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Record 1972/97

DEEP CRUSTAL SEISMIC REFLECTION/REFRACTION SURVEY BETWEEN CLERMONT AND CHARTERS TOWERS, QLD 1971

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CONTENTS

ILLUSTRATIONS

SUMMARY

During the 1971 Galilee Basin reflection seismic survey three large shots were detonated to record deep crustal reflections. The opportunity was taken to obtain refraction data from these same shots in a line to Charters Towers, extending the coverage of the Carpentaria Region Upper Mantle Project (CRUMP) survey as well as providing a control for the deep reflection work.

A crustal cross-section was deduced from the refraction and reflection results and it is probable that reflections were obtained from both the intermediate and the Mohorovicic discontinuities.

1. INTRODUCTION

The Galilee Basin Seismic Survey (Plate 1) conducted by the Bureau of Mineral Resources (BMR) between August and December of 1971 (Harrison & Brown, 1971) included, in addition to the normal reflection program, the detonation of three large shots (3600, 2700, and 1800 kg Geophex) suitable for deep crustal studies. Similar shots included in other recent BMR seismic surveys and experiments have indicated that seismic reflections can usually be obtained from deep crustal and upper mantle horizons (Moss & Brown, in prep.).

In the present survey it was expected that sufficient energy from each shot would be refracted at the Moho interface to be recorded at large distances by the recently developed BMR portable seismic stations. Depths calculated from the refraction data were to be used to verify that selected events recorded at the shot-point were in fact reflections from the Moho or other discontinuities.

The shot-point (SP1142, Traverse A) was situated about 300 km south of Charters Towers (Qld) and consequently provided an excellent opportunity to reverse the refraction data recorded at the University of Queensland Seismic Observatory near that town during the 1966 Carpentaria Region Upper Mantle Project (CRUMP) (Finlayson, 1968). The two smaller shots were available to provide near-surface crustal data and to examine the possibility of an intermediate refractor in the region.

2. GEOLOGICAL AND GEOPHYSICAL BACKGROUND

The geology of the region has been described by Olgers (1969) and Vine & Doutch (1971), and the following is a summary of their work.

The Galilee Basin (Plate 2) consists of Upper Carboniferous to Upper Triassic sediments. Its eastern boundary, although obscured by Quaternary deposits, is known to overlap the Drummond Basin, which dates from Upper Devonian to Lower Carboniferous. A third Basin, the Northern Eromanga Basin, was formed in the Jurassic to Cretaceous period and overlaps the Galilee Basin in the west. The axes of the three basins are roughly north-south.

According to Olgers (1969) the present Drummond Basin is a small structural remnant of a large intermontane basin which developed in the Tasman Geosyncline during the Devonian. In the Middle Carboniferous the eastern side of the basin was uplifted and folded by regional compression across the graben, causing a series of parallel anticlines and synclines with associated faulting. Uplift and faulting also occurred in the west and which caused the Drummond Basin, now a structural high, to act as a source of sediment for the Bowen and Galilee Basins. Vine & Doutch (1971) explain the basin structure by simple vertical basement movements.

The Galilee Basin originated with a downwarp of the original Drummond Basin. Its structure is probably caused by faulting and overlap onto the Drummond Basin topography since no major tectonic activity occurred during its formation. The major geological feature of the area is a lineament along the Belyando River (roughly N-S) marking the general division of the Galilee and Drummond Basins. Vine et al. (1965) suggest that this lineament may be a major discontinuity which initiated the formation of the Galilee Basin.

Geophysical work related to the present deep crustal investigations is limited to two refraction surveys. The first, an upper mantle project, was conducted across Cape York Peninsula as far south as Charters Towers (Finlayson, 1968), and may be tied to the present survey (Plate 1). The second provided upper mantle information from the Kununurra blasts (Denham et al., in prep.) in an east-west line to Charters Towers through Camooweal, Mount Isa, Cloncurry, and Julia Creek.

Other geophysical investigations have generally been associated with oil search and are summarized by Harrison & Brown (1971). They include regional gravity, reflection seismic, and aeromagnetic surveys. The regional gravity contours reflect the Belyando lineament which marks the boundary of the Galilee basin while the seismic results indicate the broad extent and structure of this basin.

