DEPARTMENT OF MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD 1974/61

UPPER MANTLE STRUCTURE FROM THE TRANS-AUSTRALIA SEISMIC SURVEY (TASS) AND OTHER SEISMIC REFRACTION DATA

by

D.M. Finlayson, J.P. Cull, & B.J. Drummond

RECORD 1974/61

UPPER MANTLE STRUCTURE FROM THE TRANS-AUSTRALIA SEISMIC SURVEY (TASS) AND OTHER SEISMIC REFRACTION DATA

by

D.M. Finlayson, J.P. Cull, & B.J. Drummond

UPPER MANTLE STRUCTURE FROM THE TRANS-AUSTRALIA SEISMIC SURVEY (TASS) AND OTHER SEISMIC REFRACTION DATA

by D.M. Finlayson, F.P. Cull, and B.J. Drummond

Abstract

The recordings made during 1972 from large explosions at Kunanalling (WA), Mount Fitton (SA), and Bass Strait have added considerably to seismic refraction data measured over distances of 1000 km in continental Australia. Taken together with data from the 1956 Maralinga atomic bomb and 1970-71 Ord Dam explosions they show the existence of a refractor with apparent P-wave velocity in the range 8.26-8.29 km/s, which is interpreted as the Moho under shield regions, at a depth of 34 km under Kalgoorlie and deepening eastward to 39 km under Maralinga. In South Australia and farther north and east this refractor is evident as a sub-Moho refractor at a depth of approximately 60 km; the Moho refractor is also evident, with an apparent P velocity of 8.04 $\pm$ 0.04 km/s at a depth of 40 km. Two computer models (TASS-1a and 2a) match the observed data. The subsequent arrivals recorded are consistent with the velocity of 8.53 km/s in a refractor at 165 km depth interpreted from the Ord Dam; there is little conclusive evidence for a low-velocity zone above this depth.

INTRODUCTION

During 1972 the Bureau of Mineral Resources, Geology & Geophysics (BMR) detonated three large explosions as energy sources for seismic refraction observations out to distances greater than 1000 km. The explosions were located at Mount Fitton in the north Flinders Ranges, at Kunanalling near Kalgoorlie, and in Bass Strait south of Orbost (Fig. 1).

To accompany Record No.1974/61

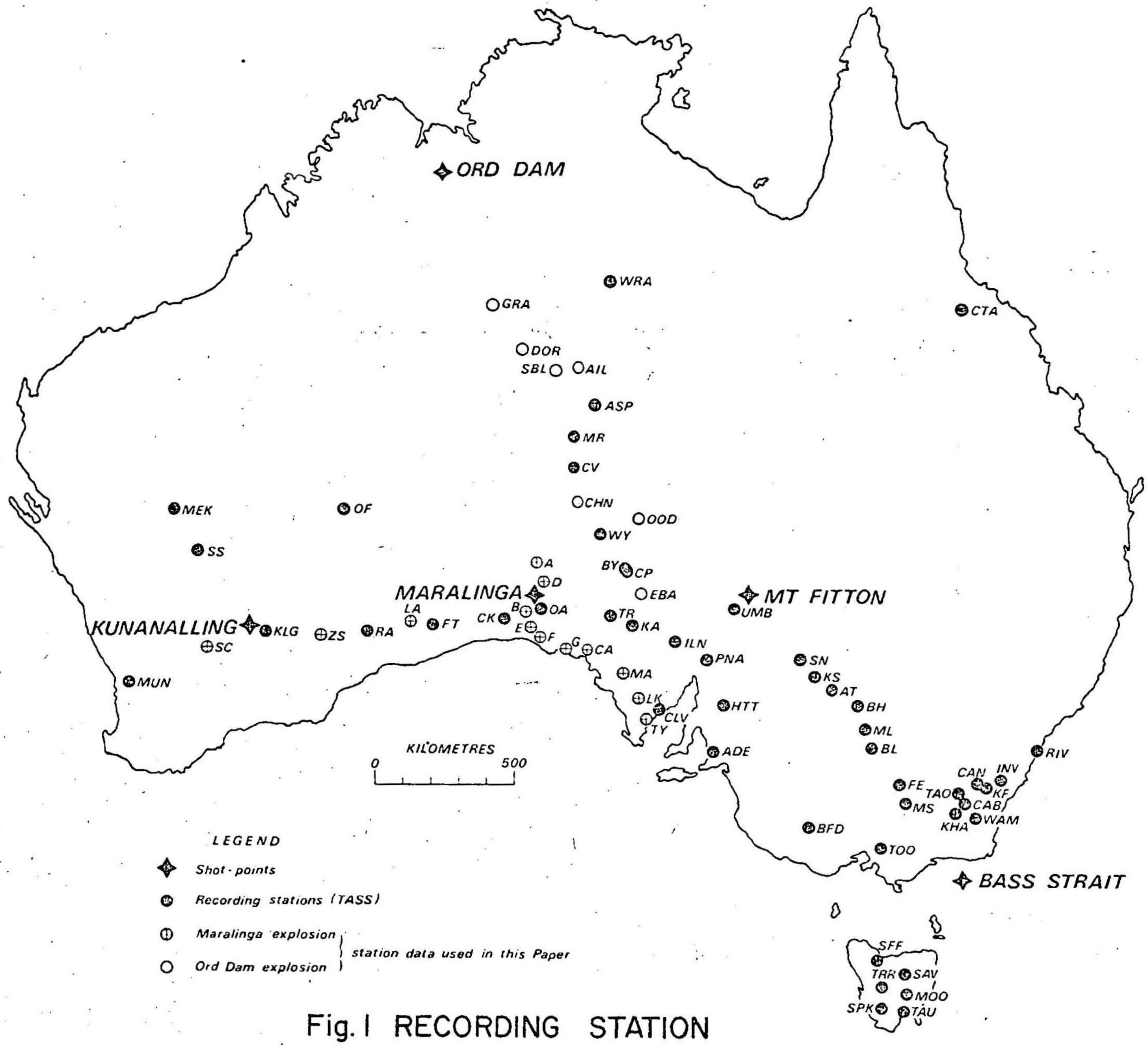

Fig. I RECORDING STATION

A/BIO-31A

BMR, together with the Australian National University and the University of Adelaide, combined to set up recording stations across the Nullarbor Plain, across New South Wales, from Port Augusta (SA) to Alice Springs (NT), and north of Meekatharra (WA). These recording lines, together with the permanent recording networks throughout Australia, were designed to give results which would supplement earlier long-distance seismic refraction information obtained from the atomic bomb tests at Maralinga during 1956 (Bolt, Doyle & Sutton, 1958; Doyle & Everingham, 1964) and the Ord River explosions of 1970-71 (Denham et al., 1972; Simpson, 1973).

THE EXPLOSIONS

In 1971 BMR received a gift from West Australian Petroleum Pty Ltd (WAPET) of 355 tonnes of Du Pont Nitramon WW explosive which was surplus to their requirements, and it was decided to use some of this explosive to further knowledge of the upper mantle structure of the Australian continent by seismic refraction methods. Details of the seismic operation are given by Finlayson & Drummond (in prep.). The Western Australian and South Australian Departments of Mines assisted in locating suitable sites for two land explosions.

The Mount Fitton South Copper Mine is at the northern end of the Mount Painter Metallogenic Province of the north Flinders Ranges in South Australia (Coats & Blissett, 1971), and was worked from 1889 until 1922. The mine workings cut through a series of sheared and jointed coarse-grained granites of Carpentarian age into Precambrian crystalline basement, which consisted of metamorphosed Proterozoic sediments intruded by several generations of granite.

Eighty tonnes of explosive packed in 30-kg cans was loaded into the end of the main adit, which went horizontally into the hillside for 100 m. Priming charges of AN 60 gelignite with no delays were located throughout the explosive, and a multiple-detonation cord was run to adit portal.

