverse density contrast situation at depth, involving an inlier of dense material within a thick layer of less dense sub-basement, to explain the gravity high. It is consistent with Olger's

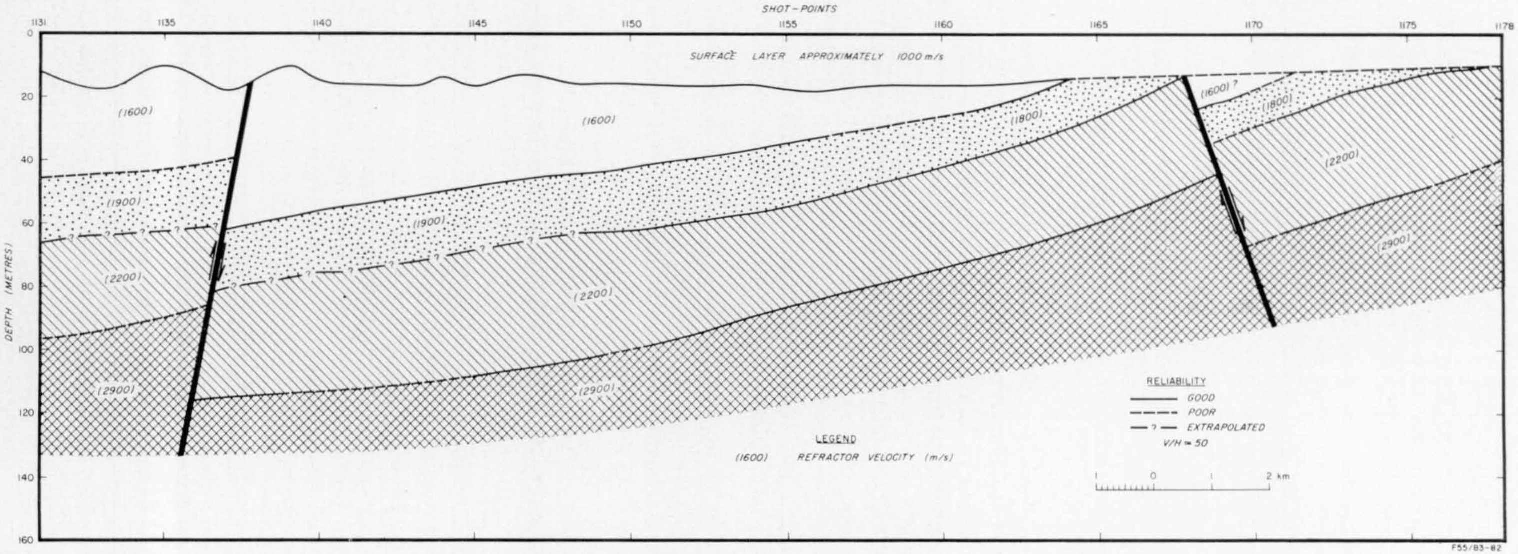


Fig. 14. Near-surface model from refraction analysis, SP 1131-1178.

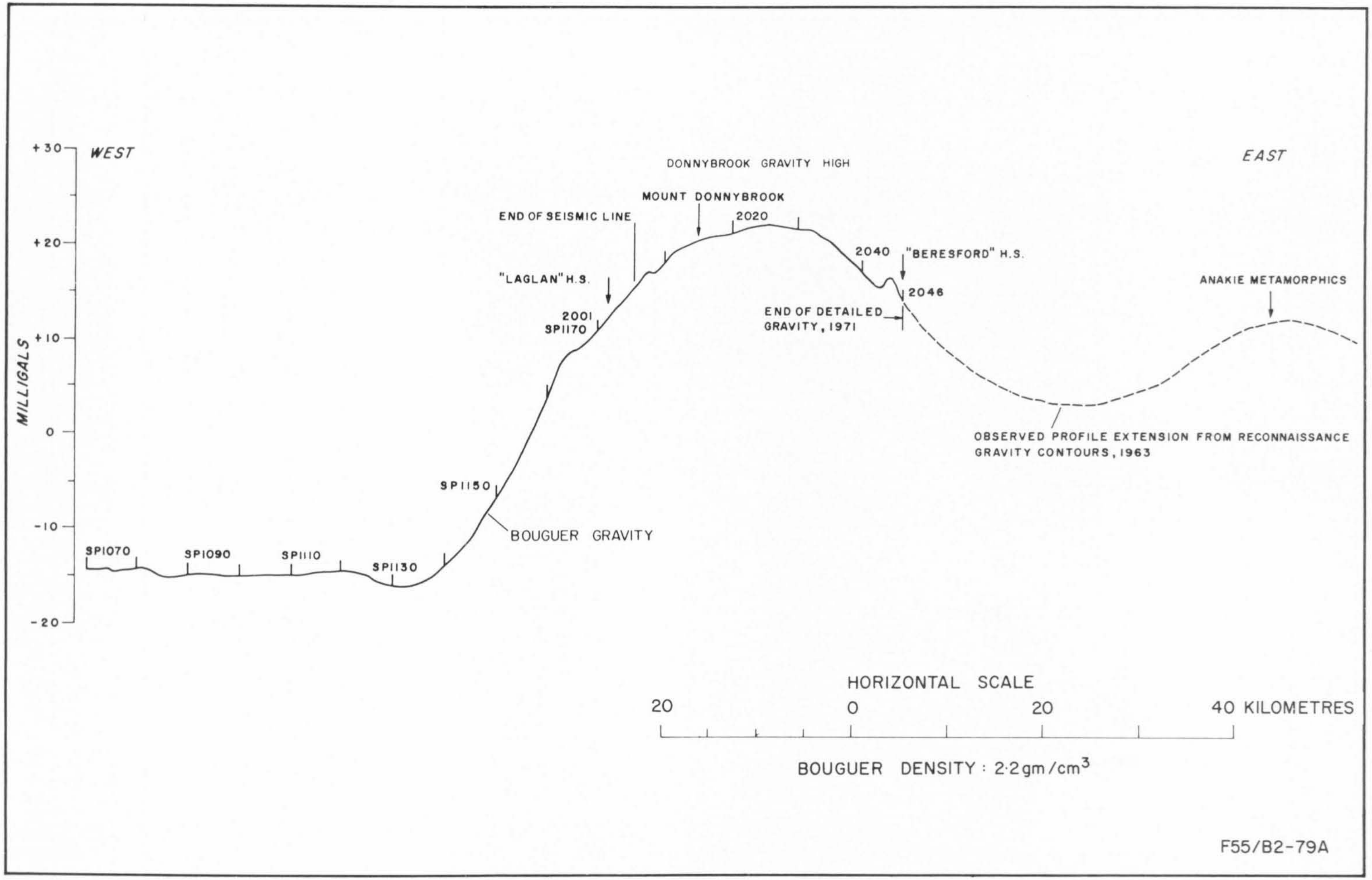


Fig. 15. Final Bouguer anomaly profile.

