DEPARTMENT OF
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# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS



Record 1973/112

## CRUSTAL STRUCTURE IN SOUTHWESTERN AUSTRALIA

by

S.P. Mathur

(Talk presented at the Second International Conference on Geophysics of the Earth and the Oceans, Sydney, January 1973)

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SUMMARY

The results of seismic reflection and refraction investigations along the Geotraverse, Western Australia, have been combined with those from other seismic and gravity surveys in the area to obtain an integrated interpretation of the structure and composition of the crust and upper mantle in the southern part of the West Australian shield.

The crust is of normal continental type in the east but is abnormal towards the Perth Basin in the west. Near Kalgoorlie it consists of two layers with velocities of 6.12 and 6.66 km/s and is 34 km thick, whereas close to the continental margin near Perth, it is 44 km thick owing to the presence of a high-velocity, 7.42 km/s, extra basal layer which thins out towards the east and southeast. The upper two layers in the crust, on the other hand, show thickening along these directions. In the Perth Basin, about 7.5 km of sediments overlie a block of the shield crust which has been thrown down to the west along the Darling Fault. Southeast of Coolgardie, the high-velocity basal layer is shown to be thin and the southeastern part of the crustal block has been upthrust to the northwest along the Fraser Fault. The measured velocity of the mantle underneath the abnormal crust is 8.39 km/s in E-W direction and 8.11 km/s in NW-SE direction.

The generally low magnitude of the free-air anomalies in southewestern Australia, excepting the tectonic zones of the Perth Basin and the Fraser Fault, suggest that the shield crust is in or close to isostatic equilibrium. Assuming the seismically determined model of the crust to be floating in the mantle according to Archimedes's Principle and assigning densities of 2.78, 2.94, and 3.10 g/cm$^3$ to the crustal layers, the density for the upper mantle is estimated to increase from 3.28 under the normal crust in the east to 3.51 under the abnormal crust in the west. This model of the crust is also consistent with the regional Bouguer anomalies in the area.

## 1. INTRODUCTION

During the last decade, the Bureau of Mineral Resources has obtained a substantial amount of seismic and gravity data in southwestern Australia. In this paper are presented the results of analysis of these data to determine the nature and structure of the crust and upper mantle in the southern part of the West Australian shield. The analysis of the data was carried out in three steps:

The refraction data were used to obtain velocities and a structural model of the crust along the seismic traverses.

The reflection results were used to provide check-points on the refraction interpretation.

The gravity data were studied to ascertain if these were consistent with the seismically derived structure, and to obtain density estimates for the crust and upper mantle.

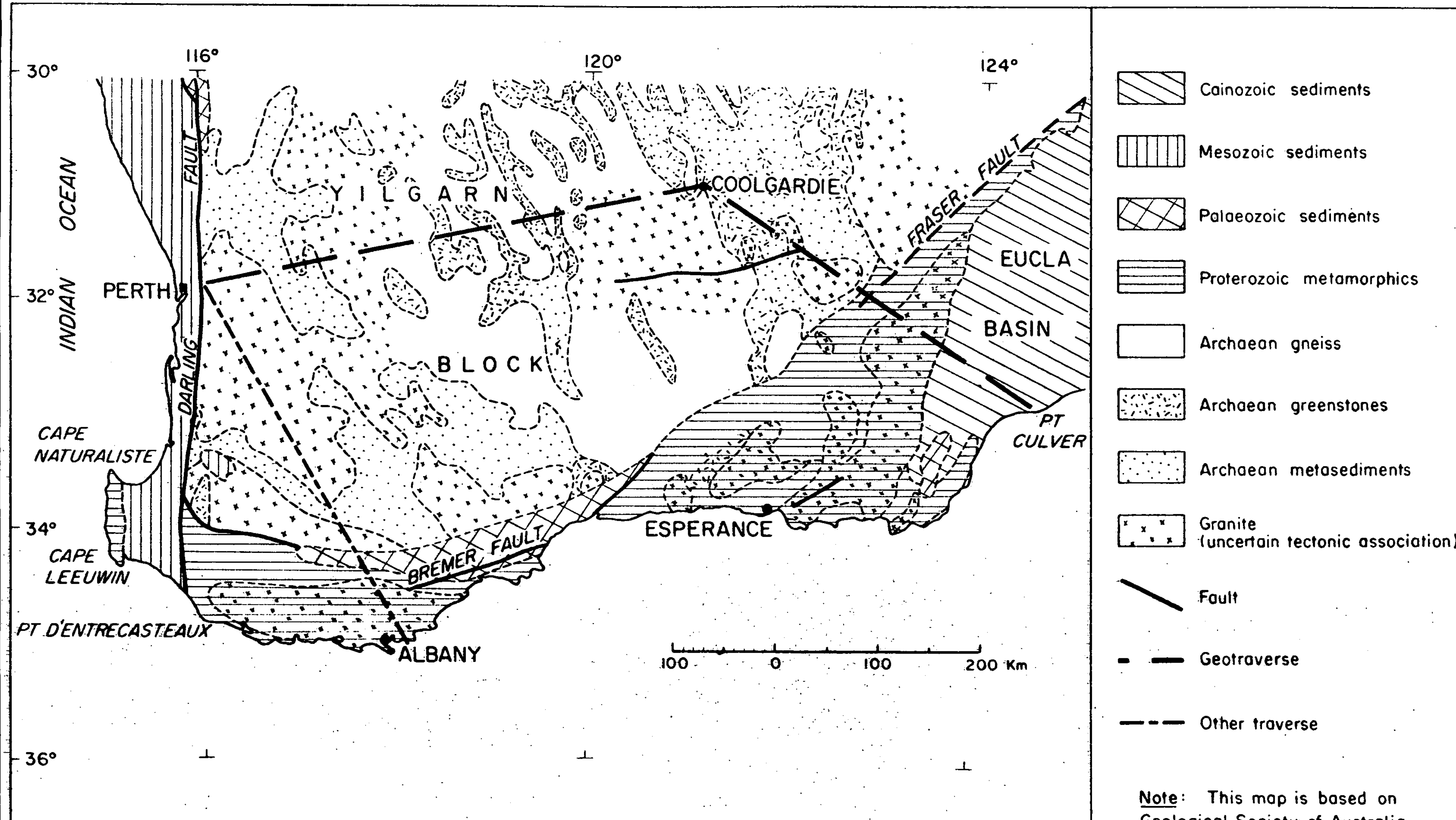
Seismic data were recorded along the Geotraverse, a line from Perth to Coolgardie and thence to Point Culver, and another traverse between Perth and Albany, shown in Figure 1. In the five areas shown in Figure 2, shots were fired and reflections were recorded. Refractions from these shots as well as from other offshore shots near Perth and Albany were also recorded along the traverses between Perth and Coolgardie, and Perth and Albany.