The main adit was sandbagged up to half way along its length, and the open stopes above the main adit were filled with broken rock. The explosive was detonated electrically, and shot time was measured by recording VNG radio time signals, the signal from a geophone near the adit portal, and a chronometer signal on a multi-channel recorder. Details of the shot-point data are given in Table I together with those from the other shots.

The Premier Gold Mine at Kunanalling is 40 km west of Kalgoorlie and 33 km north of Coolgardie; Western Mining Corp indicated that there was little possibility of it ever becoming a viable gold mine again. The rocks in the area are composed of a metamorphosed shale, greywacke, and granite sequence alternating with a sequence of altered mafic and ultramafic extrusive igneous rocks (Kriewaldt, 1969). The Premier mine shaft used for the explosion was in sheared oxidized Archaean 'greenstone'. Eighty tonnes of Du Pont Nitramon was loaded into a drive off the bottom of the main shaft, which was 40 m deep. Four separate Cordtex lines were run through the explosive stack with AN60 gelignite primers attached at intervals. The drive was stemmed with broken dirt in bags to the bottom of the shaft and the firing lines were run to the surface. The explosive was detonated electrically, and the shot time recorded on a multi-channel recorder as at Mount Fitton.

The Bass Strait shot was similar in design to 10 tonne marine shots fired off the coast of Scotland by the Institute of Geological Sciences (Jacob & Willmore, 1972). Those were fired in an attempt to obtain teleseismic information out to angular distances of 90°, and further trial shots were recommended by a Working Group of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) to provide a relatively cheap method of study of the Earth's deep mantle (Finlayson & Drummond, op. cit.).

A site for the shot was selected in Bass Strait where the sea bottom has a minimum gradient at 250 m depth. An explosives consultant was engaged to design and fire the shot in co-operation with the Department of Supply explosives factory at St Marys, NSW. Ten tonnes of RDX-TNT in 35-kg cans was built into a steel cage and deployed from the oil rig supply vessel Smit-Lloyd 33. RDX-TNT is estimated to be 24 percent more powerful than ordinary TNT.

The charge was suspended 25 m above a 15-tonne concrete 'sinker' on the sea-bed by a steel rope connected to four mooring buoys located 18 m below the water surface. Four Cordtex lines were run from a 35-kg primer charge in the top of the main charge to a surface buoy. A detonator and primer were attached to the top of the Cordtex after the charge had been positioned, and the shot was detonated electrically with 2 km of firing line. Shortly before detonation, the charge seems to have settled on the sea bottom as a result of leaks in the main support buoys, and thus the ideal geometry for maximum generation of seismic energy was not achieved. The shot was positioned by a Shoran VHF network and timed by recording an impluse from the shot-firing mechanism together with VNG radio time signals and a crystal-clock time code on a multi-channel recorder.

The shot site was on the northern flank of the Gippsland Basin where 1 to 2 km of Ordovician to Miocene sediments overlie Cambrian or Precambrian metamorphic basement. The Upper Cretaceous to Miocene marine sediments contain oil source and reservoir rocks (Weeks & Hopkins, 1967; Underwood, 1969). The site lies near the edge of the continental shelf (which is usually taken as the 200 m isobath), and the sea bottom gradient was estimated to be 10°.

RECORDING STATIONS

The three shots were fired on two separate days, the two land shots on 25 October and the marine shot on 19 December. The temporary and permanent recording stations involved are plotted in Figure 1.

The permanent seismic observatory network recordings were nearly all obtained from short-period seismometers that use galvanometers and record on photographic paper. The temporary recording stations were nearly all short-period seismometers that use a high-gain amplifier and record on slow-speed tape recorders. All stations recorded VNG radio time signals as their time reference standard. The survey was designed to obtain upper mantle arrivals out to distances greater than 1000 km, and no recordings were made at distances less than 200 km except where permanent stations happened to be within that radius.

The main temporary recording lines for the Mount Fitton and Kunanalling shots were across the Nullarbor Plain, from Mount Fitton to Alice Springs, and from Mount Fitton to the Snowy Mountains in southeast New South Wales. The main temporary recording line for the Bass Strait shot was from the Snowy Mountains to Mount Fitton. Finlayson & Drummond (op. cit.) list all the station positions and recorded data except those obtained along the Mount Fitton/Snowy Mountains line, which are being analysed separately by Australian National University staff.

NULLARBOR REGION VELOCITIES AND UPPER MANTLE STRUCTURE

Most of the data were recorded in the range 200 to 1400 km and Figure 2 shows the travel times of the seismic arrivals plotted on a reduced scale against distance from shot to recorder. The data from the 1956 Maralinga atom bomb tests (Bolt et al., 1958), are also plotted. A least-squares analysis of the data in the distance range 200-1400 km gives apparent P_n velocities and intercepts of 8.31 ± 0.01 km/s and 8.57 ± 0.17 s from the Mount Fitton shot, and 8.26 ± 0.02 km/s and 7.34 ± 0.25 s from the Kunanalling shot (Table II). The Maralinga data towards the west give an apparent P_n velocity of 8.21 ± 0.01 km/s and intercept of 7.24 ± 0.06 s when the Southern Cross data are excluded. Southern Cross, together with other stations west of Kalgoorlie (MUN, MEK and SS), appears to record arrivals earlier than stations on the Nullarbor line, and this may indicate a different crustal structure.