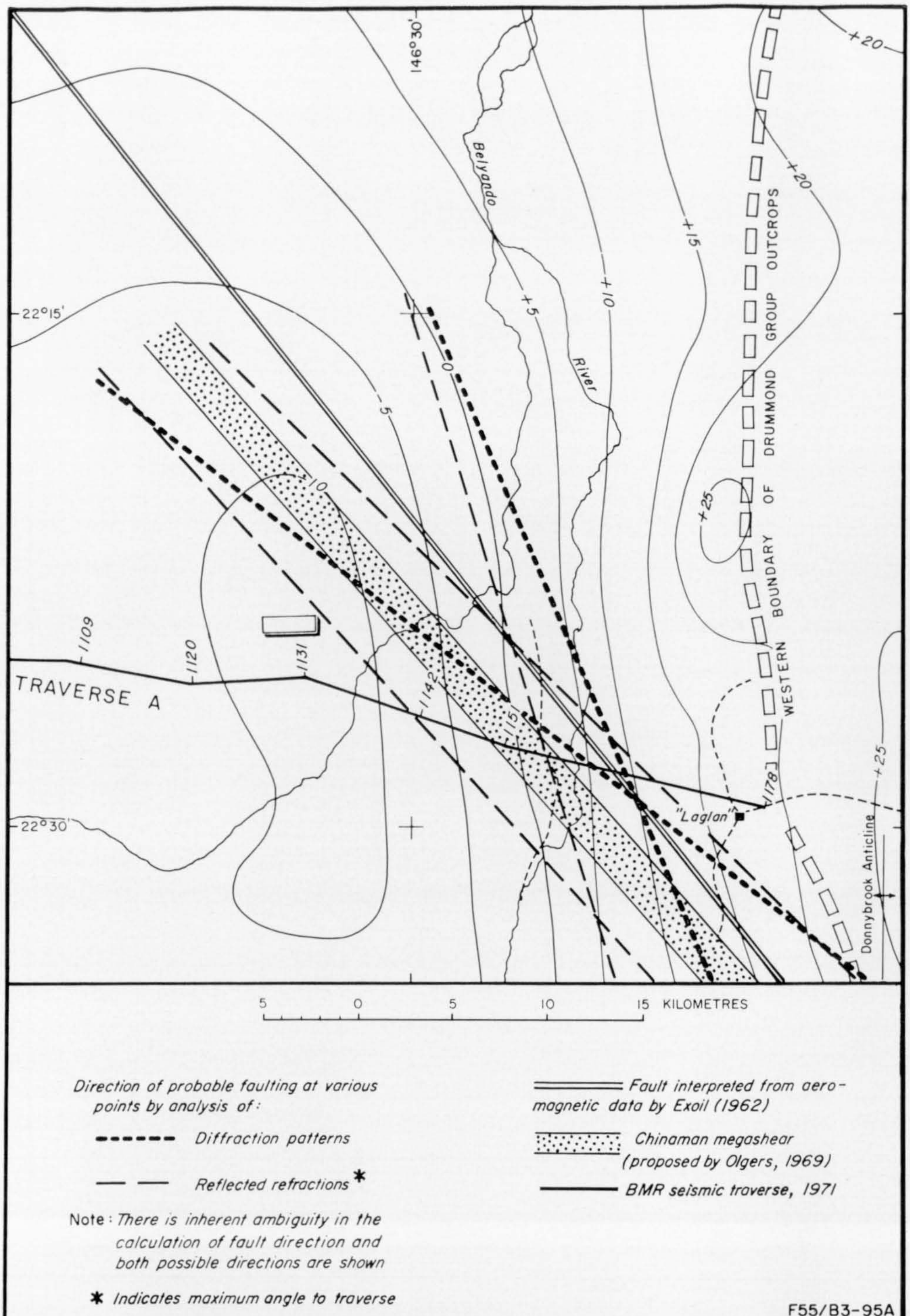


Fig. 16. Orientation of probable faulting.

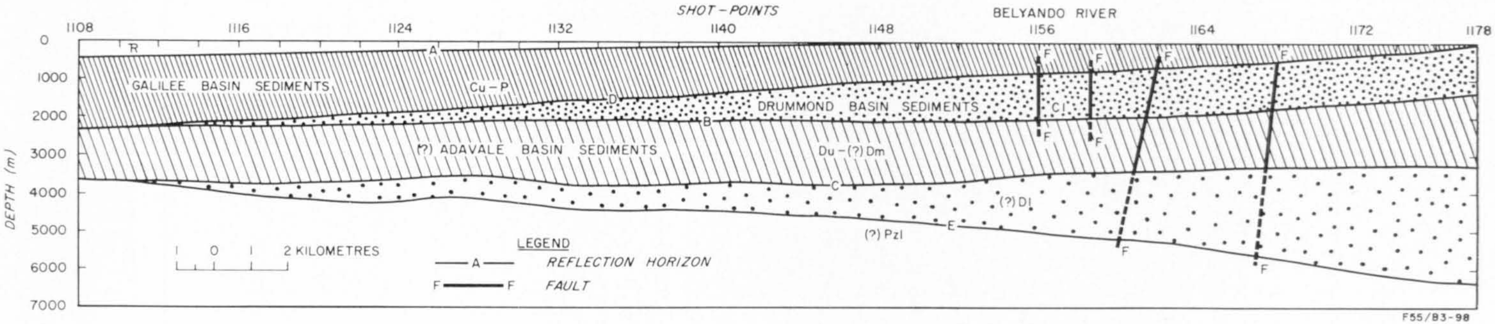


Fig. 17. Structural model of eastern margin of Galilee and Drummond Basins.

(1973) concept of horizontal compressional movements for the Drummond Basin region.

The two interpretations of structure across the Drummond Basin represent two extremes of possible basin development. These are a series of basement uplifts during overall basin subsidence and deposition, and alternating erosion and deposition with mild folding. The second possibility is considered to be the less substantiated since it involves a reverse density contrast, on a large scale, between formations whose compositions are largely unknown. The requirement for a thick, ubiquitous low-density sub-basement layer, presumably acid volcanics of density about 2.5 g/cm^3, is the particular weakness of this hypothesis.

The basement uplift interpretation gives the simpler explanation of the gravity anomaly at Mount Donnybrook. A two-dimensional structural model involving basement uplift, which satisfies the requirements set by the surface geology and the seismic and gravity results, is shown in Figure 18. The model consists of 7 units with assigned densities as shown.

		g/cm^3
Unit 1	Upper Galilee Basin sequence	2.2
Unit 2	Lower Galilee Basin sequence	2.3
Unit 3	Drummond Basin sequence	2.5
Unit 4	Middle Devonian sequence	2.55
Unit 5	Anakie Metamorphics (sub-basement)	2.60
Unit 6	Crystalline basement	2.80
Unit 7	? Granite pluton	2.60

The model depicts a thinning of Galilee Basin formations eastwards across the basin margin, and a remnant erosional wedge of Drummond Basin rocks extending under the Galilee Basin. The older Upper to Middle Devonian sequence shallows eastwards slightly, and is truncated by Drummond rocks. The maximum basement uplift of 2 km is assumed to have occurred before and during deposition of this sequence. The Anakie Metamorphics are shown as truncating westwards against the uplift. Their presence west of the uplift is not excluded, however, if their density is similar to that of the basement in that region.