## 2. GEOPHYSICAL INVESTIGATIONS

### Refraction seismic

Travel-time data have been recorded from shots in offshore area near Perth (OFF-P), near the shield boundary (SB), at Hines Hill (HHL), Boorabbin (BOO), and the Jubilee Mine (JUB) near Kalgoorlie (Figure 3). The travel-time curves are based on first as well as later arrivals. The crustal structure derived from the data is shown in the lower part of the diagram. Near Kalgoorlie, the crust is 34 km thick and consists of two layers of velocities 6.13 and 6.74 km/s. In the western part of the shield, the crust consists of three layers of velocities 6.13, 6.70, and 7.49 km/s, and is 44 km thick near Perth close to the continental margin. The measured velocity of the upper mantle is 8.39 km/s under the shield. In the Perth Basin about 7.5 km of sediments, consisting of two layers of velocities 2.52 and 4.67 km/s, overlie a downthrown block of the shield crust.

Figure 4 shows the travel-time data along the NW-SE traverse between Perth and Albany from shots offshore (OFF-P and OFF-A) as well as at the shield boundary (SB). Here also the travel-time curves are based on the first and later arrivals. The crust consists of three layers of velocities 6.11, 6.60, and 7.34 km/s and is about 44 km thick near Perth and about 34 km thick near Albany. The measured upper mantle velocity is 8.11 km/s in this direction. The thicknesses of the crustal layers near Perth obtained from the analyses of E-W and NW-SE profiles agree within 3 km and the velocities are somewhat (less than 4%) lower in the NW-SE direction.




Note: This map is based on Geological Society of Australia, 1971–Tectonic Map of Australia and New Guinea 1:5 000 000. Sydney