To accompany Record No. 1974/61

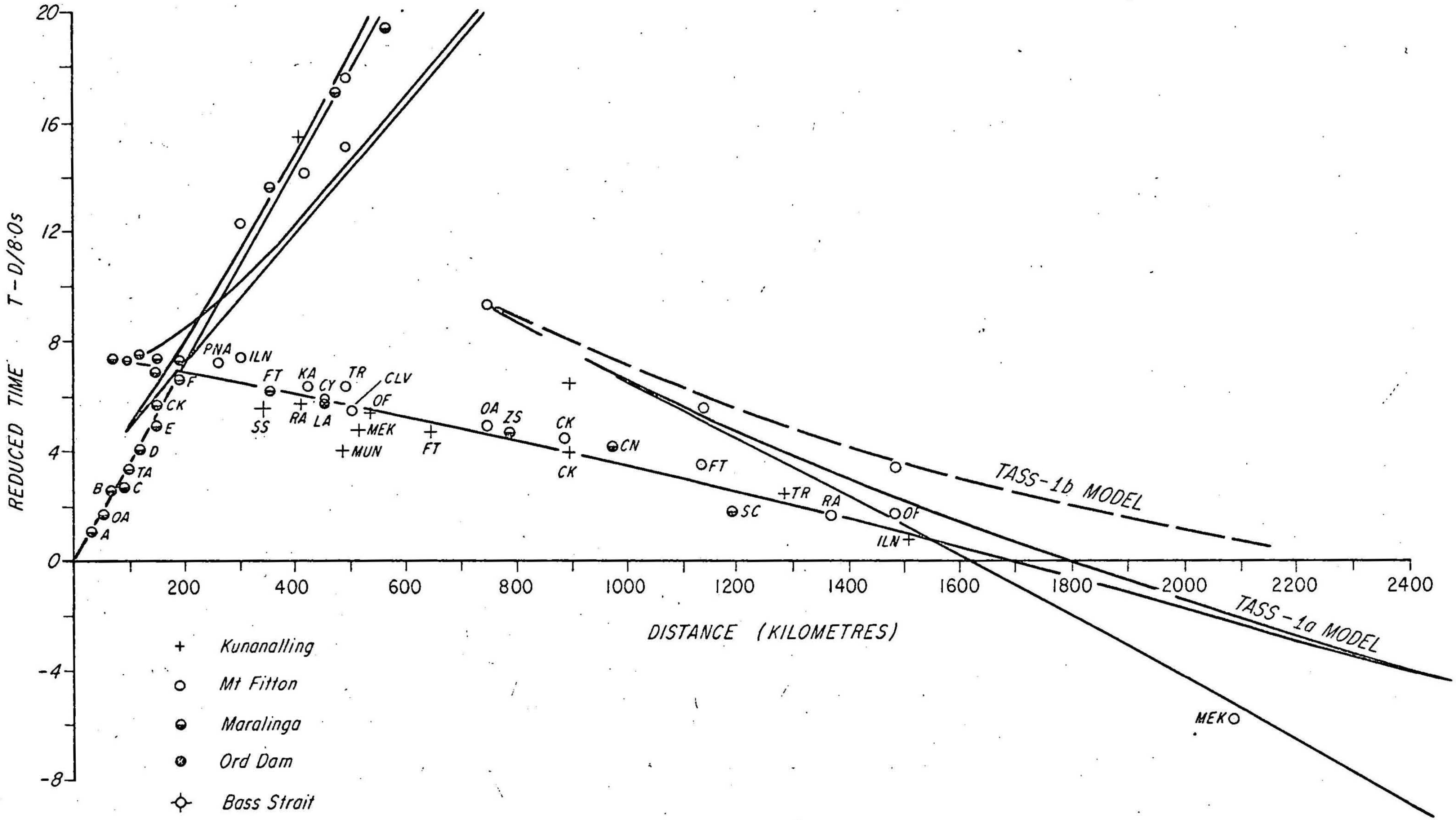

Fig. 2 NULLARBOR LINE TIME/DISTANCE PLOT

A/B10-32A

The combined data from the Nullarbor stations give a least-squares apparent P_n velocity of 8.29 ± 0.02 km/s and intercept of 8.08 ± 0.02 s. The data from Coober Pedy (CY), Mount Brady (BY), Cleve (CLV), and Officer Basin (OF) also fit these figures even though they are not on the direct recording line across the Nullarbor.

Various corrections for Earth curvature must be applied to the apparent velocities in order to obtain a value for the velocity in the refractor. The first correction takes into account the difference in arc lengths at the Earth's surface and at the refractor depth (Mereu, 1967); the second correction takes into account differences in the arc-chord path length, which become signigicant at distances greater than 600 km (Cull, 1973). These corrections reduce the apparent P_n velocity for the Nullarbor region from 8.29 km/s to 8.23 km/s (Table 2). Mereu (op. cit.) also outlines the procedure for correcting depth estimates, and observes that corrections to refractor depths become important only at depths greater than 60 km and that, in practice, the apparent velocities may be used with uncorrected time/depth data to derive depths less than 60 km.

The data from the Mount Fitton, Kunanalling, and Maralinga shots along the east-west traverse across the Nullarbor have been treated as a reversed profile to obtain refractor depth estimates by the time/depth method (Hawkins, 1961). The TASS survey recorded very few crustal first arrivals and therefore the velocity model adopted for the crust must be obtained from other surveys. Bolt et al. (1958) give a crustal P_i velocity of 6.03 ± 0.09 km/s from the Maralinga data and Doyle & Everingham (1964) derive a velocity of 6.30 ± 0.06 km/s for the region southeast of Maralinga. Hawkins et al. (1965) obtained basement velocities of 6.26 km/s on the continental shelf off South Australia, and Stewart (1972) has taken all these results into account in his derivation of a crustal model for use with the South Australian seismic recording network to locate local earthquakes. Stewart's 1971(b) preferred model has a uniform crust with P velocity 6.25 ± 0.03 km/s overlying a mantle with apparent velocity 8.02 ± 0.03 km/s.

The most recent investigation of crustal velocity in the shield region is BMR's Geotraverse, which adjoins the western end of the TASS survey (Mathur, 1973). Just west of Kalgoorlie Mathur derives a P_1 velocity of 6.13 ± 0.01 km/s, a P_2 velocity of 6.74 km/s at 19.5 km depth and an apparent P_n velocity of 8.29 ± 0.39 km/s at a depth of 34.0 km. Cleary (1971) has indicated that the data available in shield regions suggest a P_1 velocity of 6.2 km/s and a P_2 velocity greater than 6.5 km/s at 20 km depth, and these are the values adopted by Simpson (1973) for his modelling studies of the Ord explosion data along the Ord-Adelaide line. The crustal model adopted for the interpretation of the TASS Nullarbor data consists of a uniform layer with a P_1 velocity of 6.20 km/s and a thickness of 20 km overlying a lower crust with a P_2 velocity of 6.70 km/s.

Time depths were computed from arrivals from opposite directions for five Nullarbor stations and were used to derive delay times at a further eight sites. The resulting depths to the Moho refractor with a corrected P_n velocity of 8.23 ± 0.02 km/s are shown in Figure 3. The values show a general thinning of the crust from east to west: the depth to the refractor ranges between 41 and 49 km in the Adelaide Geosyncline region, decreases to 39-40 km under the eastern Nullarbor shield area, and further decreases to 34-35 km under the western Nullarbor. The crust and upper mantle section in the Adelaide Geosyncline are discussed later in this paper, and it is probable that a wedge of upper mantle material with velocity 7.96 km/s occurs in that region at a depth of 40 km.

A spherically symmetric model of the crust and upper mantle structure in the Nullarbor region (Fig. 4, TASS-1a) was incorporated into a computer ray-tracing program (Cull, 1973). This model had a mantle structure similar to that of Simpson (1973) from the results of the Ord Dam explosion. The resultant fit of the data to the model travel-time curve (Fig. 2) was considered to be good along the section with apparent velocity 8.29 km/s.