The gravity low on the western flank of the Donnybrook Gravity High is assumed to be caused by a local variation in the density of the basement complex, possibly associated with a granite pluton. The postulated granitic intrusion is not delineated in the seismic results. However, there is evidence of local uplift, at the seismic Horizons E and C about SP 1128, which supports the hypothesis. The intrusion may be dated as pre-Drummond Basin sedimentation as there is no evidence of uplift on the Horizon B. The model does not allow for a density contrast at the Horizon E level. It is assumed that although a velocity contrast may exist, there is little or no density contrast between the rock types above and below this level.

CONCLUSIONS

The Galilee Basin is a difficult area in which to record good seismic data; many of the problems result from the presence of the 'P' horizon, a strong, fairly shallow reflector associated with the Upper Permian coal measures. Single-coverage

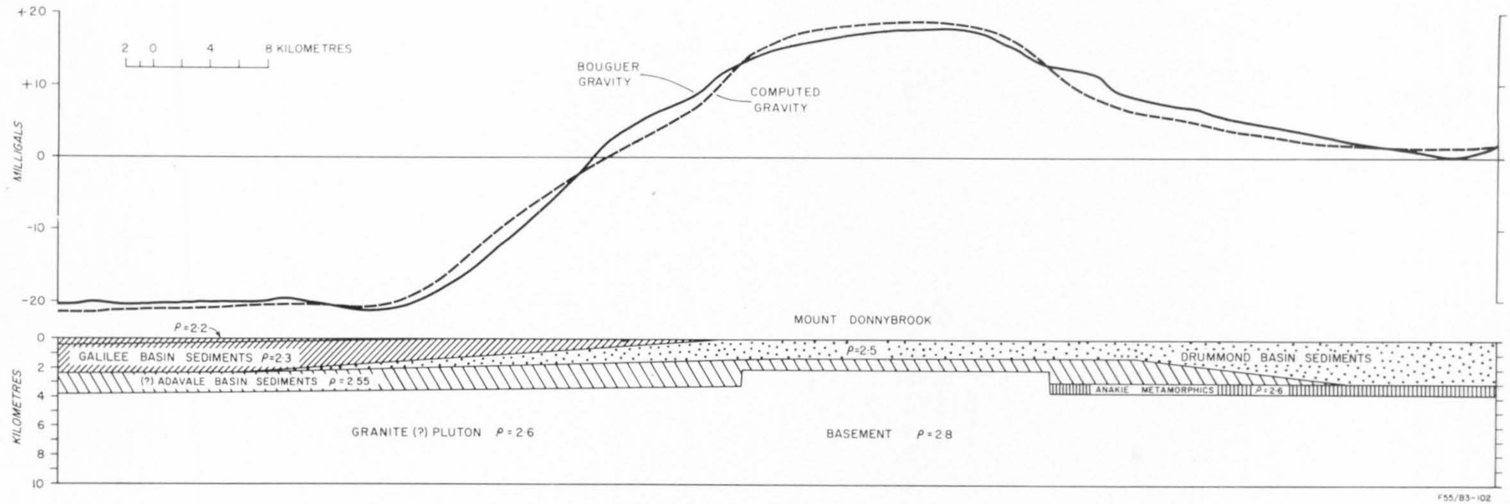


Fig. 18. Two-dimensional gravity model across Galilee and Drummond Basins.

recording used over most of traverse yielded data of only fair quality. Several 6-fold CDP multiple-coverage probes provided data of improved quality.

The seismic results confirm the gentle westerly dip of the Galilee Basin sediments inferred from surface geology. Two holes drilled to 100 m at SP 1146 and 1156 did not penetrate the Upper Permian Coal Measures, which were expected to subcrop at shallow depth from the extrapolation of the 'P' horizon event eastwards from SP 1135. The coal measures probably subcrop at shallow depth between SP 1135 and SP 1146.

Drummond Basin sediments do not appear to extend farther than 20 km west of the Belyando River. A sequence of about 1800 m of probable Middle to Upper Devonian sediments, tentatively postulated as a northerly continuation of the Adavale Basin sedimentation, is present below the Galilee and Drummond Basin sequences. Further exploration for petroleum in the area would appear to be justified, particularly as similar sediments in the Adavale Basin are petroliferous.

Seismic results indicate that the eastern margin of the Galilee Basin in GALILEE is a shear zone which has been only moderately disturbed tectonically. The Galilee, Drummond, and possibly Adavale Basin sediments are indicated in the seismic model to have a simple onlapping relation, and the sedimentary section appears to thicken steadily towards the Drummond Basin.

The analysis of the gravity results indicates that the Donnybrook Gravity High may be attributed to a 2 km uplift in basement, an interpretation supported by a recent interpretation of aeromagnetic data. The gravity results also suggest the presence of a granite pluton at depth, presumably associated with the seismic fracture zone. The granite pluton and adjacent basement uplift may be linked to the same tectonic process, and may occur in similar places around the eastern margin of the Galilee Basin where combined low and high Bouguer anomalies have been observed.

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PLATE 1

LINE R – 58

Shot by
Ray Geophysics (Aust.) Pty. Ltd.,
for
Amerada Petroleum Corporation
of Australia Ltd. (Amerada, 1967)

Fig. 1. Record section, line R-58 (Amerada).