3. OBJECTIVES

The combined reflection/refraction investigation was designed with several aims:

1. To determine whether seismic reflections can be recorded from deep crustal layers beneath the Galilee Basin.
2. To extend the coverage of the CRUMP survey by providing a reverse shoot to Charters Towers.
3. To deduce a crustal model between Clermont and Charters Towers based on the combined reflection and refraction results.

4. REFRACTION RESULTS

Of the four portable seismic recorders available for the survey, three were developmental magnetic tape systems consisting of a Willmore Mk II seismometer coupled to a BMR TAM4 voltage amplifier and a PI. 5107 seven track tape recorder which was run at 6 mm/s (15/64 i.p.s.); the fourth system consisted of a 2-Hz geophone, a TAM4 voltage amplifier and a ZSD1 power amplifier which was used to drive a Kelvin & Hughes paper recorder. For each system timing was provided by a Labtronics radio tuned to VNG radio time signals and connected to the recorders. Shot instant was recorded by applying VNG signals directly onto the uphole trace of the reflection recorder.

The two largest shots (3600 and 2700 kg) were recorde at eight sites including Charters Towers in a roughly north-south line from the shot-point (SP1142). The recording sites, chosen after consideration of access and geology, are shown in Plate 1. It was expected that events from the upper mantle would be recorded as first arrivals at about 120 km; consequently most sites were located in the range 80 to 170 km with two closer stations providing crustal data. Rock outcrops were available for sites 4, 5, 6, 7, and 9; the remaining sites were on hard packed soil.

Travel times and associated data obtained for these stations are listed in Table 1 and are plotted in Plate 3. Shot and station elevations ranged between 200 m and 355 m (Plate 1); reduction to sea level would modify the travel times by less than 0.1 second (reduction to a datum level of 200 m would cause modifications of less than 0.03 second); consequently no corrections were made to the observed travel times. The apparent velocities and intercept times indicated on the plot were obtained by a least-squares analysis of the data except for the 5.1 km/s refractor, for which the data are poor. Data obtained at station 1 were not used in the analysis because of poor timing signals.

The crustal cross-section shown in Plate 4 was derived by assuming that the delay times at the shot-point could be equated to the half intercept times (TI/2) of the plot; station delay times (DT) were then obtained from the equation:

$$DT = tt - D/V - TI/2 \quad \text{.....................(1)}$$

where tt is the travel time to the station(s)

D is the shot-to-station distance (km)

and V is the refraction velocity (km/s)

Depths and offset distances, calculated from delay times according to refraction theory, are plotted in Plate 4.

Extension to CRUMP survey area

Actual velocities, used in equation (1), were obtained by reversing the apparent velocities indicated in Plate 3 with those obtained in the CRUMP survey (Finlayson, 1968). Of the four main shot groups in CRUMP, three groups were recorded by stations roughly in line to the south giving average apparent velocities of (7.98 $\pm$ 0.06), (6.68 $\pm$ 0.09), and (5.88 $\pm$ 0.05) km/s. In the present survey, shooting from south to north, the apparent velocities assumed to correspond to the same refractors are (8.02 $\pm$ 0.08), (6.82 $\pm$ 0.04), and (6.07 $\pm$ 0.03) km/s. A comparison of these results suggests that the two shallow refractors are, on average, dipping slightly from north to south, while no significant dip is indicated for the Moho.

The distribution of shots and recording stations in the CRUMP survey is such that the time terms obtained for Charters Towers are more correctly called delay times; the refractor depths calculated for this station and shown in Plate 4 should be offset towards the north (at least 50 km for the Moho depth). In this 1972 survey, data obtained at Charters Towers are used to define refractor depths offset towards the south, there is no overlap of data between the two survey areas and thus the measured apparent velocities mentioned above may be misleading; the suggested dips are not true if there is a change in lateral velocity or in refractor gradient near Charters Towers. The dips suggested by the apparent velocities are consistent with the shallow refractor depths north of Charters Towers but are contrary to the Moho depths obtained from CRUMP.

Because the 1971 recording stations lie in a line roughly parallel to the topographical trends (and Coral Sea margin) it would be expected that the derived crustal cross-section cuts at right angles the main slope of the refracting interfaces. However, the variations in recording station longitudes and refractor gradients are insufficient to establish a correlation with refractor depths and consequently with the main interface slopes.