Fig. I
GENERALIZED GEOLOGICAL MAP OF SOUTHWESTERN AUSTRALIA

*To accompany Record No. 1973/112*
*To accompany Record No 1973/63*

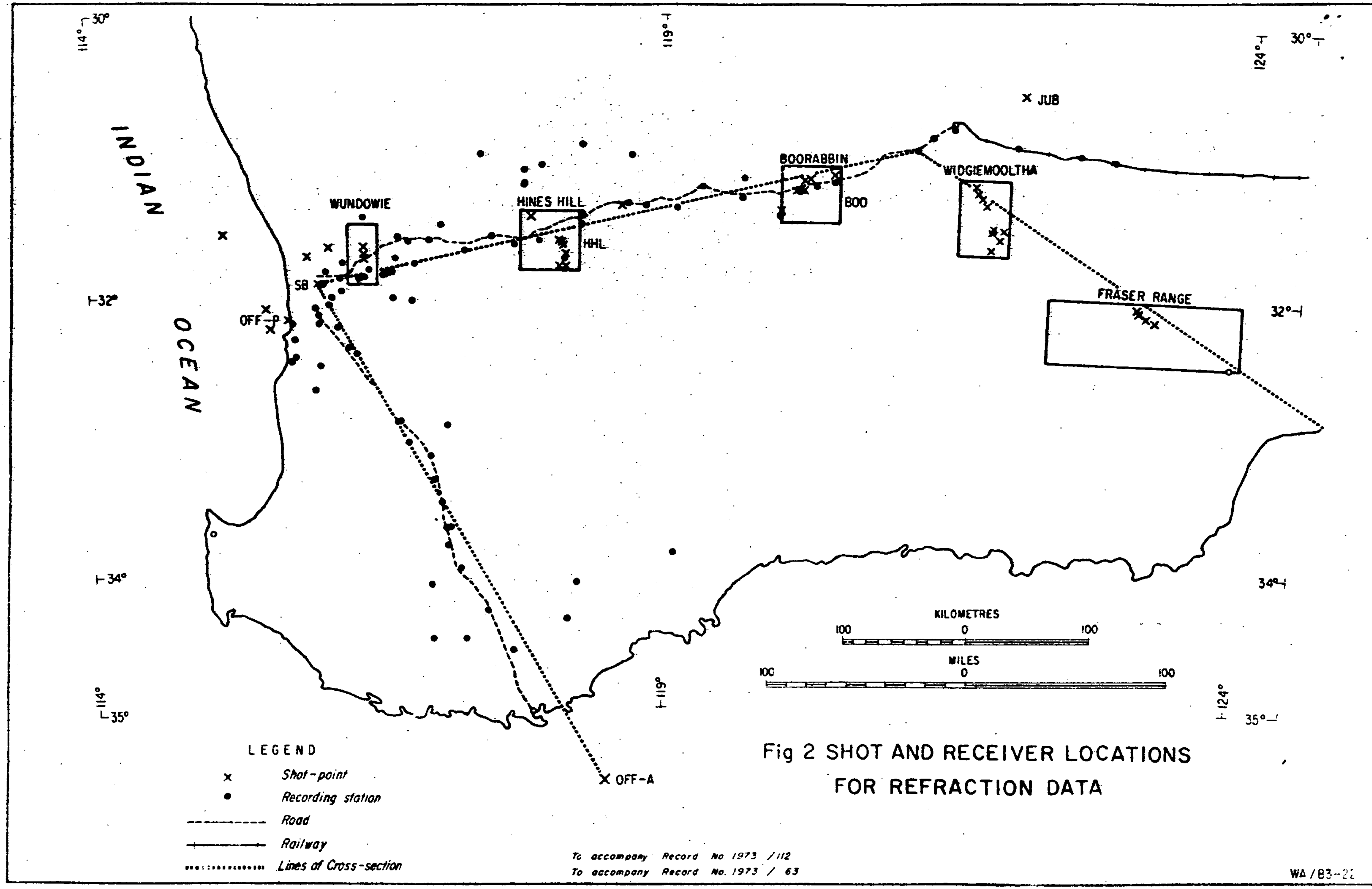



Fig 2 SHOT AND RECEIVER LOCATIONS FOR REFRACTION DATA

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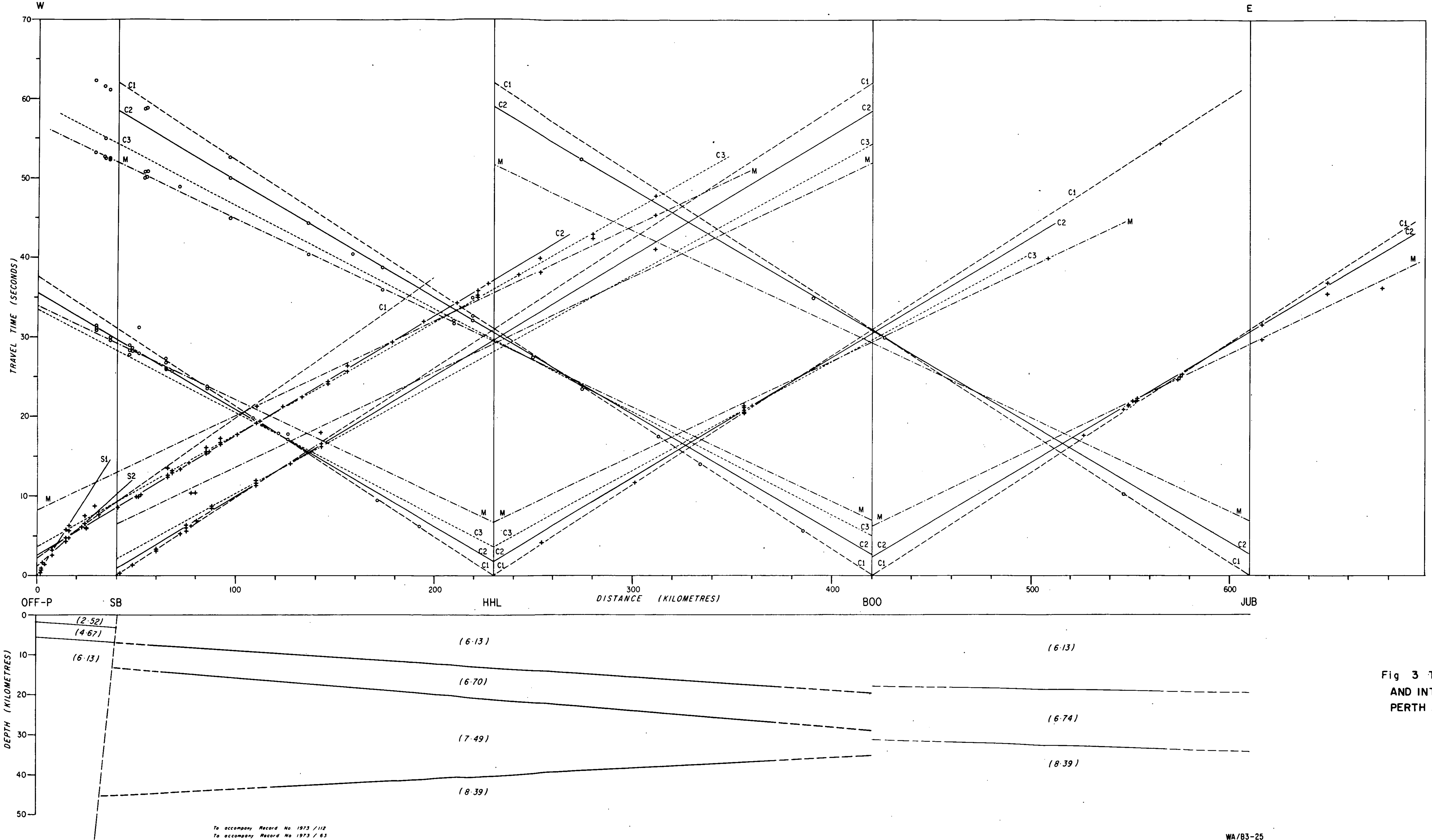


OFF-P (E)
S1 Δ / (2·52 ± 0·01)
S2 Δ / (4·41 ± 0·06) + (1·15 ± 0·06)
C1 Δ / (5·65 ± 0·04) + (2·23 ± 0·03)
C2 Δ / (6·63 ± 0·02) + (2·53 ± 0·05)
C3 Δ / (7·08 ± 0·03) + (3·67 ± 0·10)
M Δ / (8·37 ± 0·06) + (8·16 ± 0·17)

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

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

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

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

* ASSUMED VELOCITY

Fig 3 TIME-DISTANCE CURVES AND INTERPRETATION BETWEEN PERTH AND THE JUBILEE MINE

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To accompany Record No 1973/63

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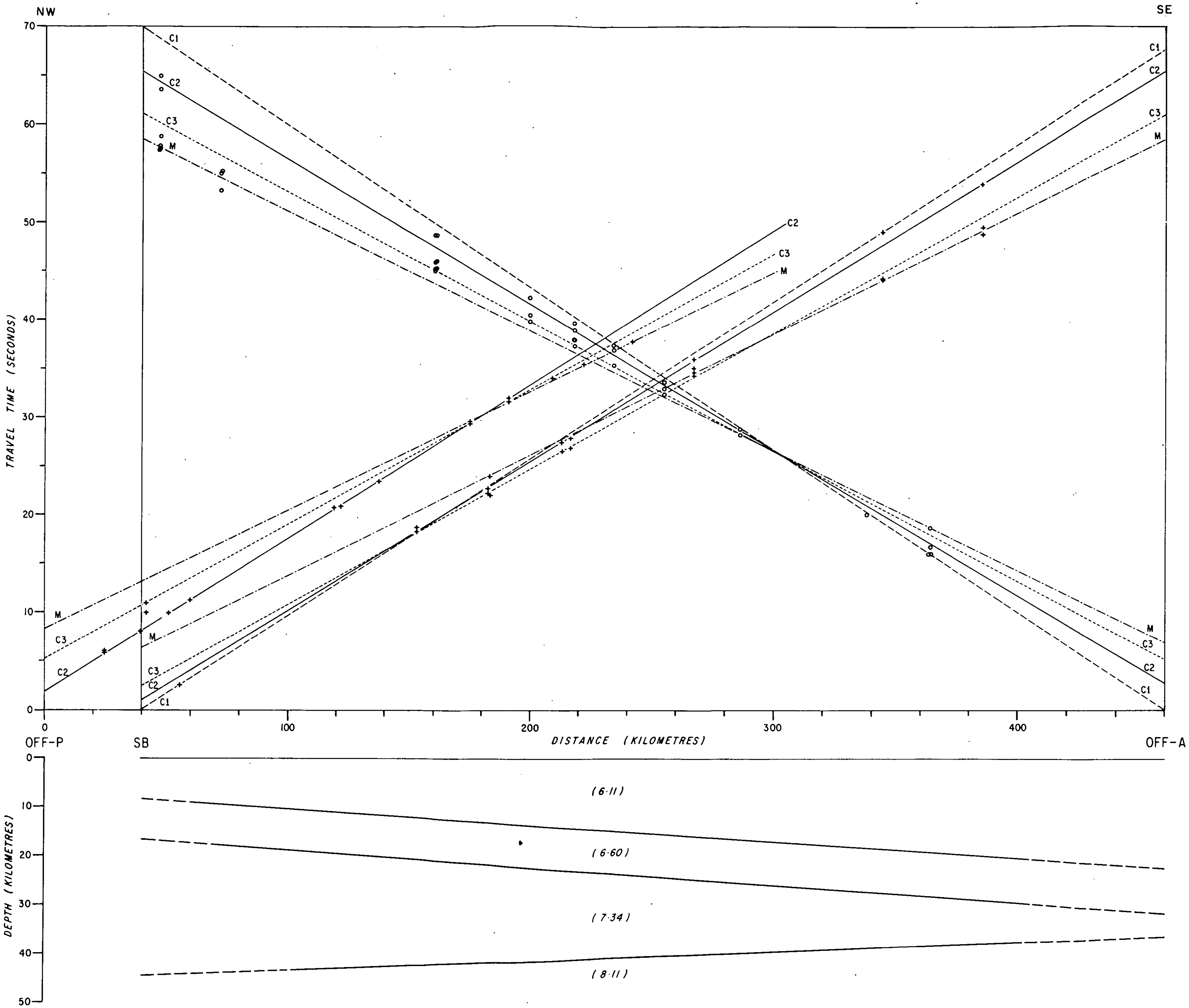


OFF-P (SE)
C2 Δ / (6·35 ± 0·02) + (1·91 ± 0·07)
C3 Δ / (7·22 ± 0·01) + (5·19 ± 0·04)
M Δ / (8·19 ± 0·09) + (8·31 ± 0·28)