F55/B3–99

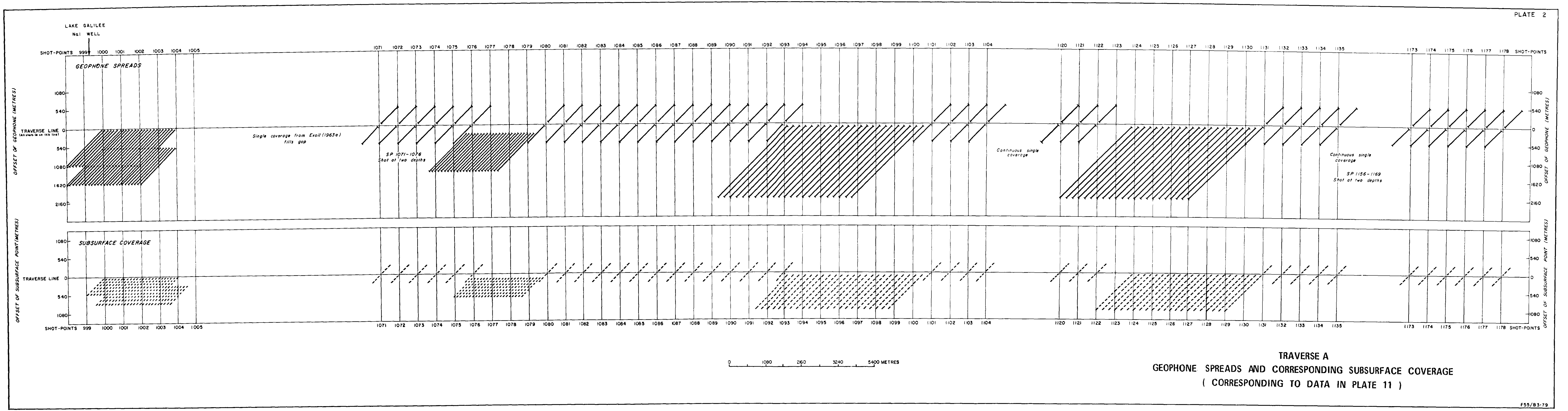
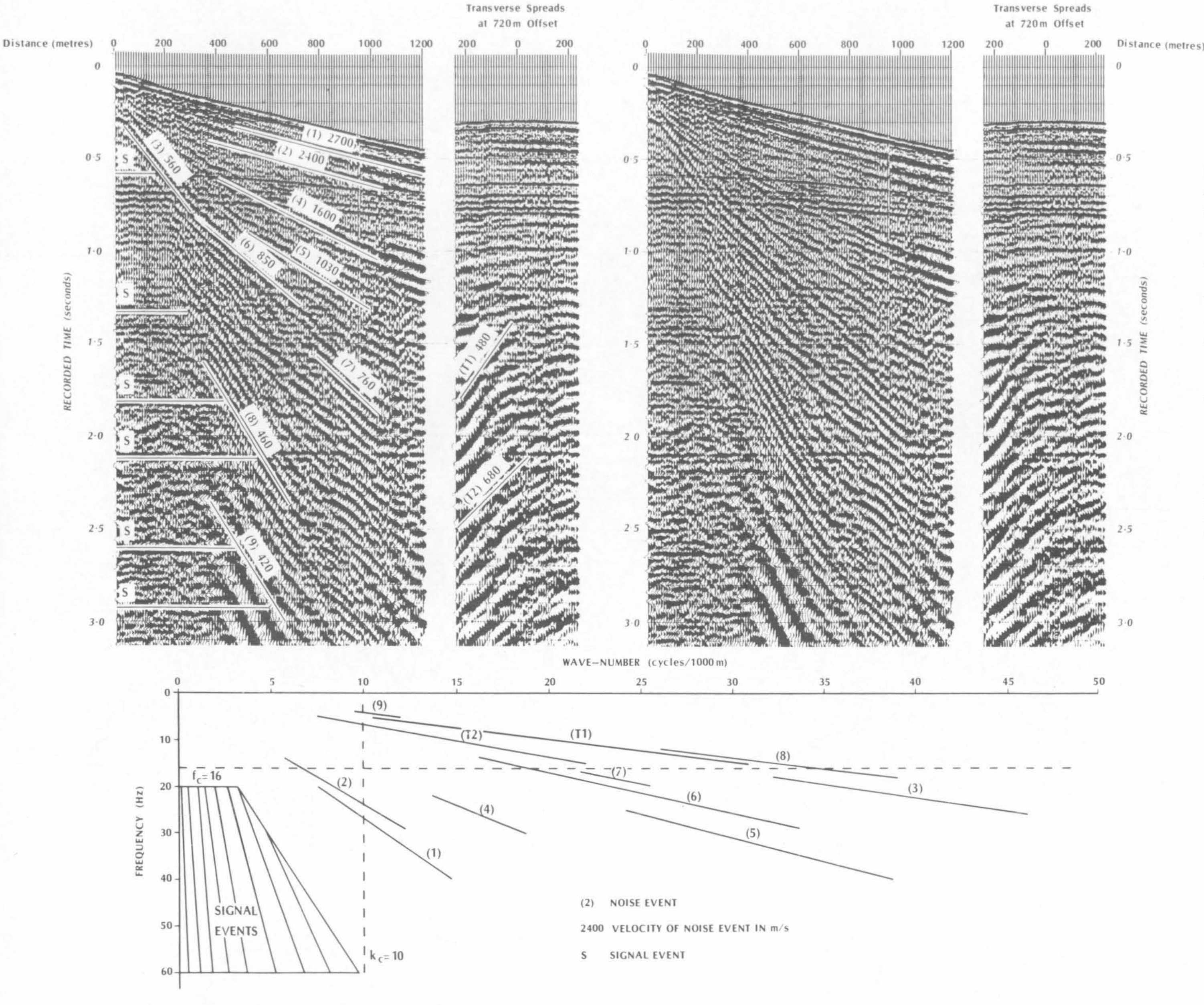


Fig. 2. Geophone spreads and corresponding sub-surface coverage.

PLATE 3



RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters: Out

Filters : Out

Programmed Gain:

Function: A

Geophones: HS – J, 14 Hz

Geophone Station Interval: 10 m

Geophone Pattern: 8/trace, bunched

Shot Hole Pattern:

Single

Depth 25 – 26 m

Charge 5 kg

PLAYBACK INFORMATION

Filters: Out

AGC : SS

Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

as indicated

GALILEE BASIN

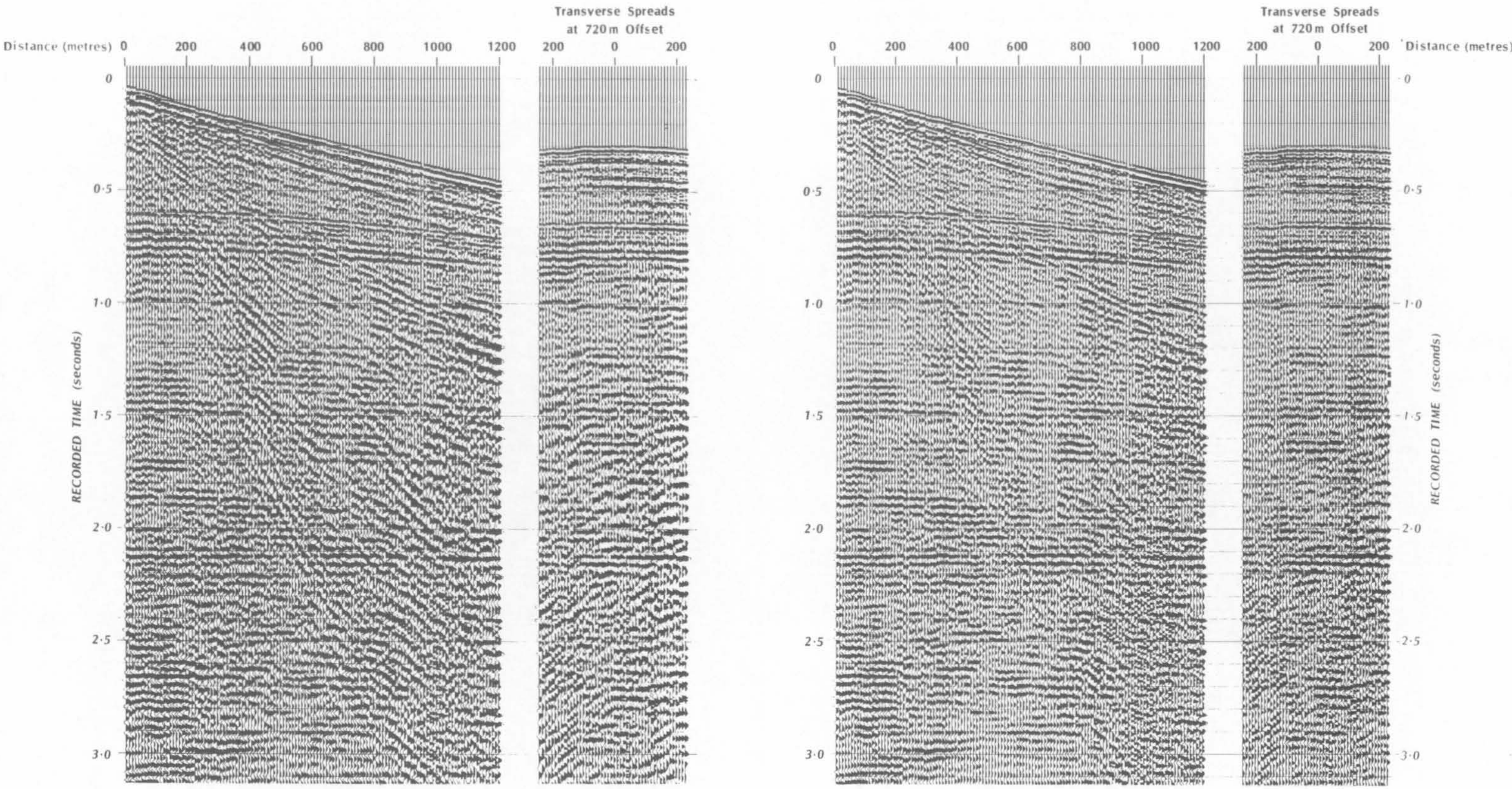
SEISMIC SURVEY, 1971

NOISE TEST

TRAVERSE A, SP 1000

F55/B3–88

Fig. 3. Noise test, SP 1000—unfiltered record sections and f-k diagram.



PLAYBACK FILTERS: LL 16 – KK 100
(Normal Recording Filters)

PLAYBACK FILTERS: LL 20 – KK 78
(Normal Playback Filters)

RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters: Out

Filters : Out

Programmed Gain:
Function: A

Geophones: HS – J, 14 Hz

Geophone Station Interval: 10 m

Geophone Pattern: 8/trace, bunched

Shot Hole Pattern: Single
Depth 25 – 26 m
Charge 5 kg

PLAYBACK INFORMATION

Filters: as indicated

AGC : SS

Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

as indicated

GALILEE BASIN
SEISMIC SURVEY, 1971
NOISE TEST

TRAVERSE A SP 1000

(Based on G85/3–173A)

Fig. 4. Noise test, SP 1000—filtered record sections.

F55/B3–87

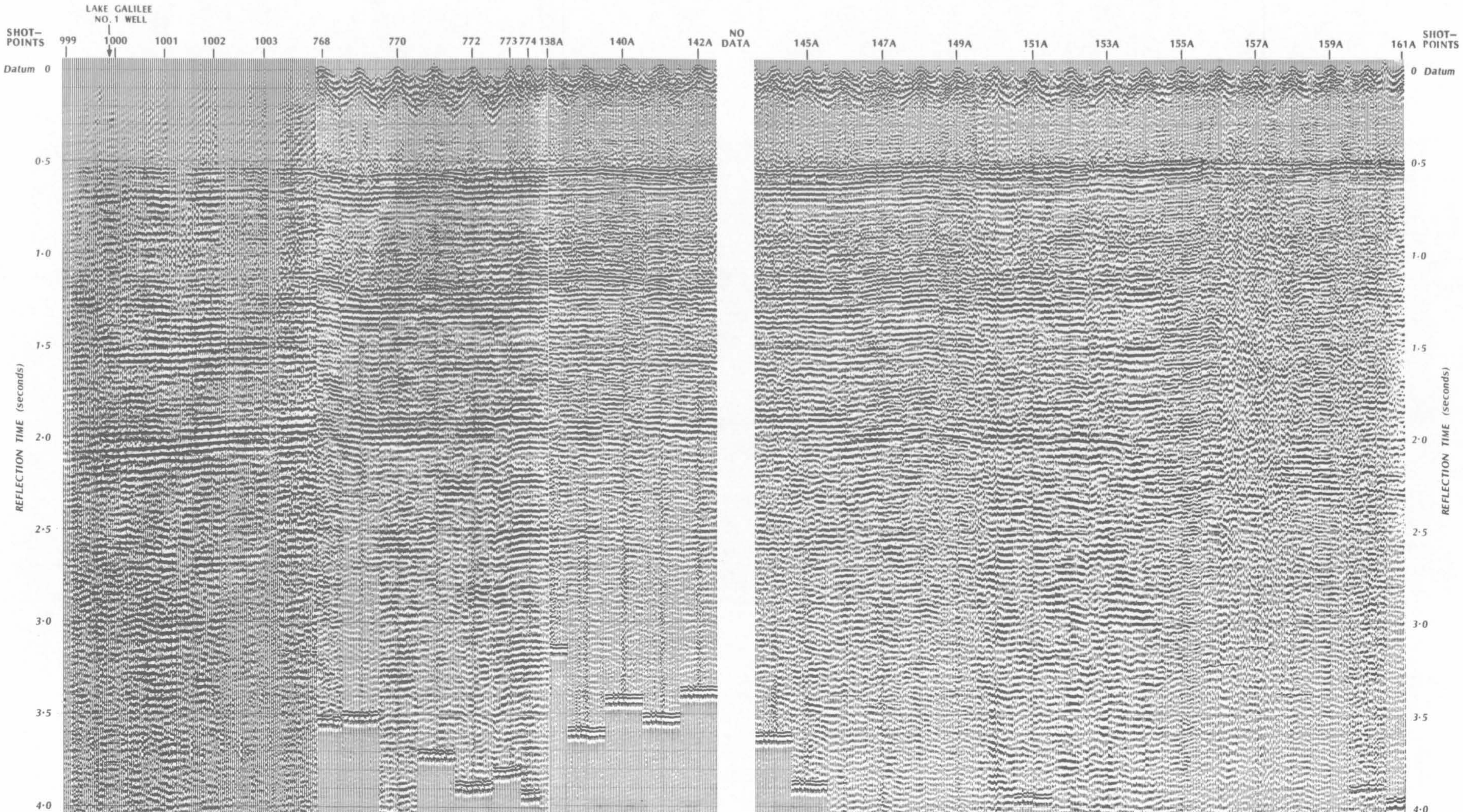


PLATE 5

CORRECTED RECORD SECTION

BMR, 1971 TRAVERSE A	LINE 7	EXOIL, 1962 LINE 3	
1–9 9–fold 9–1		Single	Multiplicity of Coverage
3 holes in line, 15 m apart		1 or 3 holes	Shot Hole Pattern
Average Depth 25 m		Average Depth 25 m	Depth
33 kg		15 kg	Average Total Charge
45 m		34·8 m	Geophone Station Interval
32/trace in 4 lines of 8 Spacing in line 6 m Spacing between lines 8 m		8 or 16/trace Spacing in line 9·1 m	Geophone Pattern
Programmed Gain Function A		A.G.C.	Recording Mode
A.G.C. SS		A.G.C. SS	Playback Mode