To accompany Record No. 1974/61

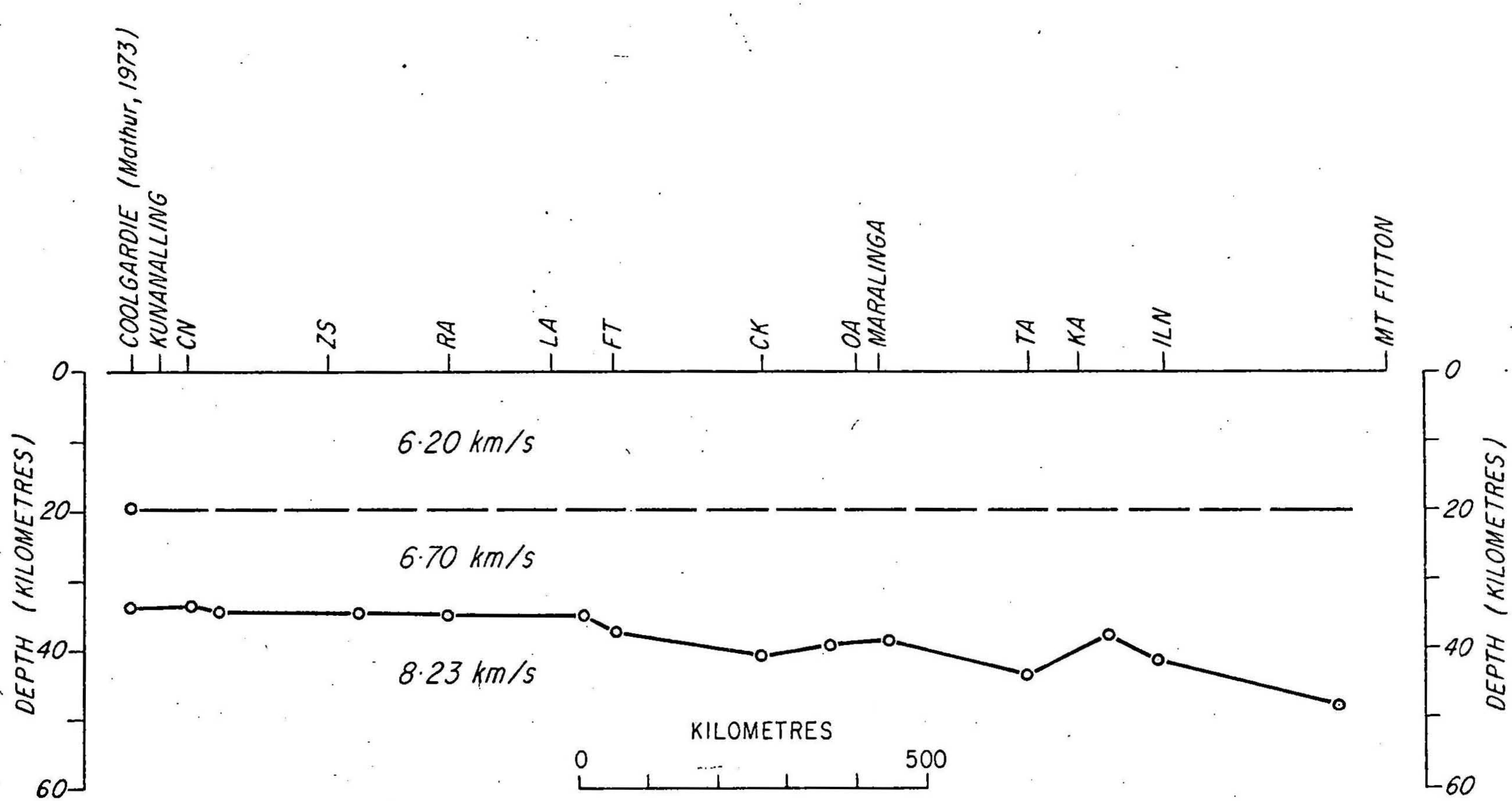

Fig.3 TASS NULLABOR PROFILE

A/B10-33A

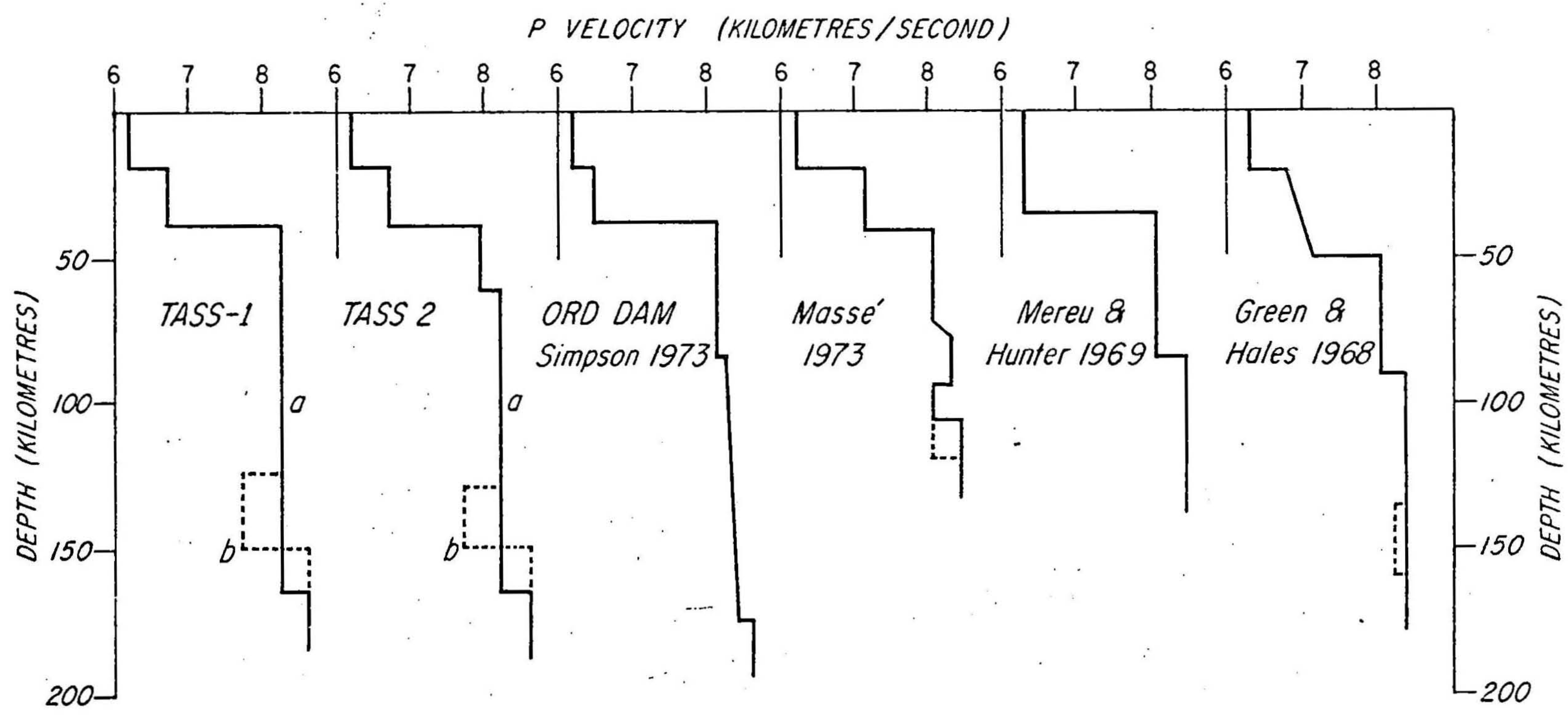

Fig.4 UPPER MANTLE P VELOCITY MODELS

To accompany Record No 1974/61

A/B10-34A

The triplication in the travel time curve at about 1400 km results from the increase in apparent velocity to approximately 8.85 km/s within the upper mantle.

The possibility of there being a low-velocity zone within the upper mantle was considered, and the TASS-1b model (Fig. 4) and a number of variations were tried. Figure 5 illustrates the record sections for some of the recording stations across the Nullarbor; it is difficult to identify the retrograde cusp points with any certainty. Bearing in mind the amplitude variations expected at the cusp points, these records offer no convincing evidence for a low-velocity zone for P waves.

CENTRAL AUSTRALIA VELOCITIES AND UPPER MANTLE STRUCTURE

The seismic arrivals from the Mount Fitton shot recorded along the lines towards Alice Springs and Adelaide, together with those from Maralinga explosions towards Adelaide and the Ord Dam explosions southward across central Australia, are plotted in Figure 6. A least-squares analysis of the arrivals from the Maralinga explosion towards Adelaide gives an apparent P_n velocity of 8.05 ± 0.04 km/s and an intercept of 7.74 ± 9.99 s (Doyle & Everingham, 1964), and the results from the Mount Fitton shot in the Adelaide Geosyncline region seem to substantiate that this velocity is lower than that in the shield regions. There is a degree of scatter from the Mount Fitton shot not evident in the Maralinga data; the good first arrival at CLV seems particularly early.

However at distances beyond 550 km towards Alice Springs the least-squares analysis gives an apparent velocity of 8.24 ± 0.02 km/s and intercept of 8.63 ± 0.32 s for P_n arrivals and the data together with the Ord Dam data, can be treated as a reversed profile as was done with the Nullarbor data.

The first interpretation model for the crust was taken to be the same as that for the Nullarbor line. The resulting Moho depths varied between 44 km and 48 km over the 2000 km profile. This was about 6-8 km deeper than