SB (SE)
C1 Δ / (6·20 ± 0·01)
C2 Δ / (6·52 ± 0·02) + (0·98 ± 0·12)
C3 Δ / (7·18 ± 0·02) + (2·54 ± 0·10)
M Δ / (8·07 ± 0·06) + (6·34 ± 0·29)

OFF-A (NW)
C1 Δ / (6·02 ± 0·02)
C2 Δ / (6·69 ± 0·05) + (2·76 ± 0·32)
C3 Δ / (7·52 ± 0·01) + (5·26 ± 0·07)
M Δ / (8·16 ± 0·02) + (7·02 ± 0·13)

Fig 4 TIME-DISTANCE CURVES AND INTERPRETATION BETWEEN PERTH AND ALBANY

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Reflection seismic

In Figure 5 are shown seismic reflection sections recorded along the Geotraverse, superimposed on a crustal model based on the refraction interpretation and structural information from surface geology. In the sections between Perth and Coolgardie, reflections of fair quality can be identified corresponding to the refracting horizons which have been plotted as two-way travel times using refraction velocities. Between Coolgardie and Point Culver, no refraction data are available, but reflections of fair to poor quality can be picked at times which may correspond to the crustal boundaries in this area. Thus the reflection data provide support to the refraction interpretation along the Geotraverse.