RECORDING INFORMATION (Not Applicable to Exoil Data)

Magnetic Recorder: PMR–20

Amplifiers: PT–700

Prefilters: Nil

Filters : LL 16 – KK 100

Geophones: HS–J, 14 Hz

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

VELOCITY INFORMATION

Function shown in Plate

HORIZONTAL SCALE

0 500 1000 METRES

408 816 (EXOIL)
540 1080 (BMR)

GALILEE BASIN
SEISMIC SURVEY, 1971
SP 999 – 1104 (BMR)
SP 768 – 775, 138A – 161A (EXOIL)

OTHER RECORDING AND PROCESSING INFORMATION

Data Recorded by

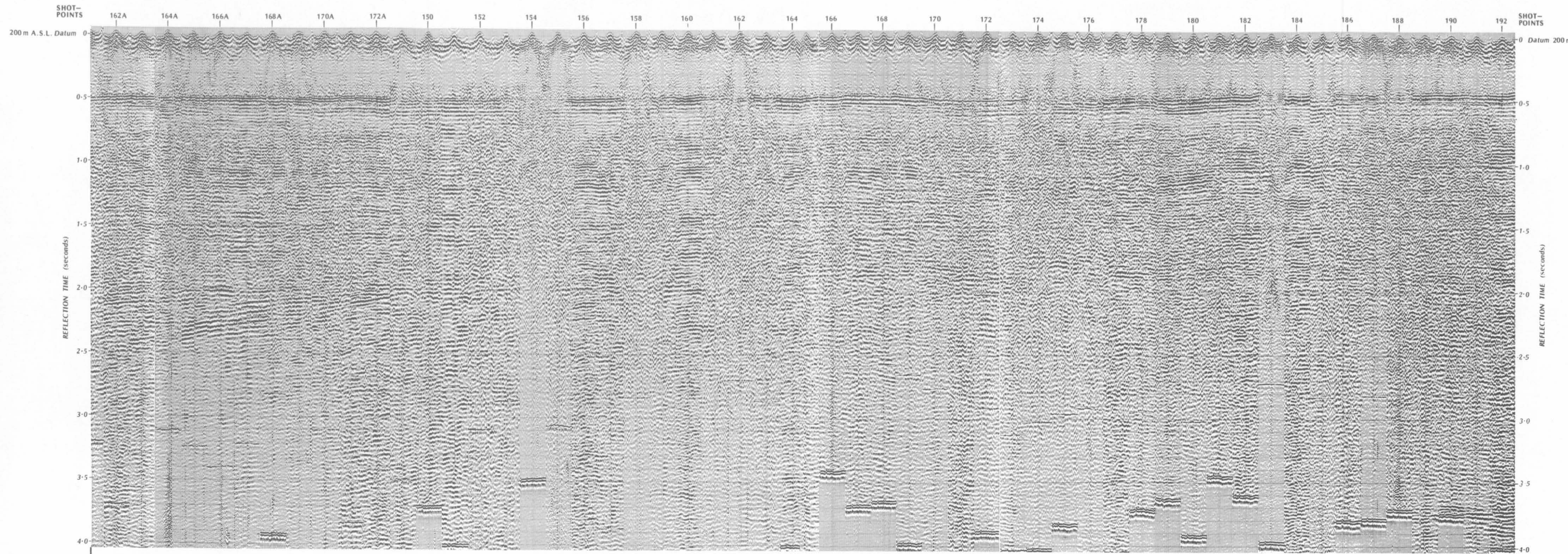
Traverse

F55/B3–94

Fig. 5. Record section, SP 999-1004 (BMR); 768-775 and 138A-161A (Exoil).

PLATE 6

CORRECTED RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder: Fortune

Amplifiers: SIE PT – 100

Prefilters: Nil

Filters : 20 – 100 Hz

Geophones: Electro – Tech 30 Hz

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

VELOCITY INFORMATION

Based on Refraction

(Exoil, 1963 a)

HORIZONTAL SCALE

0 500 1000 METRES

408 816

GALILEE BASIN
SEISMIC SURVEY, 1971
SP 161A – 173A, 149 – 192 (EXOIL)

OTHER RECORDING AND PROCESSING INFORMATION

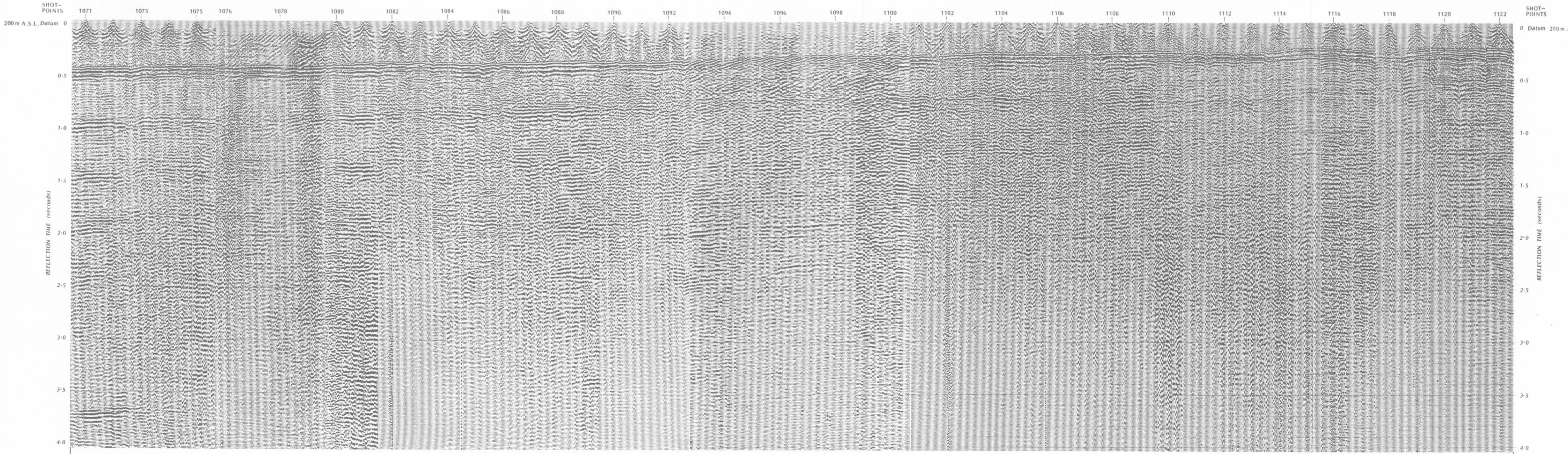
Data Recorded by		EXOIL, 1962
Traverse	LINE 10	LINE 1
Multiplicity of Coverage		Single
Shot Hole Pattern		1 or 3 holes
Depth		Average Depth 25 m
Average Total Charge		15 kg
Geophone Station Interval		34·8 m
Geophone Pattern		1 or 2 rows of 8 Spacing in line 10 m Spacing between lines 10 m
Recording Mode		A.G.C.
Playback Mode		A.G.C. SS

F55/B3–92

Fig. 6. Record section, SP 161A-173A and 149-192 (Exoil).