To accompany Record No. 1974/61

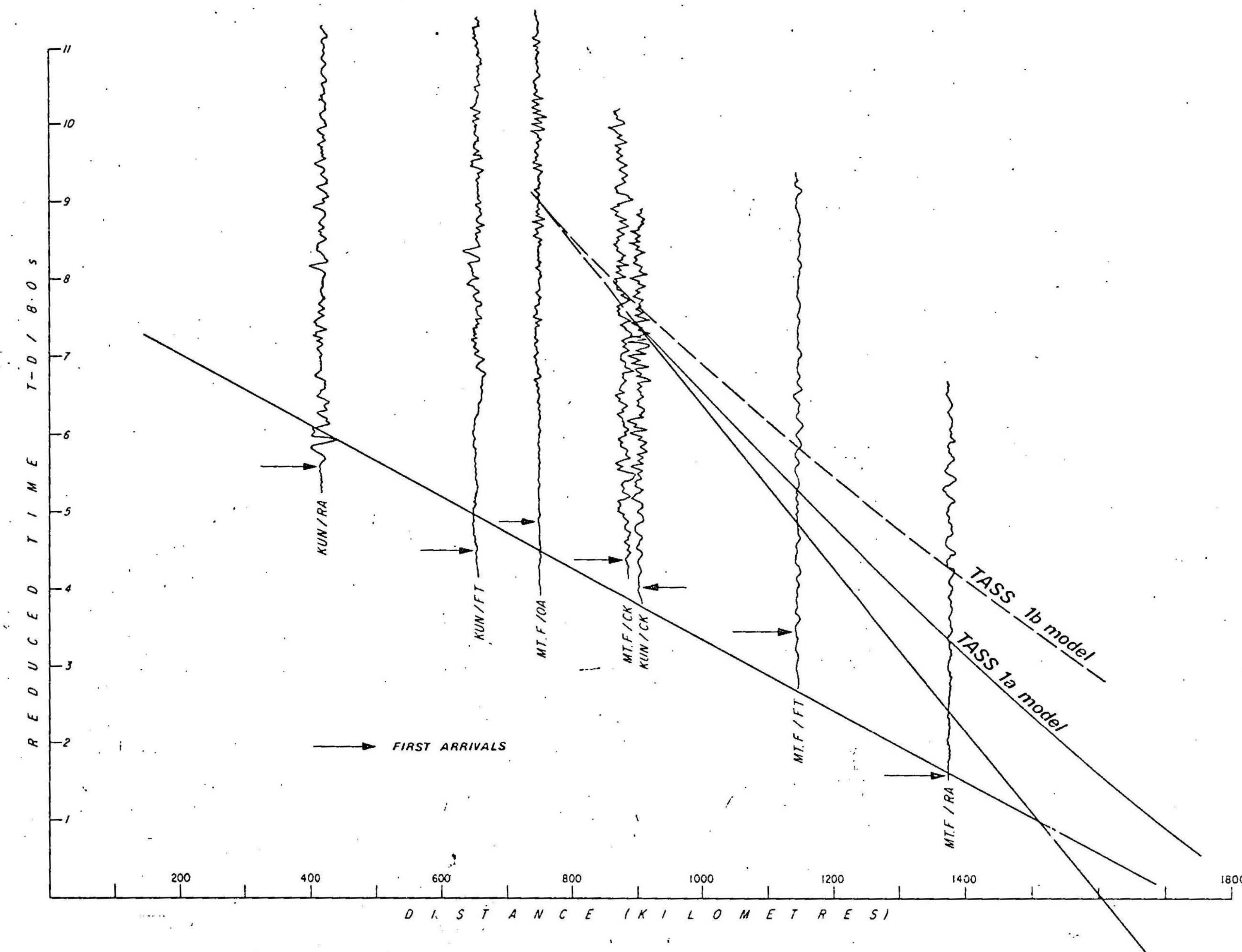

Fig. 5

A/B10-35A

the 8.23 km/s refractor under the Nullarbor Plain and was also thicker than the value of about 40 km determined from surface-wave dispersion studies (Thomas, 1969), so alternative models were tried.

The feature of the TASS and associated data which seems to indicate that the first model is too simple is that the first arrivals in the Adelaide Geosyncline region give an apparent velocity of 8.04 ± 0.04 km/s and an intercept of 7.71 ± 0.28 s (Table II). This velocity agrees with the upper mantle apparent velocity of 8.02 ± 0.03 km/s Stewart (1972) used for his earthquake modelling studies. The data from the Maralinga and Mount Fitton shots are not along reversed profiles so it would be inappropriate to use them in a formal refraction interpretation; nor are there sufficient data for a time-term analysis. However, computer modelling of spherical layered Earth models shows that the data are consistent with a Moho velocity of 7.96 km/s at 40 km depth and a further increase in velocity to 8.18 km/s at a depth of 61 km (Fig. 4, TASS-2a). The resultant travel time curve is plotted in Figure 6.

The data from the 8.18 km/s refractor in central Australia can be treated as a reversed profile from the Ord Dam to Mount Fitton using the TASS-2a model for the crustal and Moho refractors with horizontal boundaries. The resultant profile is shown in Figure 7. The large variations in depth to the sub-Moho refractor correspond to comparatively small travel-time residuals which are amplified because of the small seismic velocity contrast across the boundary. These residuals could also be explained by smaller depth variations in one of the upper refracting boundaries. Thus those variations should not be taken as a definitive interpretation, though the average depth to the boundary is probably fairly accurate.

A low-velocity zone at a depth of 130 km was modelled also (TASS-2b), but as with the Nullarbor line there was not sufficient evidence in the record sections to define the retrograde part of the time/distance curve with any survey.