Gravity

A free-air anomaly map is shown in Figure 6. The anomalies range between +20 and -20 mGal over most of the shield area except the tectonically disturbed zones along the Perth Basin and the Fraser Fault. The generally low magnitude of the anomalies suggests that the shield crust is in or near isostatic equilibrium. The relatively high anomalies in the southwest corner of the shield seem to reflect the presence of the thick and dense extra basal layer in the crust.

In Table 1 are summarized the crustal layer thicknesses in five areas of the shield, viz., shield boundary near Perth (SB), Hines Hill (HHL), Boorabbin (BOO), Jubilee Mine (JUB), and Albany (OFF-A). On the basis of the assumptions that (1) the densities of the crustal layers are 2.78, 2.94, and 3.10 $g/cm^3$, (2) the standard column is 31 km thick and has a density of 2.84 $g/cm^3$, and (3) the crust is floating in the mantle according to the Archimedes's Principle, estimates of the density of the upper mantle in the five areas have been made. The density is shown to increase from 3.28 under the normal crust in the east to about 3.51 under the abnormal crust in the west.

The Bouguer anomalies are shown in Figure 7. In general, the shorter-wavelength anomaly features show a good correlation with the surface geology shown in Figure 1. The highs correspond to the denser greenstone areas and the lows, to the lighter granite areas. The longer-wavelength features should therefore correspond to deep crustal structure.

## 3. RESULTS AND INTERPRETATION

A cross-section along the Geotraverse from west to east is shown in Figure 8. The free-air anomaly, Bouguer anomaly, and surface elevation profiles are shown with geology according to Figure 1, and the crustal model as derived from the seismic refraction and reflection data. Assuming the densities of 2.38 and 2.63 for the sediments, 2.78, 2.94, and 3.10 for the crustal layers, and an average of 3.45 for the upper mantle, a theoretical gravity anomaly profile has been computed for the seismic model. The computed curve shows a good match with the mean Bouguer anomaly profile whereas the shorter-wavelength features of the observed Bouguer anomaly profile show a good correlation with the surface geology; i.e. the highs correspond to the denser greenstones and the lows to the lighter granites.


Fig 5 REFLECTION RESULTS AND STRUCTURE ALONG GEOTRAVERSE

To accompany Record No. 1973 /112

To accompany Record No. 1973 / 63

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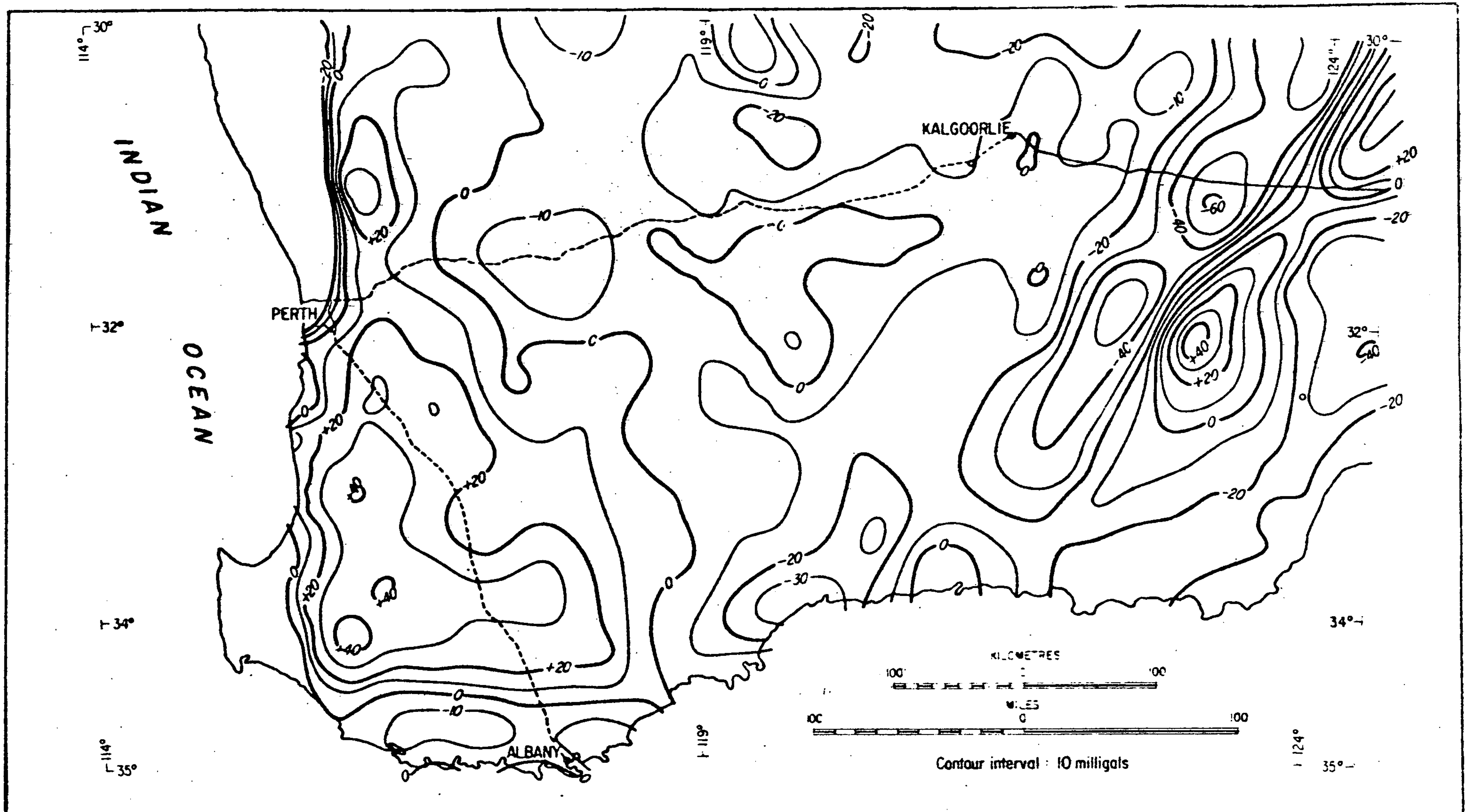