Gravity analysis

The Bouguer anomaly profile shown in Plate 4 was derived by direct scaling off BMR 1:500 000 contour sheets; the Bouguer anomalies for these sheets were reduced from the observed gravity using a density of 1.9 g/cm^3. Anomaly values were scaled in a straight line (from Charters Towers to the shot-point) corresponding to the crustal cross-section, which was derived by assuming a linear distribution of recording sites.

Because the derived crustal cross-section is parallel to the geological trends in the area, two-dimensional gravity analysis is not a good approximation, and consequently no attempt was made to model the cross-section for correlation with the observed gravity values. However, the general level of the gravity profile was checked using, as a linear approximation to the curves of Nafe & Drake (Talwani et al., 1959), the empirical relation:

$$\text{DENSITY} = 0.21 \ (\text{P velocity}) + 1.58 \ (\pm 0.15) \ \text{g/cm}^3$$

The levels of the observed and calculated anomalies roughly coincide if a 'standard crust' of density 2.83 g/cm^3, to a depth of 32 km, is assumed to overlie an upper mantle of density 3.3 g/cm^3.

5. DEEP CRUSTAL REFLECTION RESULTS

Reflection events at two-way times greater than 6 seconds were recorded from each of the three shots used to obtain the refraction data. Magnetic tapes recorded from the two smaller shots have been summed and filtered on playback to produce the processed record shown in Plate 5. Deep crustal information from the third and largest shot was recorded on a paper record only.

Five events were picked with reasonable confidence from the processed records and are listed in Table 3 along with their probable nature. A refraction probe shot from SP 1142 as part of the sedimentary investigations also showed reflection events at times which correspond with those on the reflection records.

A cross traverse had been planned to check that the recorded events were near-vertical rather than side reflections and at the same time to provide information on dip; however, there was insufficient time to accomplish this.

The depths indicated in Table 3 and plotted on the crustal cross-section (Plate 4) were derived by using the following velocity functions:

t less than 2.5 s	:	Va = 2.9 + 0.86 t	..........(a)
t between 2.5 and 7.0 s	:	Va = 4.0 + 0.42 t	..........(b)
t greater than 7.0 s	:	Va = Vr	..........(c)

where Va (km/s) is the average velocity to the layer with a two-way time of t and Vr (km/s) is an average layer velocity obtained from refraction data. Equations (a) and (b) above were derived during the Galilee Basin seismic survey (Harrison & Anfiloff, 1972).

6. DISCUSSION AND CONCLUSIONS

Deep crustal reflection events have been identified with reasonable confidence on the reflection records and have been used to calculate depths which show good agreement with the refraction results.

The apparent refractor velocities within the crust obtained in this survey (Plate 3) are higher than those obtained in the CRUMP survey; this indicates thinning of the upper crustal layers from central Queensland towards the Coral Sea. The intermediate layer (6.75 km/s) is widespread throughout Cape York Peninsula and north Queensland and it ranges in depth from 25 kilometres beneath the Galilee Basin (SP 1142) to 20 kilometres near Charters Towers. In this same interval the depth to the top of the upper mantle (velocity 8.00 km/s) ranges between 45 and 35 kilometres.

An interesting feature of the cross-section (Plate 4) is the pinching out of the 5.1-km/s refractor, roughly at the boundary of the Galilee and Drummond basins as indicated from geological mapping (Plate 2). However, the data for the 5.1-km/s layer are poor so this conclusion is not definite.

The Bouguer gravity anomalies in the area of the derived cross-section suggest that the regional crustal density is less than the world average of 2.92 g/cm^3 suggested by Woollard (1969).

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SHOT LOCATION : 22°26.8 S 146°29.1 E