PLATE 7

CORRECTED RECORD SECTION



BMR, 1971

TRAVERSE A

2 – fold vertical	6 – fold (6 – 1)	Single (5)	6 – fold (6 – 1)	Single
3 holes in line Spacing in line 15 m	5 or 3 holes in line Spacing in line 15 m	10 holes in 2 lines of 5 Spacing in line 12 m Spacing between lines 20 m	5 or 10 holes in lines of 5 Spacing in line 12 m Spacing between lines 20 m	10 holes in 2 lines of 5 Spacing in line 12 m Spacing between lines 20 m
Depth 25 m and 40 m	Depth 25 m	Depth 25 m	Depth 25 m	Depth 25 m
21 kg	44 kg	90 kg	130 kg	110 kg
45 m	45 m	45 m	90 m	45 m
32/trace, in 4 lines of 8 Spacing in line 6 m Spacing between lines 8 m	32/trace, in 4 lines of 8 Spacing in line 6 m Spacing between lines 8 m	32/trace in 4 lines of 8 Spacing in line 6 m Spacing between lines 8 m	32/trace, in 2 lines of 16 Spacing in line 6 m Spacing between lines 8 m	32/trace in 4 lines of 8 Spacing in line 6 m Spacing between lines 8 m
Programmed Gain Function A	A.G.C SS	A.G.C. SS	Programmed Gain Function A	A.G.C. SS
A.G.C. SS	Fixed Gain	Fixed Gain	A.G.C. SS	Fixed Gain

RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers: PT – 700

Prefilters: Out

Filters : LL 16 – KK 100

Geophones: HS – J, 14 Hz

PLAYBACK INFORMATION

Filters: LL 20 – KK 78

VELOCITY INFORMATION

Function shown in

Plate

HORIZONTAL SCALE

GALILEE BASIN
SEISMIC SURVEY, 1971
SP 1071 – 1122

OTHER RECORDING AND PROCESSING INFORMATION

Data Recorded by
Traverse
Multiplicity of Coverage
Shot Hole Pattern

Depth
Average Total Charge
Geophone Station Interval
Geophone Pattern

Recording Mode
Playback Mode

F55/B3–93

Fig. 7, Record section, SP 1071-1122.

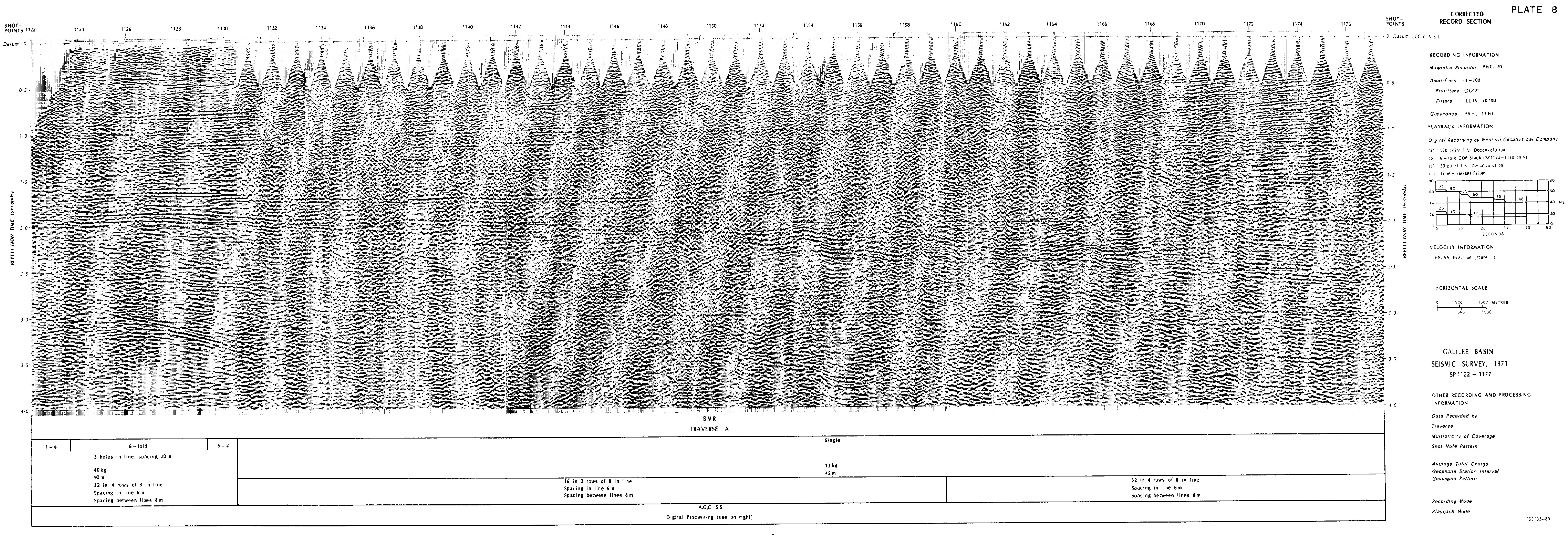
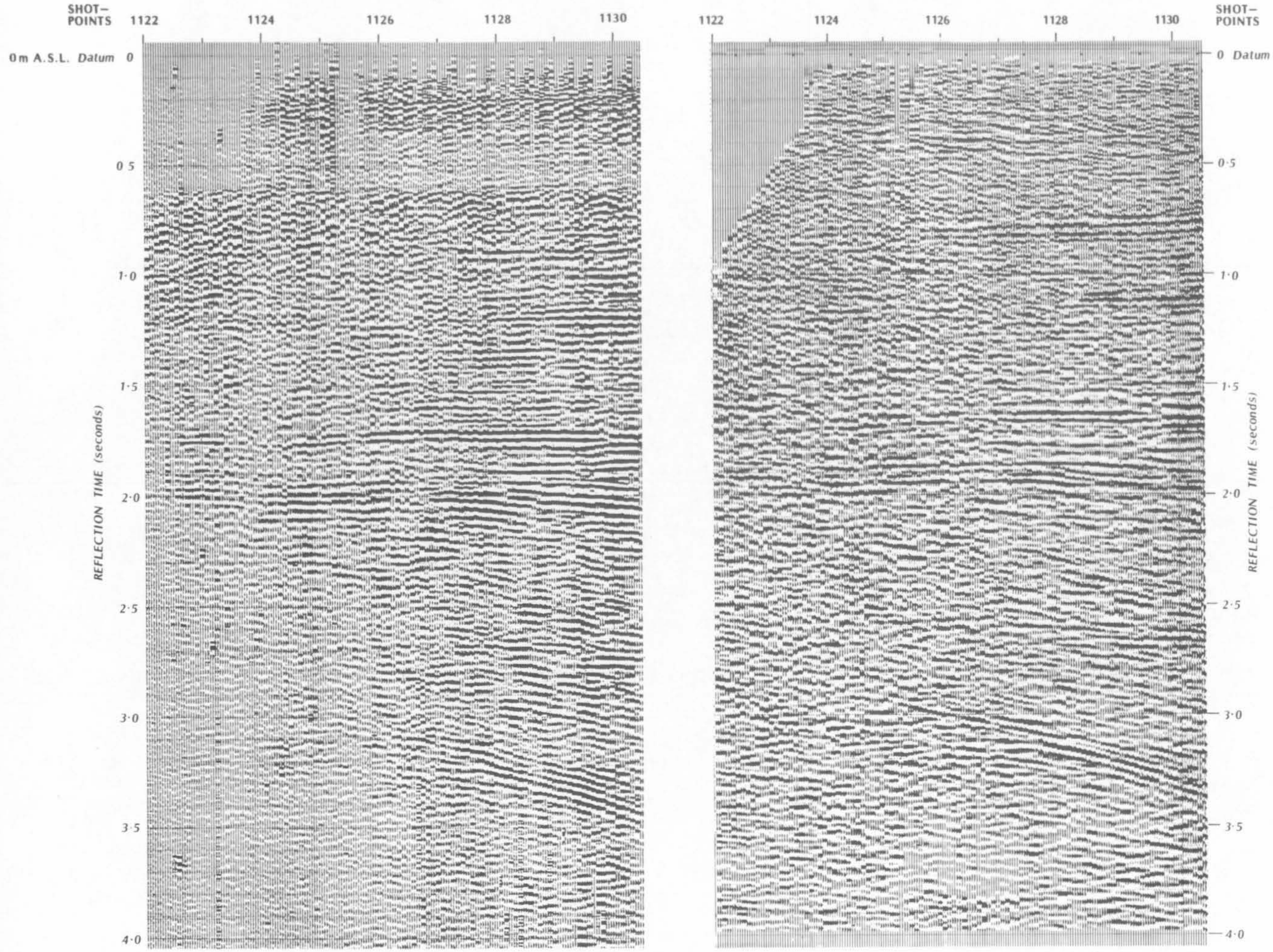