Fig 6 REGIONAL FREE-AIR ANOMALY MAP

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TABLE 1. **CALCULATION OF UPPER MANTLE DENSITY**

| AREA | | SB | HHL | BOO | JUB | OFF–A |
|---|---|---|---|---|---|---|
| Elevation ($\Delta h$ km) | | 0.30 | 0.40 | 0.40 | 0.40 | 0.00 |
| THICKNESS (km) | Layer 1 | 7.45 | 13.60 | 19.76 | 19.61 | 19.50 |
| | Layer 2 | 7.31 | 8.33 | 9.34 | 14.69 | 9.30 |
| | Layer 3 | 29.64 | 18.02 | 6.39 | – | 5.00 |
| | Crust ($H_S$) | 44.40 | 39.95 | 35.49 | 34.30 | 33.80 |
| DENSITY ($gm/cm^3$) | Crust ($\rho_c$) | 3.02 | 2.96 | 2.88 | 2.85 | 2.85 |
| | Mantle ($\rho_m$) | 3.51 | 3.50 | 3.41 | 3.28 | 3.23 |

**ASSUMPTIONS:**

1. Densities:

   Layer 1 – 2.78

   Layer 2 – 2.94

   Layer 3 – 3.10

   ($gm/cm^3$)

2. Standard Column:

   Thickness ($H_{ST}$) = 31.0 km

   Density ($\rho_{ST}$) = 2.84 $gm/cm^3$

3. Crust floating in mantle:

$$\rho_m = \rho_c + \frac{\rho_c \cdot \Delta h + H_{ST} \cdot (\rho_c - \rho_{ST})}{H_S - H_{ST}}$$

(After Woollard, 1969)