PARTY	LOCATION		DISTANCE (km)	AZIMUTH	TRAVEL-TIME (sec)	ASSESSMENT	
1	22°11.7 S	146°33.2 E	28.77	14.2	7.24	Good	1
					7.87	Fair	2
					12.28	Good	2
2	21°57.3 S	146°35.3 E	55.48	11.1	10.57	Good	1
					13.57	Good	2
					16.93	Fair	2
					18.89	Good	2
					19.82	Good	2
					25.85	Good	2
					33.82	Good	2
4	21°40.4 S	146°40.5 E	87.88	12.9	16.21	Good	1
					17.85	Poor	2
					18.99	Poor	2
					21.31	Good	2
					23.44	Fair	2
5	21°29.4 S	146°39.5 E	107.48	9.6	18.51	Good	2
					20.39	Good	2
					21.41	Good	2
					22.20	Good	2
					23.04	Poor	2
					24.73	Fair	2
					26.41	Fair	2
6	21°18.5 S	146°31.3 E	126.17	1.7	21.95	Good	2
					23.58	Good	2
					24.14	Fair	2
					26.04	Fair	2
					28.28	Good	2
					30.46	Fair	2
					37.28	Good	2
7	21°8.7 S	146°26.1 E	144.30	357.9	24.70	Good	1
					25.43	Good	2
					28.34	Good	2
					31.05	Good	2
					33.74	Good	2
					34.90	Fair	2
					39.65	Good	2
8	20°55.4 S	146°22.3 E	169.14	356.0	28.50	Good	2
					29.23	Fair	2
					30.15	Good	3
					31.36	Good	2
					34.16	Fair	2
					34.94	Fair	3
					41.74	Poor	3
9	20°5.3 S	146°15.0 E	262.39	354.6	40.78	Fair	3
					44.58	Good	3
					43.27	Good	3
					45.37	Good	3
					57.27	Fair	3
					71.87	Good	3
					74.68	Good	3