Fig. 8. Record section, SP 1122-1177.

PLATE 9

RECORD SECTION



ANALOGUE PROCESSED

(a) NMO correction using selected velocity functions (Plate)

(b) 6 – fold CDP stack

(c) Filter LL 20 – KK 78

DIGITALLY PROCESSED

(a) 100 point T.V. Deconvolution

(b) NMO correction using VELAN velocity functions (Plate)

(c) 6 – fold CDP stack

(d) 50 point T.V. Deconvolution

(e) Time–variant Filter (see Plate)

RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters: Nil

Filters : LL 16 – KK 100

A.G.C. : SS

Gain Initial: –25

Final : –10

Geophones: HS – J, 14 Hz

Geophone Station Interval: 45 m

Geophone Pattern:

32 in 4 rows of 8 in line

Spacing in line 6 m

Spacing between lines 8 m

Shot Hole Pattern:

3 holes in line, spacing 20 m

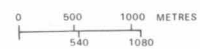
PLAYBACK INFORMATION

(See under sections)

VELOCITY INFORMATION

(See under sections)

HORIZONTAL SCALE



GALILEE BASIN

SEISMIC SURVEY, 1971

SP 1122 – 1131

ANALOGUE AND DIGITAL PROCESSED SECTIONS

F55/B3–1(

Fig. 9. Analogue and digital processed section, SP 1122-1131.

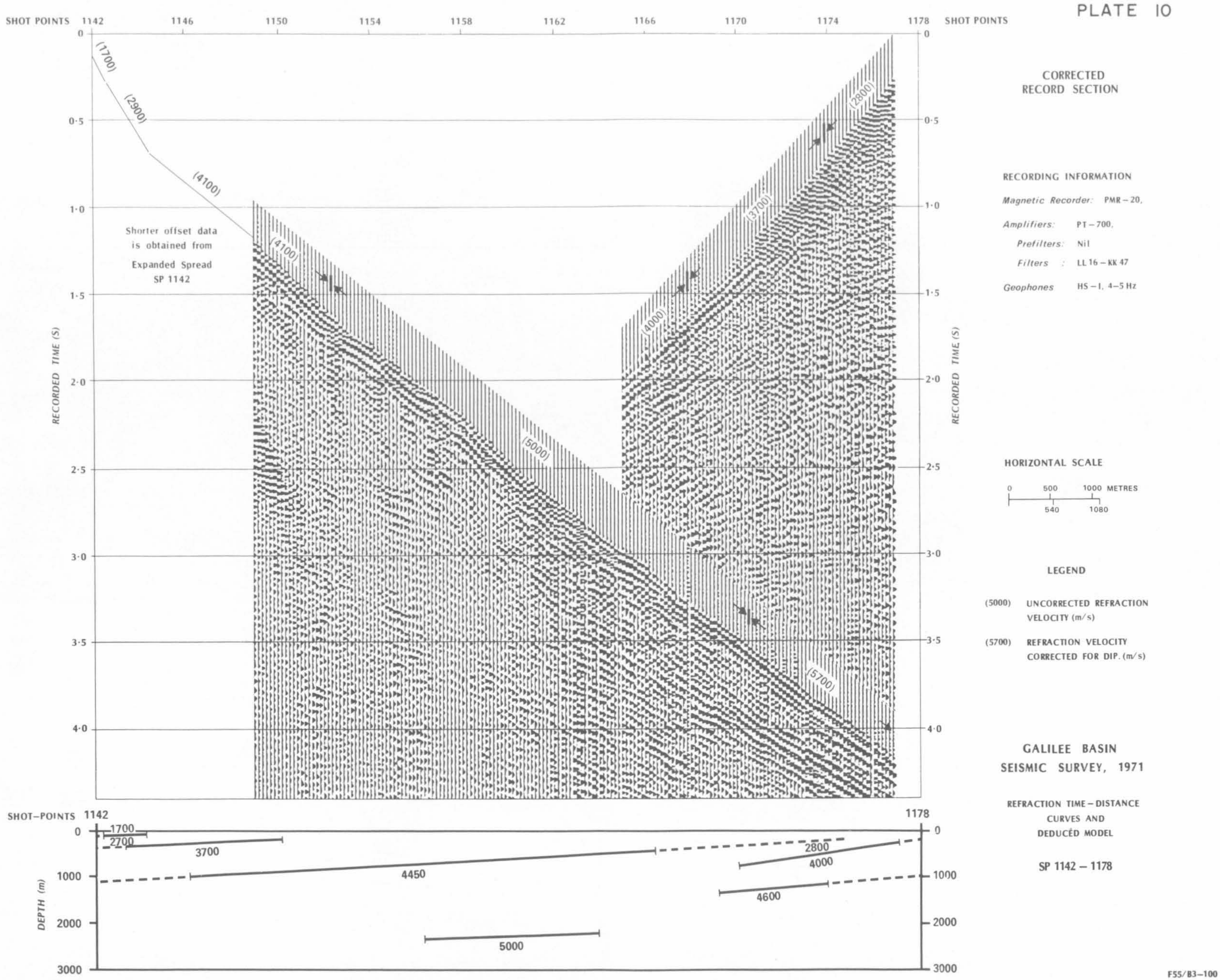


Fig. 10. Refraction time-distance curves and deduced model, SP 1142-1178.

Fig. 11. Interpreted seismic record section and Bouguer anomaly profile.