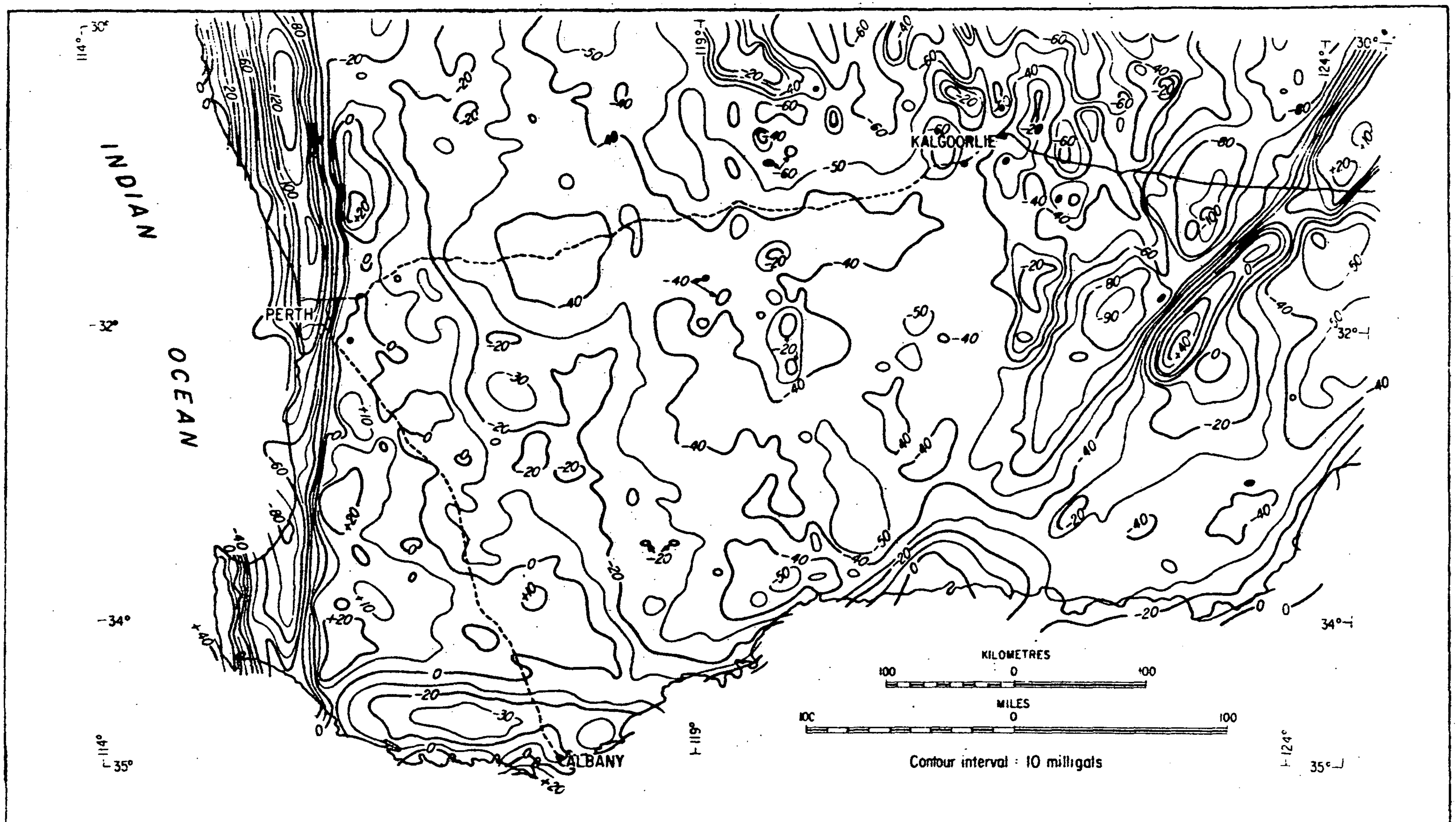


Fig 7 BOUGUER ANOMALY MAP

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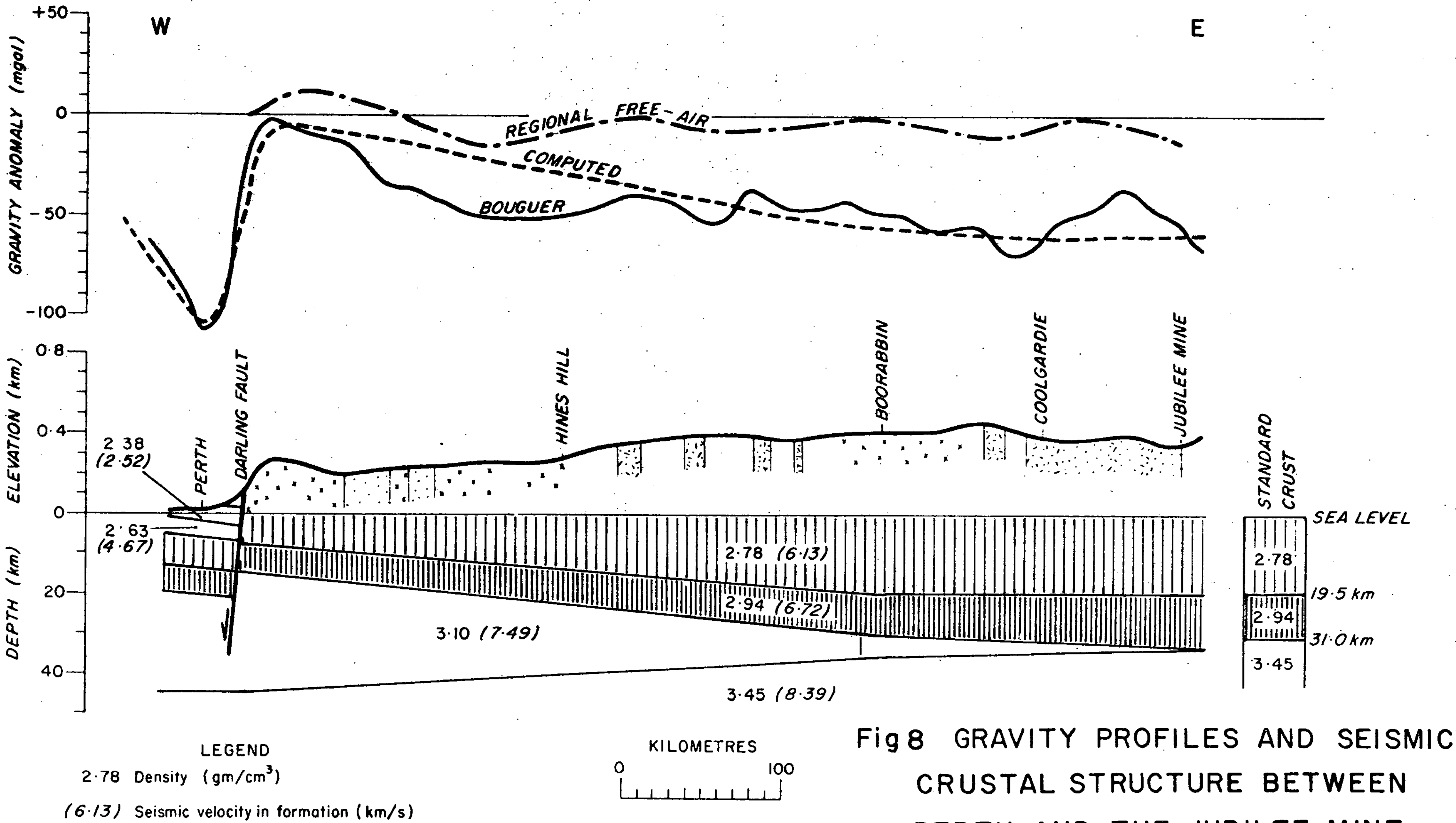


Fig 8 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN PERTH AND THE JUBILEE MINE

WA/B3-29-1A

Figure 9 shows a similar cross-section along NW-SE between Perth and Albany. Here the crustal model is based on the seismic refraction data alone as no reflection data are available along this traverse. The computed and observed Bouguer anomaly curves again show a good match while the shorter-wavelength features of the Bouguer anomaly curve relate to the surface geology.

Figure 10 is another section across the shield along NW-SE, between Coolgardie and Point Culver, across the Fraser Fault. The model of the crust here is based on the seismic reflection data, the geological information, and the tie with the E-W cross-section at Coolgardie. The computed gravity and mean observed Bouguer anomaly curves show fair agreement. The sharper high and low anomaly features across the Fraser Fault are related to the different near-surface rock types on either side of the fault.

Figure 11 shows several of the velocity-density relations observed by different workers. The dots represent the relation found most suitable from seismic and gravity studies in southwestern Australia. The dots do not fall on any particular curve in the figure but represent densities which are close to the mean of the wide range of values measured.

## 4. CONCLUSIONS

In summary, the results of integrated analysis of seismic and gravity data in southwestern Australia are shown in Figure 12 in the form of a fence diagram. The crust is of normal continental type in the east but is abnormal towards the Perth Basin in the west. It consists of two layers of velocities 6.12 and 6.66 km/s and is 34 km thick near Jubilee Mine (Kalgoorlie), whereas close to the continental margin near Perth, it is thicker (44 km) owing to the presence of a high-velocity, 7.42 km/s, extra basal layer which thins out towards the east and southeast. The upper two layers in the crust, on the other hand, show thickening along these directions. In the Perth Basin, about 7.5 km of sediments overlie a block of shield crust which has been thrown down to the west along the Darling Fault. Southeast of Coolgardie, the high-velocity basal layer is shown to be thin and the southeastern part of the crustal block has been upthrust to the northwest along the Fraser Fault. The measured velocity of the upper mantle is 8.25 km/s and its density is estimated to be about 3.45 km/cm$^3$ under the abnormal crust.

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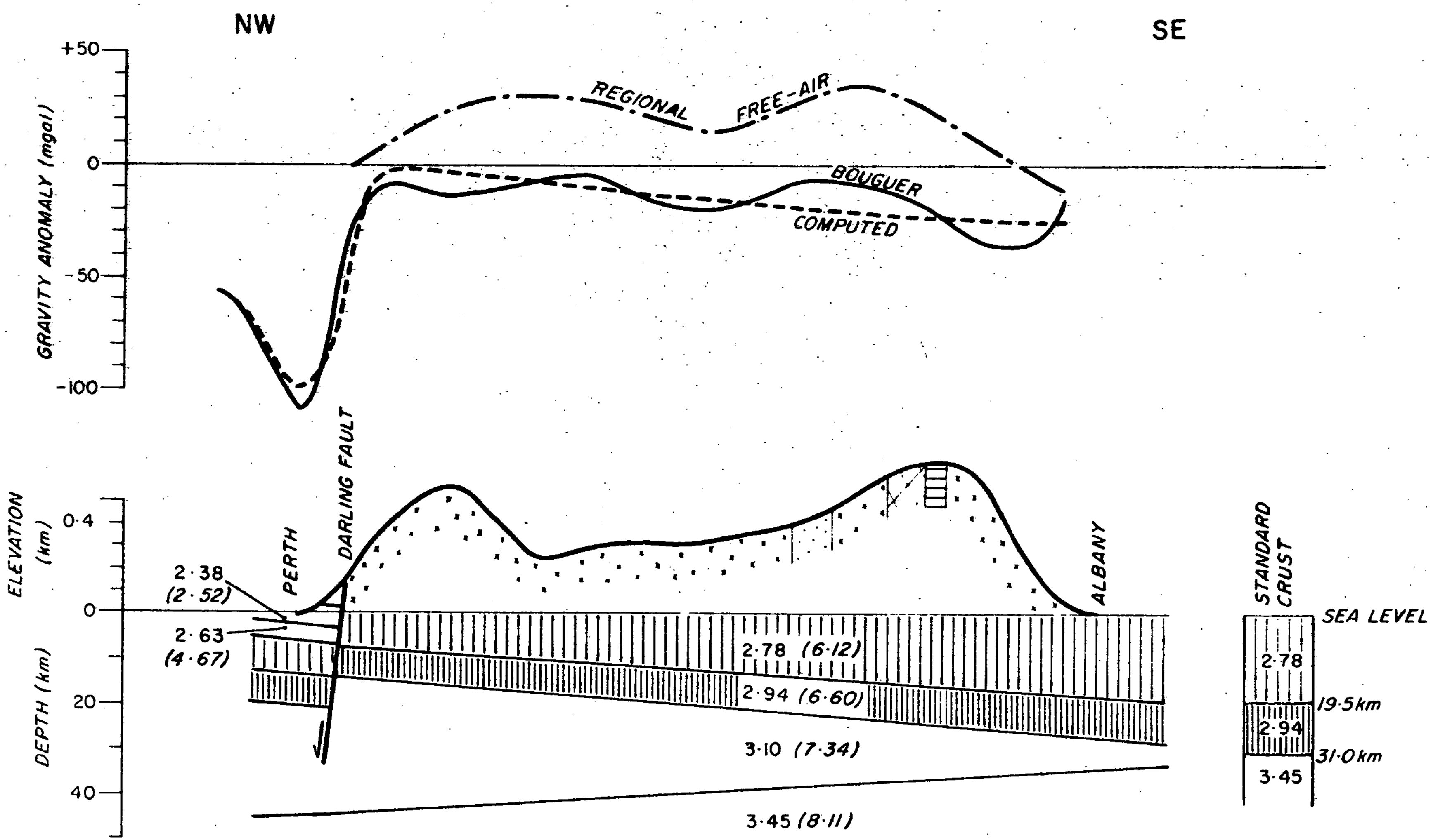



LEGEND

2·78 Density (gm/cm³)

(6·12) Seismic velocity in formation (km/s)

KILOMETRES

0 100

Fig 9 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN PERTH AND ALBANY

WA/B3-31-1A

GEOTRAVERSE W.A.