To accompany Record No. 1974/61

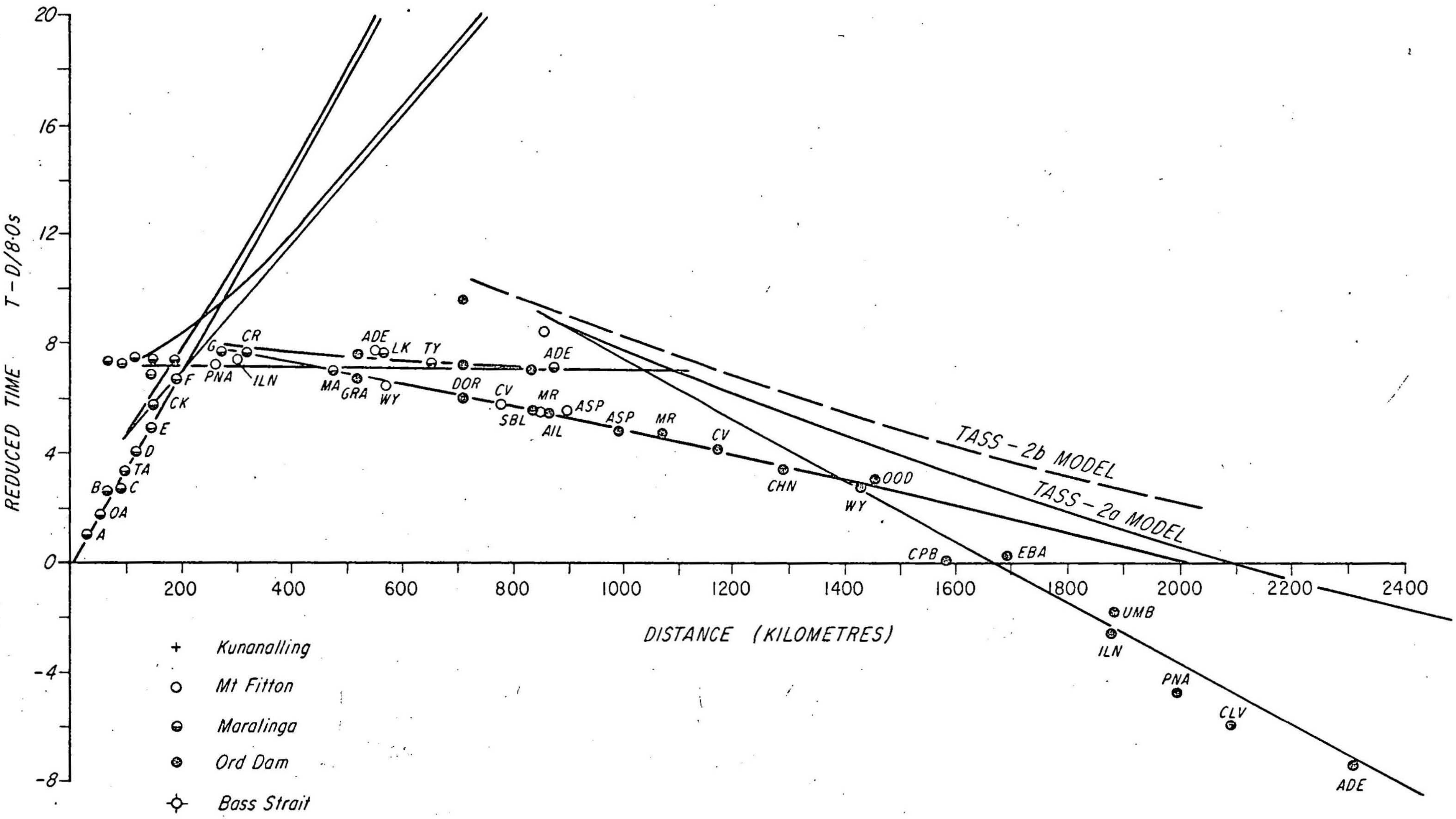

Fig.6 CENTRAL AUSTRALIA LINE TIME/DISTANCE PLOT

A/B10−36A

To accompany Record No 1974/61

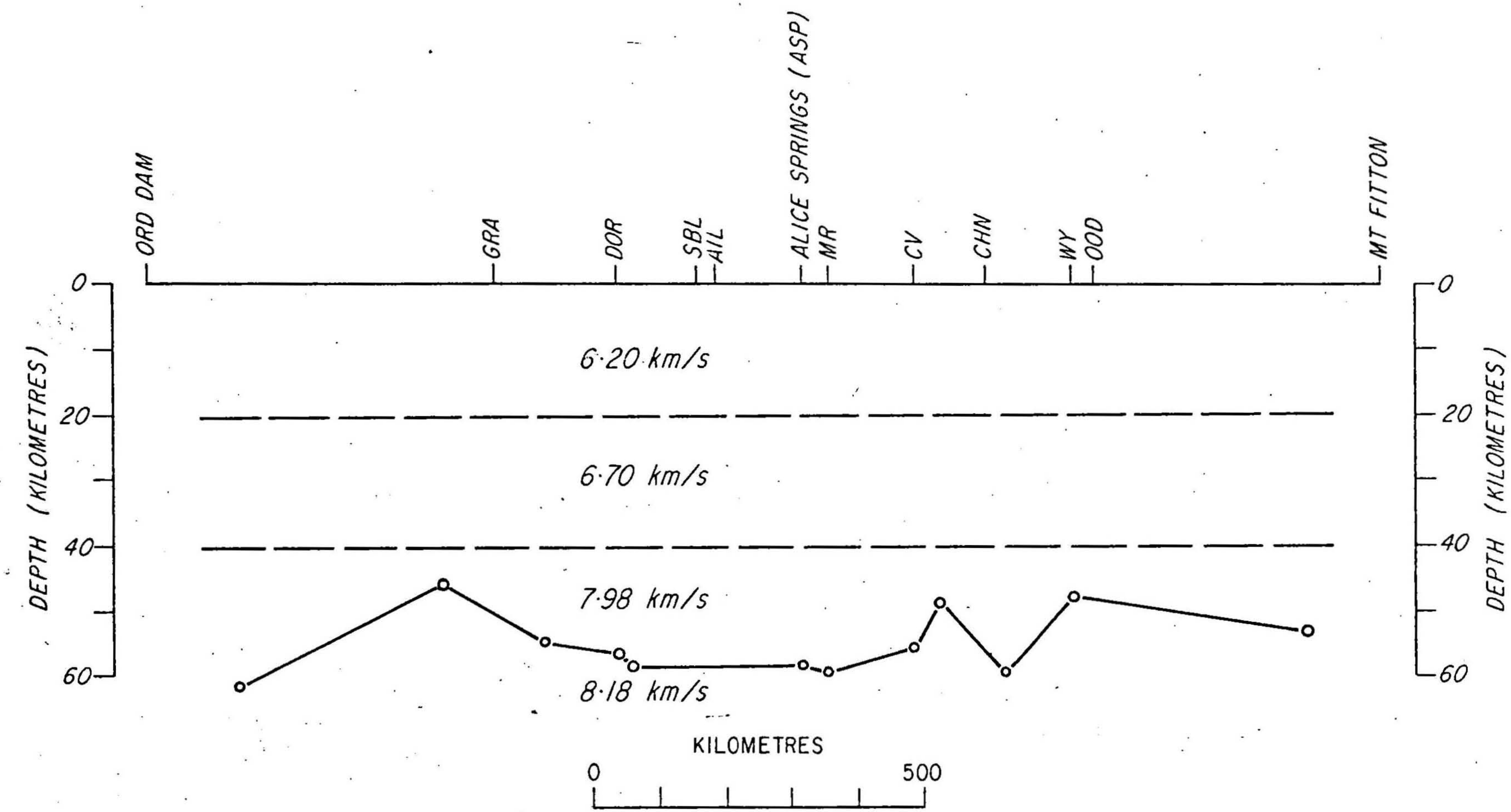

Fig.7 CENTRAL AUSTRALIAN PROFILES

A/B10-37A

OBSERVATIONS IN SOUTH AUSTRALIA, VICTORIA, AND TASMANIA

The data recorded in Victoria, eastern South Australia, and Tasmania from the Bass Strait and Mount Fitton shots are plotted in Figure 8. There are not sufficient data to provide a thorough interpretation, but a number of features are evident. At distances in the range 200 to 1200 km the apparent velocity of approximately 8.25 km/s still appears. A least-squares analysis of data from TOO, BFD, and the eastern Adelaide network stations gives an apparent velocity of 8.31 ± 0.04 km/s and intercept of 9.29 ± 0.48 s from the Mount Fitton shot, and a velocity of 8.20 ± 0.03 km/s and intercept of 8.32 ± 0.36 s from the Bass Strait shot. The TASS-2a travel time curve has been superimposed on Figure 8 and it is seen that the data are consistent with that model. The data from a line farther north from Mount Fitton across New South Wales to the Snowy Mountains seismic recording network are being analysed by Australian National University staff and should provide a more detailed interpretation. Further interpretation of the Bass Strait shot data together with other data in the region of the Tasman Geosyncline (Doyle, et al., 1959; Doyle et al., 1966; Underwood, 1969) is also being undertaken.

S_n ARRIVALS

There are not many shear wave arrivals identified on the TASS records, but in central and western Australia the data are consistent with the Maralinga data. A least-squares analysis of S arrivals in the range 250 to 1400 km from the TASS and Maralinga data gives an apparent S_n velocity of 4.78 ± 0.03 km/s and an intercept of 17.08 ± 1.04 s (Table II). These are compatible with the velocity of 4.75 ± 0.07 km/s and intercept of 12.52 ± 2.29 s obtained by Denham et al. (1972) within the range 400 to 900 km from the Ord Dam explosions.