ASSESSED ACCURACY: 1 ± 0.1 sec
2 ± 0.1 → 0.5 sec
3 > 0.5

TABLE 1: Refraction travel–times and party location date

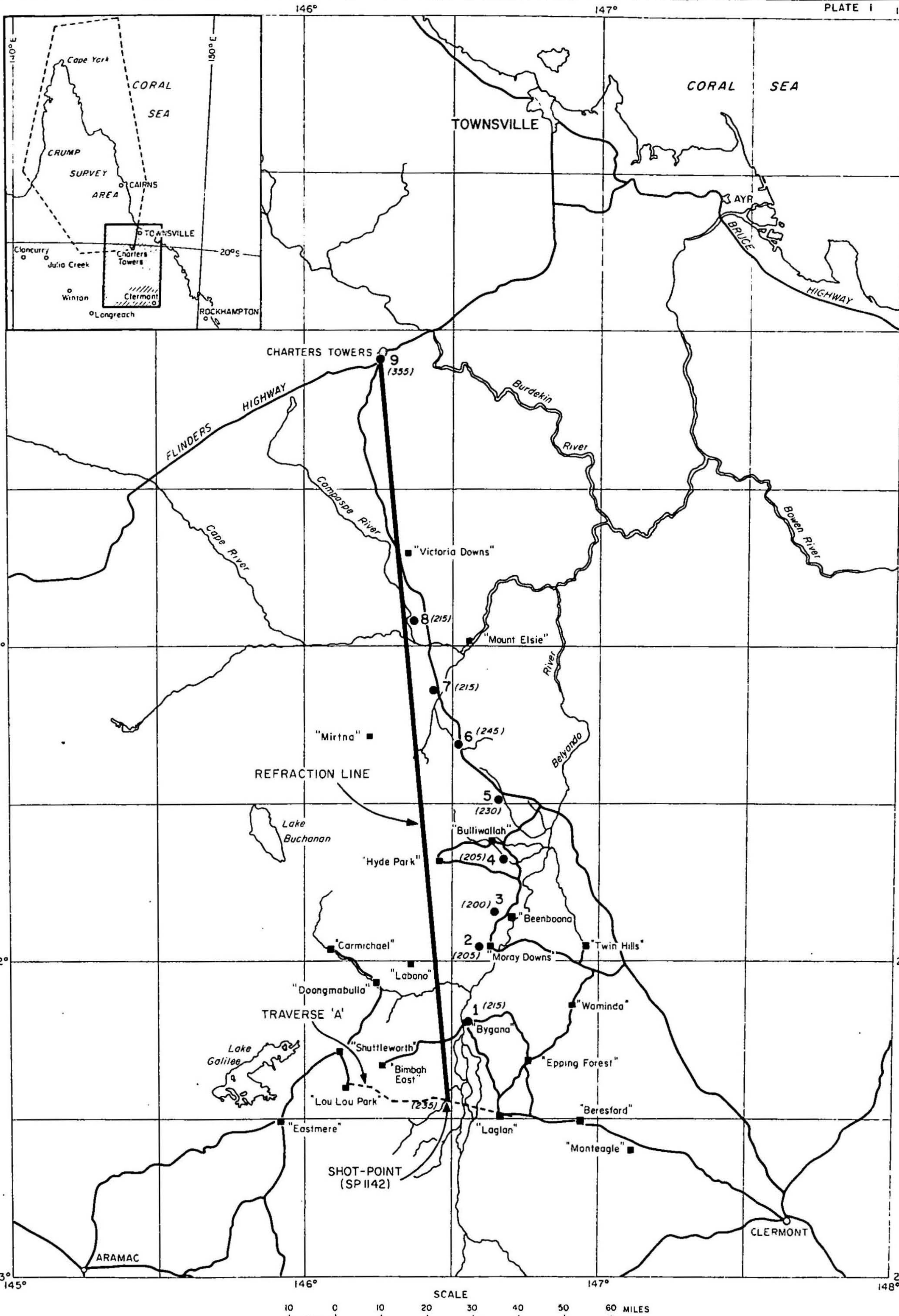
F55/B10–6A

TABLE 2. DELAY TIMES FOR REFRACTION STATIONS

STN	D (km)	V_N = 8.00 km/s tt	V_N = 8.00 km/s DT	V_4 = 6.75 km/s tt	V_4 = 6.75 km/s DT	V_3 = 6.01 km/s tt	V_3 = 6.01 km/s DT	V_1 = 4.10 km/s
2	55.48					10.57	0.58	
4	87.88	18.99	4.09	17.85	2.52	16.21	0.83	
5	107.48	21.41	4.06	20.39	2.15	18.51	0.13	
6	126.17	23.58	3.89	22.93	1.92	21.95	0.21	
7	144.30	25.63	3.67	25.63	1.94			
8	169.14	28.50	3.44	29.23	1.86	29.23	0.33	
9	262.39	40.78	4.06	43.27	2.08	44.58	0.17	
SHOT	0		3.92		2.32		0.76	

TABLE 3. REFLECTION RESULTS

Two-way time (s)	Approx. depth (km)	Probable nature
2.0	4.6	Fair Primary
4.2		Poor Multiple
7.0	24.2	Fair Primary
9.4	32.3	Poor Primary
11.8	40.4	Fair Primary