To accompany Record No. 1973/112

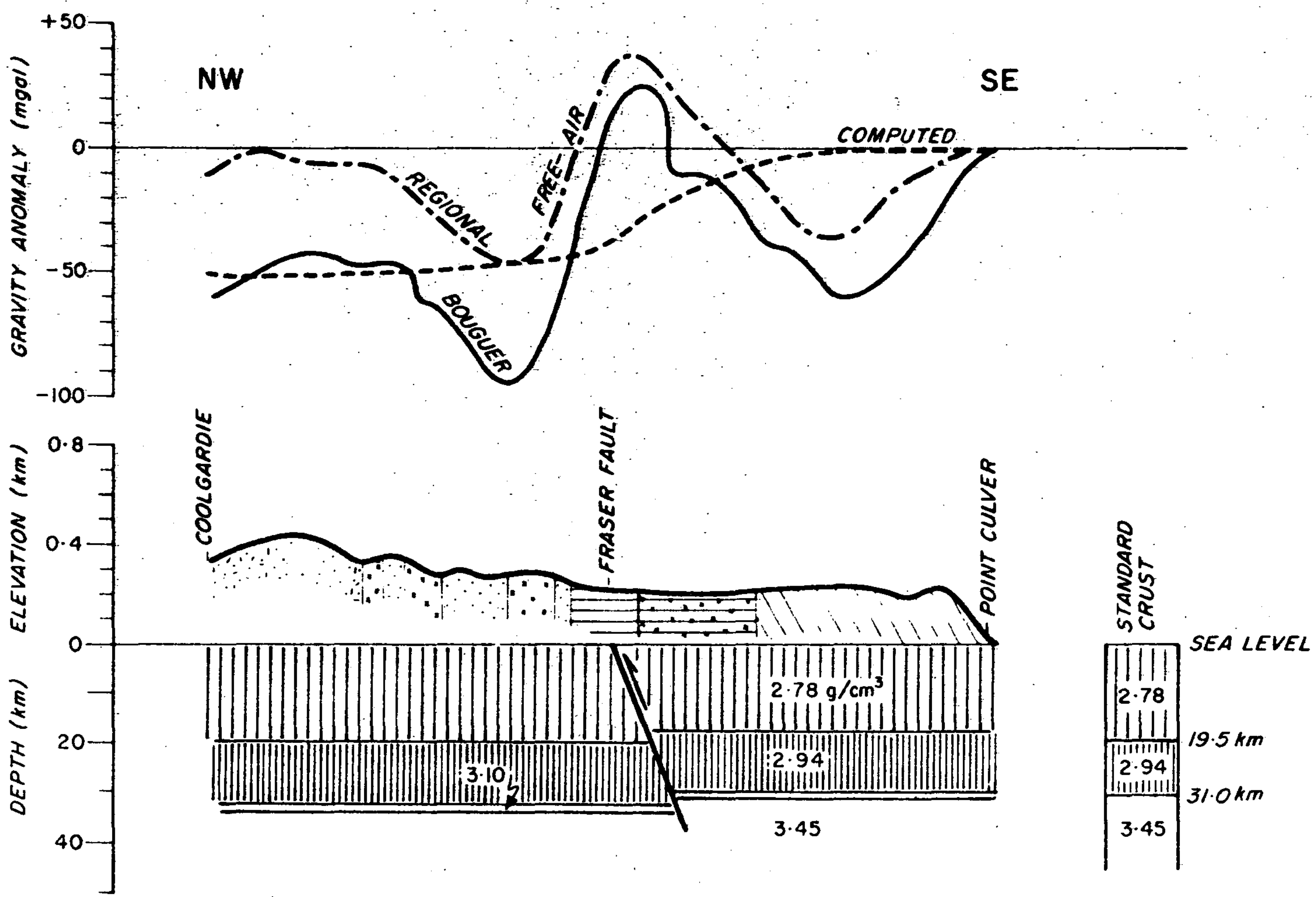



Fig 10 GRAVITY PROFILES AND SEISMIC CRUSTAL STRUCTURE BETWEEN COOLGARDIE AND POINT CULVER

WA/B3-30-1A

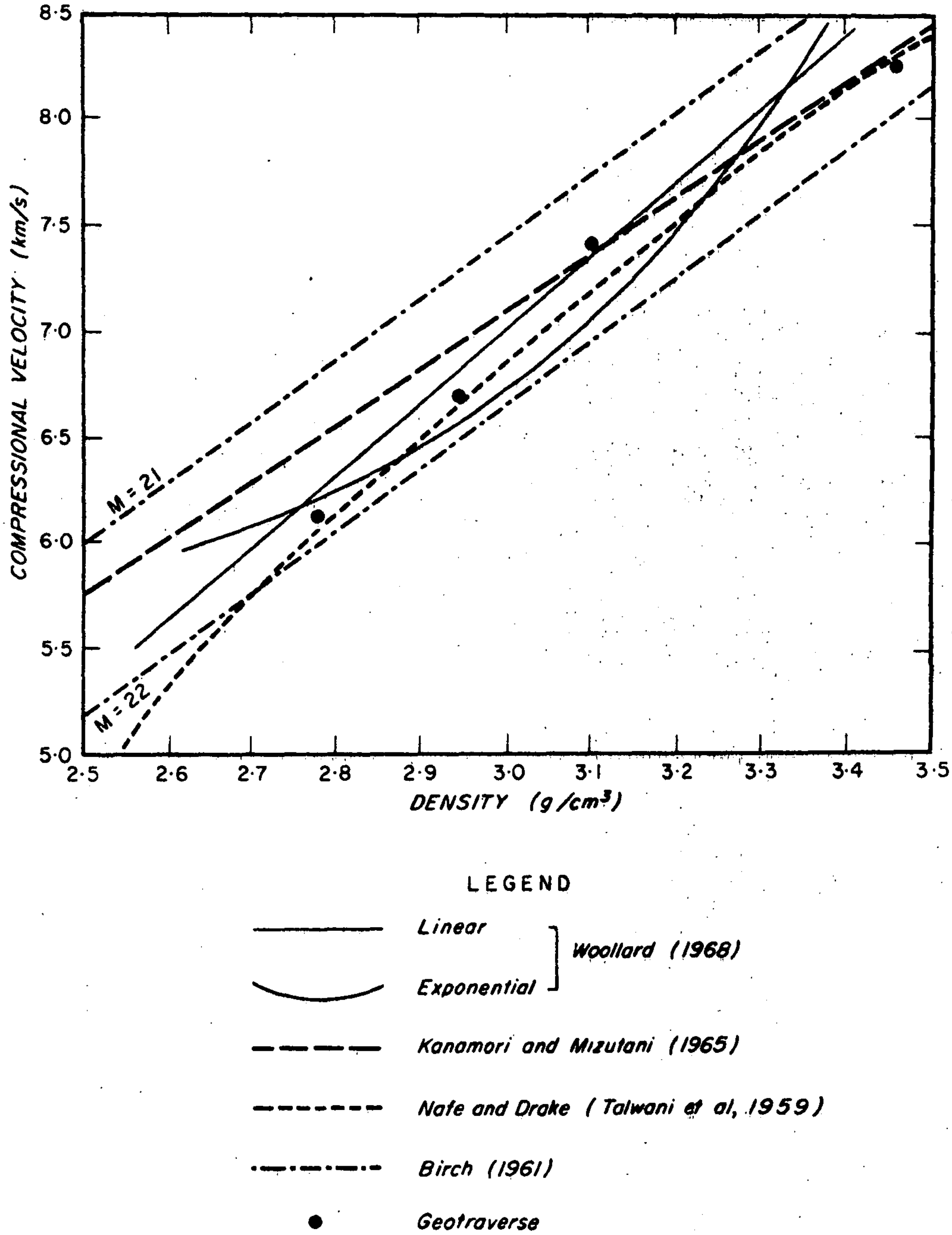
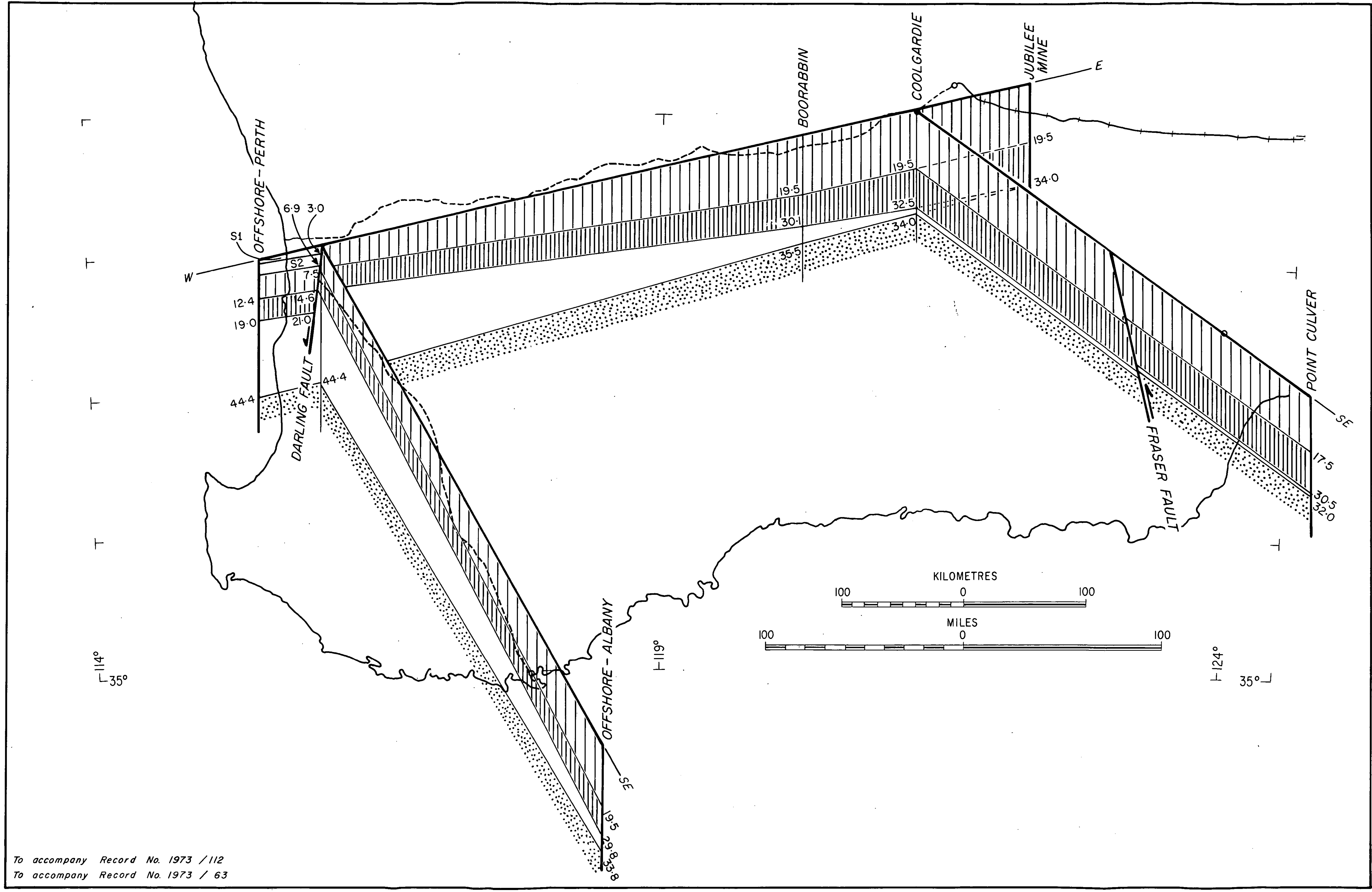



Fig. 11 DENSITY - VELOCITY RELATIONS

GEOTRAVERSE, WA.




| | VELOCITY KM/SEC | DENSITY GM/CM$^3$ |
|---|---|---|
| S1 SEDIMENTS | 2·52 | 2·38 |
| S2 SEDIMENTS | 4·67 | 2·63 |
| CRUST LAYER 1 | 6·12 | 2·78 |
| CRUST LAYER 2 | 6·67 | 2·94 |
| CRUST LAYER 3 | 7·42 | 3·10 |
| MANTLE | 8·25 | 3·45 |

DEPTHS SHOWN ARE IN KILOMETRES

## Fig 12 CRUSTAL STRUCTURE IN A FENCE DIAGRAM

WA/B3-32

GEOTRAVERSE W.A.

## 5. REFERENCES

BIRCH, F., 1961 - The velocity of compressional waves in rocks to 10 kilobars, Parts 1 and 2. J. geophys. Res., 66, 1083-1102 and 2199-2224.

KANAMORI, H. and MIZUTANI, H., 1965 - Ultrasonic measurement of elastic constants of rocks under high pressures. Bull. Earthquake Res. Inst. Tokyo, 43, 173-194.

TALWANI, M., SUTTON, G.H. and WORZEL, J.L., 1959 - A crustal section across the Puerto Rico Trench. J. geophys. Res., 64, 1545-1555.

WOOLLARD, G.P., 1968 - The interrelationship of the crust, the upper mantle, and isostatic gravity anomalies in the United States, In The crust and upper mantle of the Pacific area, Amer. geophys. Union Monograph 12, 312-341.

WOOLLARD, G.P., 1969 - Regional variations in gravity, In The earth's crust and upper mantle. Amer. geophys. Union Monograph 13, 320-341.