To accompany Record No. 1974/61

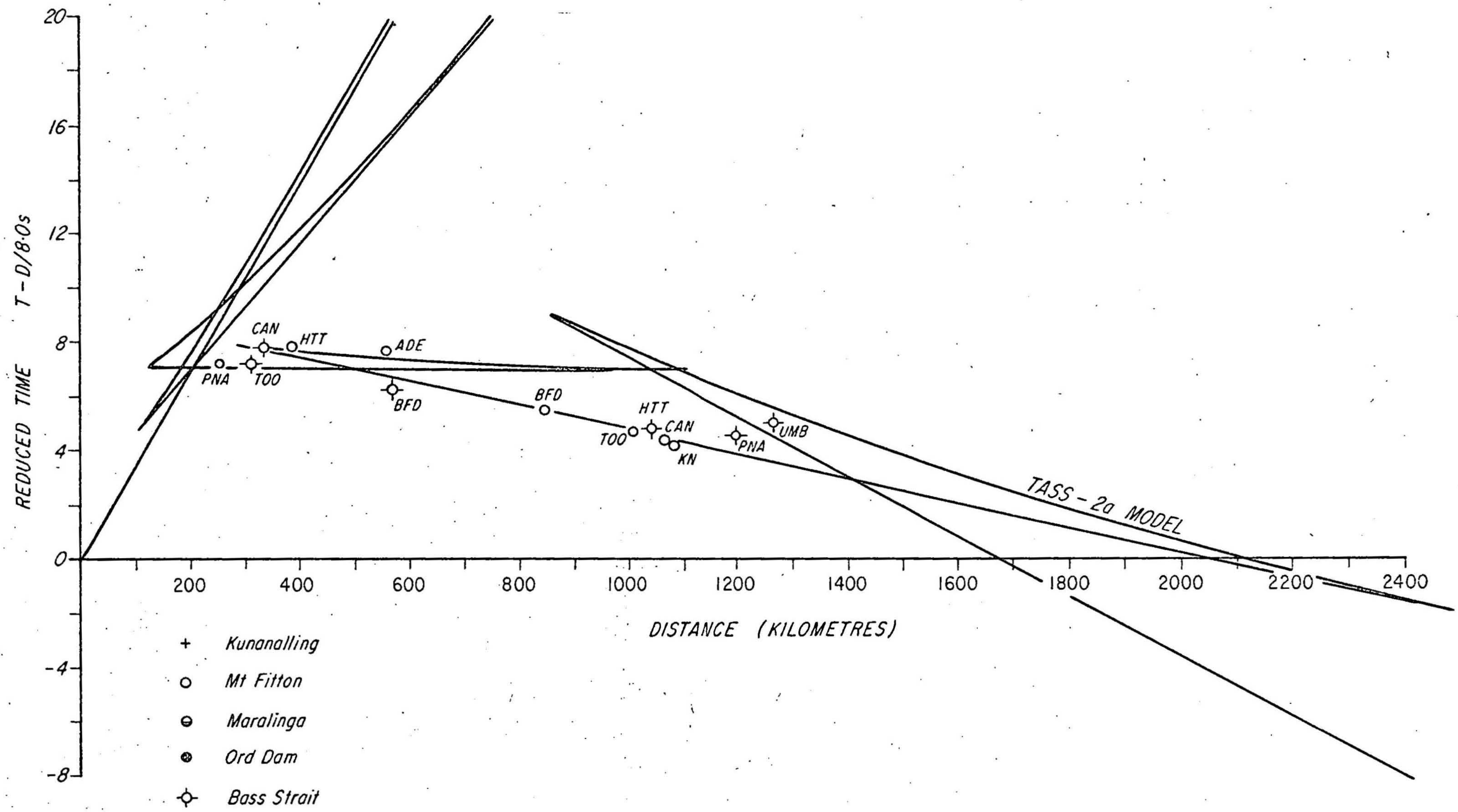

Fig.8 SOUTH AUSTRALIA LINE TIME/DISTANCE PLOT

A/B10-38A

MAGNITUDES

Estimates of the magnitudes of the three explosions have been made from a number of permanent seismic observatory records. The magnitude of a seismic event can be expressed in the form

$$m = \log (A/T) + A_2$$

where A is the ground amplitude in nanometres taken as the maximum amplitude of the initial P phase, T is the period in seconds, and A_2 is a function of distance and depth of source. The values of A_2 were taken from the curve derived by Everingham (1968) for m_b from Western Australian earthquakes. Five seismic stations were used to derive the value of $m_b = 3.7$ for the Mount Fitton shot, two for the value $m_b = 3.1$ for the Kunanalling shot, and four for the value $m_b = 3.8$ for the Bass Strait shot (Table I).

COMMENTS

In the Australian continent, the interpretations by Denham et al. (1972) and Simpson (1973 of long-range seismic refraction data were the first of their types to define sub-Moho velocity structures. In North America many such investigations have been undertaken using both chemical and nuclear explosion data (Green & Hales, 1968; Helmsberger & Wiggins, 1971; Herrin, 1969; Masse et al., 1972; Masse, 1973a; Mereu & Hunter, 1969). Some upper mantle P velocity profiles interpreted for North America are included in Figure 4.

The TASS-1a models (Table III) have features not previously recognized in the Australian continent. The refractor resulting in an apparent velocity of 8.26–8.29 km/s is recognized as the Moho under the shield areas of the Nullarbor Plain, but it dips to depths of roughly 60 km under central and eastern Australia where a Moho refractor with apparent velocity of approximately 8.03 km/s is recognized at depths of roughly 40 km. It should be noted that reconnaissance deep seismic reflection work in the

Broken Hill/Mildura region detected sub-Moho reflectors at two-way reflection times of 14 to 15 s, and these have been interpreted as a horizon at a depth of about 50 km (Branson et al., 1972). Similar two-tier increases in velocity at the Moho have been recognized under the Canadian shield (Gurbuz, 1970; Hall & Hajnal, 1973), where the Moho velocity of 7.90 km/s at 34 km gives way to a velocity of 8.48 km/s at 47 km.

It is also noted from the harmonic analysis of gravity anomalies along a number of profiles across Australia (P. Wellman, pers. comm.) that the power spectra reveal a distinct suggestion that the sources of most of the gravity anomalies are shallower than 60 km, which is approximately the depth to the sub-Moho refractor in the TASS-2a model.

Velocity distributions below 60 km are not well determined from TASS data, but inspection of subsequent seismic arrivals shows little evidence for a P-wave low-velocity zone similar to that indicated in the TASS-1b and 2b models at depths of roughly 130 km. However, data of better quality are required before the presence of such a zone can be disproved conclusively. Masse (1973b) has mentioned the possibility of such a low-velocity zone for the shield areas of Australia, but his velocity model is markedly different from the TASS models and the Ord model of Simpson (1973) and does not fit the observed data.

A number of points are raised by the wedging-out of the 7.98 km/s sub-Moho layer from east to west. Associations can be made with the age of the upper crust, which is predominantly less than 500 m.y. in eastern Australia but increases to more than 3000 m.y. in the Archaean shield areas (Geological Society of Australia 1971), and with heat flow, which decreases from east to west (Jaeger, 1970). If thinning of the sub-Moho layer with age is postulated then this implies a possible ageing process associated with phase changes in the upper mantle. If this transformation is associated with energy release, it may account for gross features of heat flow across the continent.

Variations in the crustal and upper mantle velocities have been recognized as the source of P-wave travel-time residuals to Australian permanent seismic recording stations (Cleary, 1967). Negative residuals up to 1.5 s have been found in the shield areas and positive residuals up to 1.1 s in southeastern Australia. From the Canniken explosion Cleary et. al. (1972) also found a residual difference of 1.3 s along their recording line from the Snowy Mountains to Maralinga. We estimate that the velocity variations in the upper mantle determined from the TASS results can only account for 0.5 s in the region down to 60 km, thus deeper regional velocity differences must account for the remaining travel-time residuals.

ACKNOWLEDGEMENTS

The authors are grateful for the assistance received in firing the three TASS explosions from the Western and South Australian Departments of Mines, Esso Australia Pty Ltd, Smit-Lloyd (Australia) Pty Ltd, and the Department of Supply. We are also grateful to West Australian Petroleum Pty Ltd for donating the explosives for the land shots. We are indebted to Dr D.J. Sutton (University of Adelaide), Dr J.P. Webb (University of Queensland), Dr W.D. Parkinson (University of Tasmania) and Dr L. Drake (Riverview College Observatory) for making seismic records available, and to the Australian National University team, who recorded across New South Wales and whose results will be published elsewhere. This paper is published with the permission of the Director of the Bureau of Mineral Resources, Geology & Geophysics, Canberra.

REFERENCES

BOLT, B.A., DOYLE, H.A., & SUTTON, D.J., 1958 - Seismic observations from the 1956 atomic explosions in Australia. Geophys. J. R. Astr. Soc., 1, 135.

CLEARY, J.R., 1967 - P times to Australian stations from nuclear explosions. Bull. seismol. Soc. Am., 57, 773.

CLEARY, J.R., 1971 - Australian crustal structure. Proc. IUGG Congress, Moscow. Also in Tectonophysics, (in press).

CLEARY, J.R., SIMPSON, D.W., & MUIRHEAD, K.J., 1972 - Variations in Australian upper mantle structure from observations of the Canniken explosion. Nature, 236, 111.

COATS, R.P., & BLISSETT, A.H., 1971 - Regional and economic geology of the Mount Painter Province. Geol. Surv. S. Aust. Bull. 43.