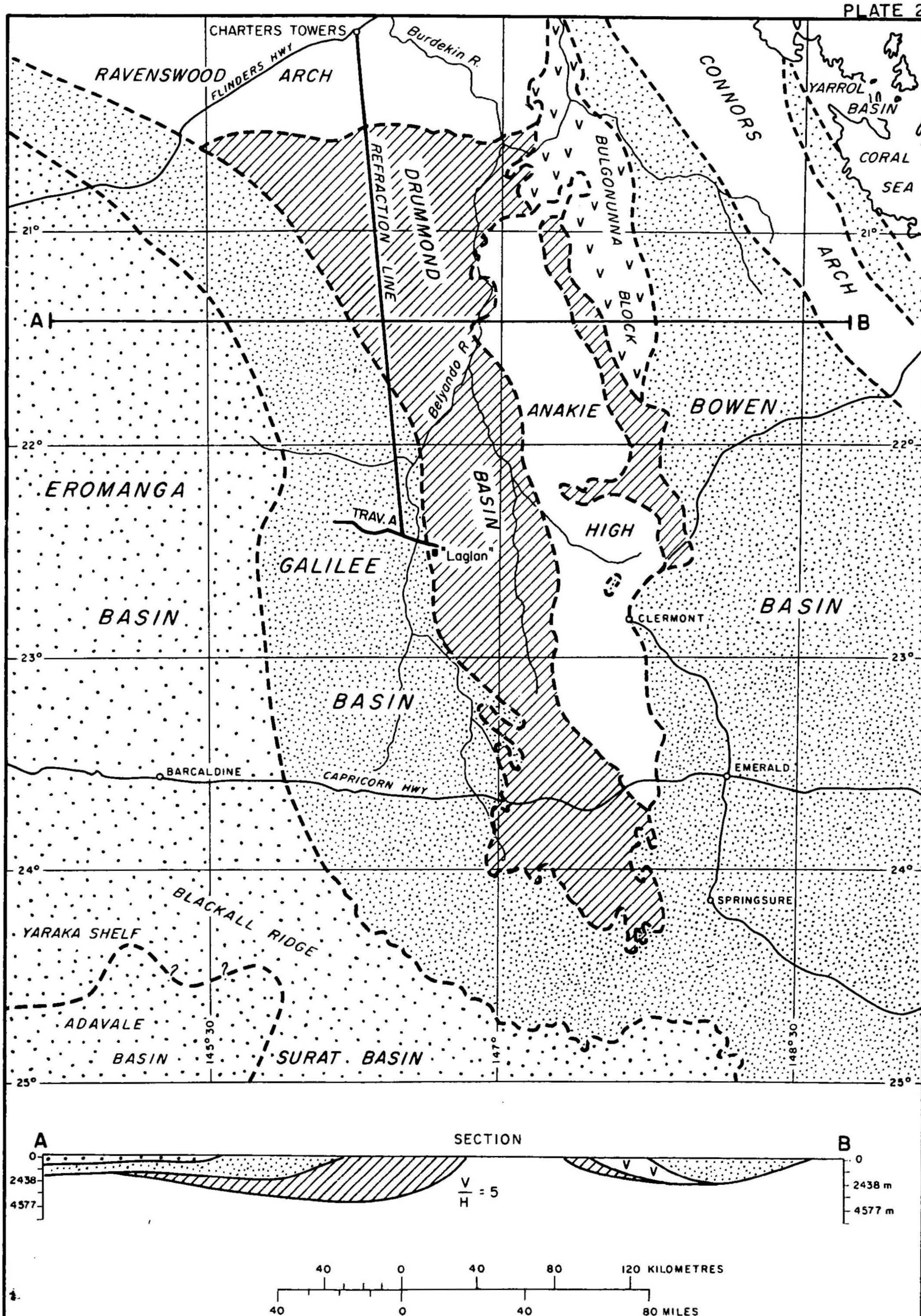


LOCATION OF REFRACTION RECORDING STATIONS

To accompany Record No 1972/97

F55/B10-1

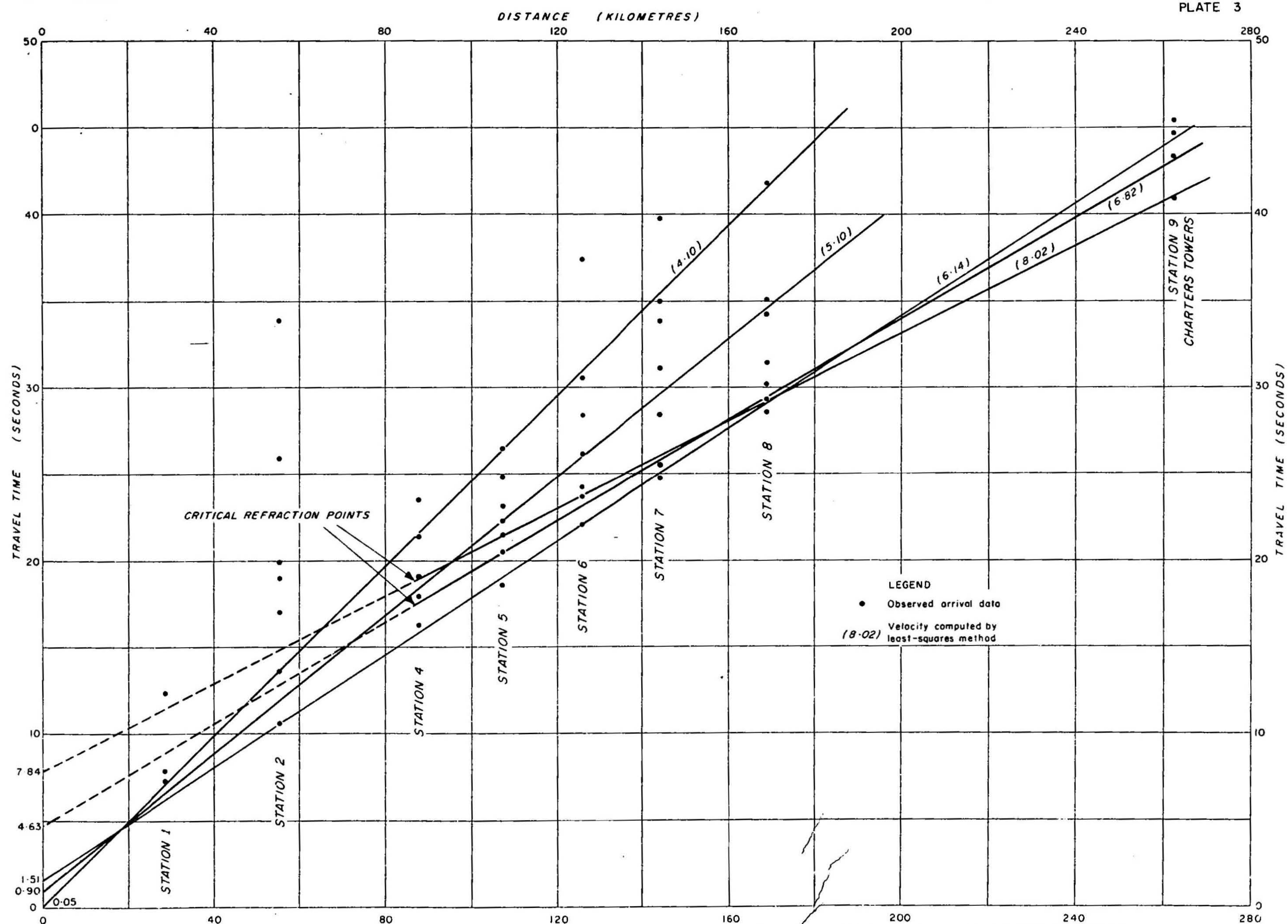
PLATE 2



REGIONAL STRUCTURAL BOUNDARIES

(GEOLOGY FROM Q/A231 - Olgers, 1969) *To accompany Record No 1972/97*

F55/B10-2A

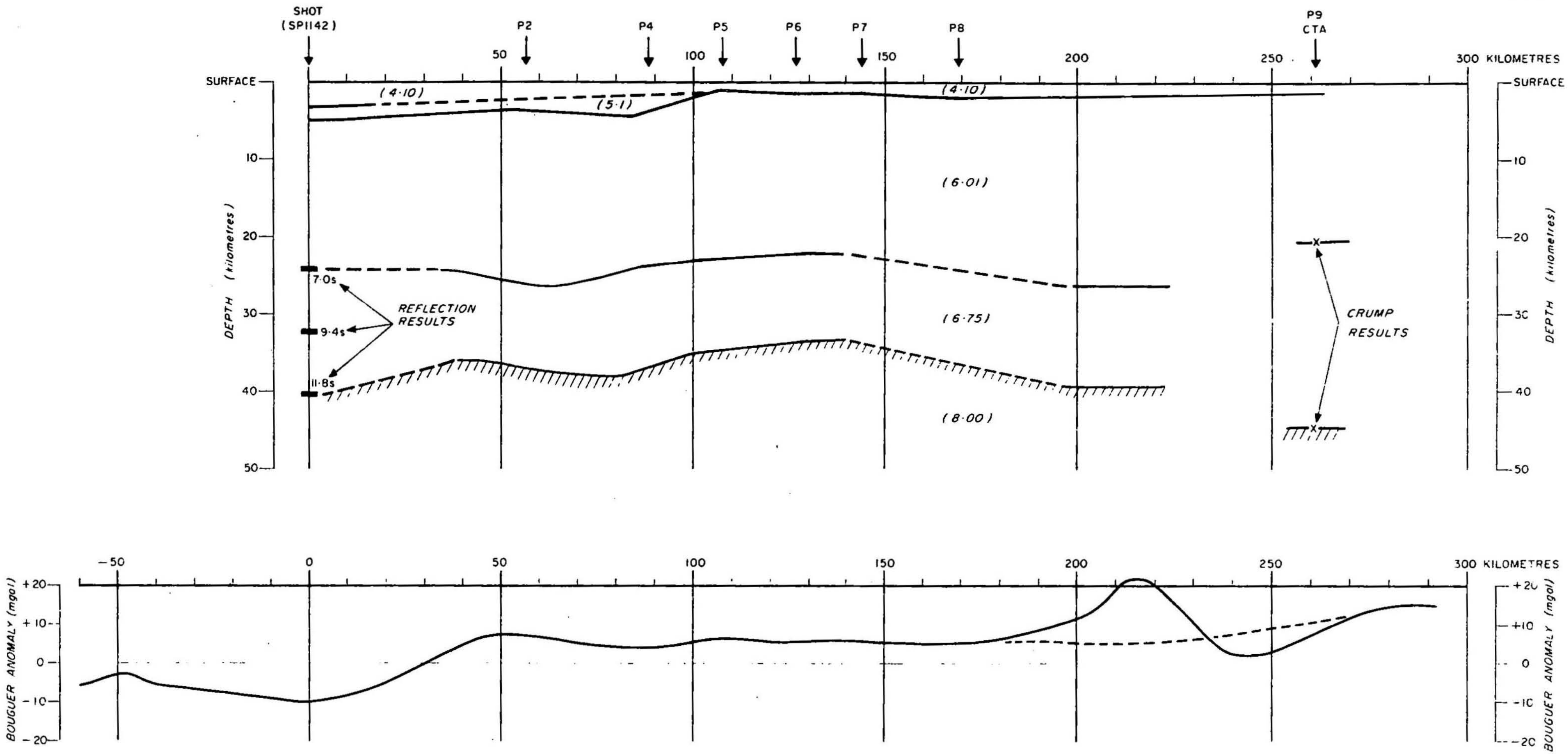


To accompany Record No 1972/97

TRAVEL TIME PLOT OF REFRACTION RESULTS

F55/B10-3

PLATE 4



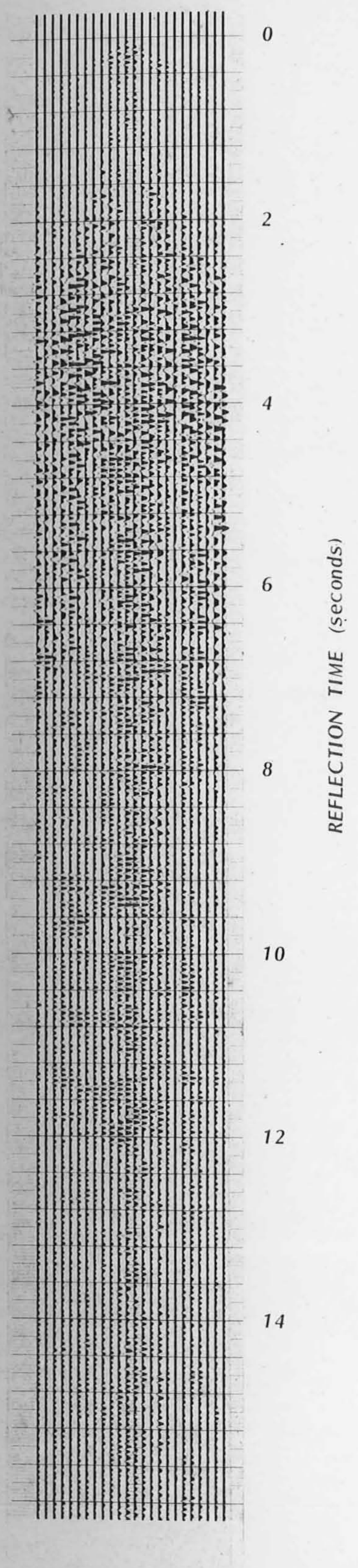