CULL, J.P., 1973 - Seismic ray tracing in a spherical Earth using computer models. Bur. Miner. Resour. Aust. Rec. 1973/122 (unpubl.)

DENHAM, D., SIMPSON, D.W., GREGSON, P.J. & SUTTON, D.J., 1972 - Travel times and amplitudes from explosions in northern Australia. Geophys. J.R. astron. Soc., 28, 225-35.

DOYLE, H.A., EVERINGHAM, I.B., & HOGAN, T.K., 1959 - Seismic recordings of large explosions in southeastern Australia. Aust. J. Phys., 12, 222.

DOYLE, H.A., & EVERINGHAM, I.B., 1964 - Seismic velocities and crustal structure in southern Australia. J. Geol. Soc. Aust., 11, 141.

DOYLE, H.A., UNDERWOOD, R., & POLAK, E.J., 1966 - Seismic velocities from explosions off the central coast of New South Wales. J. Geol. Soc. Aust., 13, 355.

EVERINGHAM, I.B., 1968 - Mundaring Geophysical Observatory annual report 1966. Bur. Miner. Resour. Aust. Rec., 1968/97 (unpubl.)

FINLAYSON, D.M., & DRUMMOND, B.J., (in prep.) - Trans-Australia seismic survey (TASS) 1972, Operational Report. Bur. Miner. Resour. Aust. Rec.

GEOLOGICAL SOCIETY OF AUSTRALIA, 1971 - Tectonic map of Australia and New Guinea. 1: 5 000 000. Sydney, Geol. Soc. Aust.

GREEN, R.W.E., & HALES, A.L., 1968 - The travel times of P waves to 30° in the central United States and upper mantle structure. Bull. Seism. Soc. Am., 58, 267-89.

GURBUZ, B.M., 1970 - A study of the Earth's crust and upper mantle using travel times and spectrum characteristics of body waves. Bull. seismol. Soc. Am., 60, 1921-35.

HALL, D.H., & HAJNAL, Z., 1973 - Deep seismic crustal studies in Manitoba. Bull. seismol. Soc. Am., 63 (3), 885-910

HAWKINS, L.V., 1961 - The reciprocal method of routine shallow seismic refraction investigations. Geophys., 26 (6), 806-19.

HAWKINS, L.V., HENNION, J.F., NAFE, J.E., & DOYLE, H.A., 1965 - Marine seismic refraction studies on the continental margin to the south of Australia. Deep Sea Res., 12, 479-95.

HELMSBERGER, D., & WIGGINS, R.A., 1971 - Upper mantle structure of mid-western United States. J. geophys. Res., 76, 3229-45.

HERRIN, E., 1969 - Regional variations of P wave velocity in the upper mantle beneath North America. In The Earth's Crust and Upper Mantle. Am. geophys. Un. Mono. 13, 242-6.

JACOB, A.W.B., & WILLMORE, P.L., 1972 - Teleseismic P waves from a 10 ton explosion. Nature, 236, 305.

JAEGER, J.C., 1970 - Heat flow and radioactivity in Australia. Earth planet. Sci. Lett., 8, 285.

KRIEWALDT, M.J.B., 1969 - Kalgoorlie, W.A., - 1: 250 000 Geological Series. Geol. Surv. W. Aust. explan. Notes SH/51-9.

MASSE, R.P., LANDISMAN, M., & JENKINS, J.B., 1972 - An investigation of the upper mantle compressional velocity distribution beneath the Basin and Range Province. Geophys. J. R. astron. Soc., 30, 19-36.

MASSE, R.P., 1973a - Compressional velocity distribution beneath central and eastern north America. Bull. seismol. Soc. Am., 63 (3), 911-35.

MASSE, R.P., 1973b - Upper mantle compressional velocity and continental drift rates. Nature Phys. Sci., 245, 134-5.

MATHUR, S.P., 1973 - Crustal structure in southwestern Australia. Bur. Miner. Resour. Aust. Rec. 1973/112 (unpubl.)

MEREU, R.F., 1967 - Curvature corrections to upper mantle seismic refraction surveys. Earth and Plan. Sci. Lett., 3, 469-75.

MEREU, R.F., & HUNTER, J.A., 1969 - Crustal and upper mantle structure under the Canadian Shield from Project Early Rise data. Bull. seismol. Soc. Am., 59, 147-65.

SIMPSON, D.W., 1973 - P wave velocity structure of the upper mantle in the Australian region. Ph.D. Thesis, Australian National University, Canberra.

STEWART, I.C.F., 1972 - Seismic interpretation of crustal structure in the Flinders-Mount Lofty Ranges and Gulf regions, South Australia. J. Geol. Soc. Aust., 19 (3), 351-62.

THOMAS, L., 1969 - Rayleigh wave dispersion in Australia. Bull. seismol. Soc. Am., 59, 167.

UNDERWOOD, R., 1969 - A seismic refraction study of the crust and upper mantle in the vicinity of Bass Strait. Aust. J. Phys., 22, 573.

WEEKS, L.G., & HOPKINS, B.M., 1967 - Geology and exploration of three Bass Strait basins, Australia. Bull. Am. Ass. petrol. Geol., 51, 742-60.

TABLE I

TASS Shot Parameters

	Mount Fitton	Kunanalling	Bass Strait
Latitude	30° 00.4' S	30° 40.5'	38° 17.6'
Longitude	139° 33.8' S	121° 04.0'	148° 48.6'
Date	25 Oct. 1972	25 Oct. 1972	19 Dec 1972
Shot time (UT)	01h 05m 00.04s	04h 05m 01.23s	07h 50m 00.77s
Size (tonnes)	80	80	10
Explosive	Du Pont Nitramon WW	Du Pont Nitramon WW	RDX-TNT
Estimated magnitude m_b	3.7	3.1	3.8
Depth of water (if applicable)	-	-	250m

TABLE II

Least-Squares Velocities and Intercepts

Area	Apparent velocity km/s	Intercept s	No. of data	RMS residual s	Corrected velocity* km/s
P_n					
Mount Fitton west	8.31 ± 0.01	8.57 ± 0.17	9	0.24	
Kunanalling east	8.26 ± 0.02	7.34 ± 0.25	6	0.32	
Maralinga west	8.21 ± 0.01	7.24 ± 0.06	4	0.03	
Nullarbor combined	8.29 ± 0.02	8.08 ± 0.20	19	0.41	8.23
Mount Fitton north	8.24 ± 0.02	8.63 ± 0.32	5	0.14	
Ord Dam south	8.27 ± 0.01	8.80 ± 0.19	11	0.15	
Central Australia combined	8.26 ± 0.01	8.82 ± 0.16	16	0.16	8.18
Adelaide Geosyncline	8.04 ± 0.04	7.71 ± 0.28	9	0.28	7.98
Mount Fitton south & east	8.31 ± 0.04	9.29 ± 0.49	8	0.51	
Bass Strait north & west	8.20 ± 0.03	8.32 ± 0.36	6	0.35	
S_n					
TASS & Maralinga	4.78 ± 0.03	17.08 ± 1.04	15	1.64	4.75

* Corrected velocity = apparent velocity with Earth curvature corrections applied (see text)

TABLE III

TASS Computer Models

TASS-1a		TASS-1b		TASS-2a		TASS-2b	
depth, km	velocity, km/s	depth	velocity	depth	velocity	depth	velocity
0	6.20	0	6.20	0	6.20	0	6.20
20	6.20	20	6.20	20	6.20	20	6.20
20	6.70	20	6.70	20	6.70	20	6.70
40	6.70	40	6.70	40	6.70	40	6.70
40	8.23	40	8.23	40	7.98	40	7.98
165	8.23	125	8.23	61	7.98	61	7.98
165	8.53	125	7.70	61	8.18	61	8.18
		150	7.70	165	8.18	130	8.18
		150	8.53	165	8.53	130	7.70
						150	7.70
						150	8.53