LEGEND

(6·75)	Seismic velocity in formation (km/sec)
P4	Refraction recording site No. 4
/////////	Mohorovicic Discontinuity
11·8s	Two-way time (seconds)
X	CRUMP data
————	Boundaries from refraction data with offset applied

NORTH-SOUTH CRUSTAL CROSS-SECTION

PLATE 5

RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder: DS 7–7

Amplifiers : 8000 Explorer

Prefilters: Nil

Filters : (a) M14–M92 (b) M18–M72

AGC : (a) SS (b) Off

Gain Initial: –80

Final : –10

Geophones: HS–I, 4.5 Hz

Geophone Station Interval: 90 m

Geophone Pattern:

4/trace, 6 m apart transverse

Shot Hole Pattern:

(a) 20 holes in 2 rows of 10 in line

(b) 30 holes in 3 rows of 10 in line

Rows 10 m apart

Depth 20 m

Charge per hole 91 kg

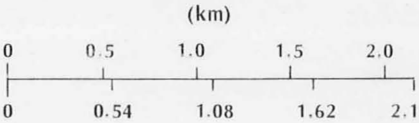
PLAYBACK INFORMATION

Filters: LL6 – KK20

AGC : Off

Compositing: 2 – fold sum of (a) and (b)

HORIZONTAL SCALE
(km)



TRAVERSE A

SP 1142

F55/B10–5A

To accompany Record No 1972/97