DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/69

A PROPOSAL FOR A DEEP SEISMIC SOUNDING AND ASSOCIATED GRAVITY SURVEY IN CENTRAL AUSTRALIA

by

S.P. Mathur

Record 1974/69

A PROPOSAL FOR A DEEP SEISMIC SOUNDING AND ASSOCIATED GRAVITY SURVEY IN CENTRAL AUSTRALIA

by

S.P. Mathur

CONTENTS

ILLUSTRATIONS

SUMMARY

On the basis of geologic mapping and reconnaissance geophysical surveys in central Australia, the major features such as basins, basin margins, nappes, and thrusts have been related to the deformation of the entire crust and upper mantle in the area. It has been suggested that the crust and upper mantle have been upthrust along three major deformed zones on the north and south margins of the Amadeus and Ngalia Basins.

In order to test the validity of the model and to improve the interpretation of the surface data, a comprehensive deep seismic sounding and detailed gravity survey of the deformed zones along the northern margins of the Amadeus and Ngalia Basins is proposed. The seismic work would consist of continuous reflection and expanded spread recording along three 28-km traverses and simultaneous refraction recording along about 2000 km of N-S and E-W traverses centred at the three probes. Gravity measurements would be made at 1-km intervals along the seismic traverses. The proposed survey would require a Bureau of Mineral Resources seismic and gravity combined party of normal size to operate for about five months, and the cost is estimated to be as for a sedimentary basin survey of the same duration.

The proposed survey is planned to provide additional information that is necessary for the interpretation of the major gravity features leading to a better understanding of the structural framework and the regional setting of mineral provinces in central Australia.

INTRODUCTION

The constitution of the crust and the upper mantle, and the processes occuring within them, greatly influence the near-surface geology. Information about the entire crust and upper mantle is needed to assist in the broad interpretations of regional geology, structure, and gravity and magnetic fields mapped at the surface. Such deep crustal investigations contribute to the studies of the Earth as a whole, the studies of particular aspects of its evolution, and to a better understanding of the regional setting of mineral provinces.

In central Australia the Bureau of Mineral Resources (BMR) has carried out, since 1949, reconnaissance geological mapping and geophysical surveys over the Amadeus and Ngalia Basins and the metamorphic areas around them. Results of reconnaissance gravity surveys during the 1960s by Langron (1962), Lonsdale & Flavelle (1968), and Whitworth (1970) indicated that the major gravity features (Amadeus and Yuendumu Lows and Papunya Ridge) could not be explained by the near-surface structure in and around the Amadeus and Ngalia Basins, and warranted seismic surveys to investigate the structure deep in the crust and upper mantle. A deep structure seismic survey was first proposed by E.R. Smith in 1967 to be included in the BMR program, and in 1969 the Seismic Group (Brown, 1970) at the instigation of F.J. Moss carried out initial deep reflection studies in the Amadeus and Ngalia Basins during the course of the basin seismic surveys. At about this time, on the basis of geological studies carried out during the late 1960s, D.J. Forman also pointed out the need for a large-scale seismic survey to investigate the main geological and gravity features and their interrelations and in 1969, along with F.J. Moss, proposed seismic investigations along a line across the basin, basin margins, and the metamorphic areas in central Australia. The proposal has since been debated for its merits and demerits, particularly in discussions by F.J. Moss, A. Turpie, R.F. Thyer, S.P. Mathur, and D.J. Forman, and a revised version formulated by S.P. Mathur is presented here.

The proposed investigations, consisting of seismic and gravity traverses, are considered necessary to obtain subsurface information about the nature and structure of the crust and upper mantle in central Australia. This information is required to test the validity of deep structure models derived from surface geology and gravity data and to improve the overall interpretation.

Previous deep seismic sounding surveys by the BMR in sedimentary and metamorphic areas of eastern and southwestern Australia have produced reflections that yielded depths and velocities to the deep layers in the crust and upper mantle, and delineated regional structure consistent with the observed gravity field (Branson, Moss, & Taylor, 1972; Taylor, Moss & Branson, 1972; Mathur, 1973).

In the Gosses Bluff area of the Amadeus Basin, large shots produced fair-quality reflections from deep within the crust (Brown, 1970). Below, these are shown to be consistent with a probable structure derived from gravity data. It may be expected that techniques designed on the basis of previous experience would provide at least similar-quality reflections and results in the relatively undisturbed parts of the proposed traverses away from the main deformed zones. Furthermore, these techniques should be tried over the areas of main deformation to find out if the seismic data obtained in such areas can be meaningfully interpreted and tied to the information in the adjacent undisturbed areas.

Further detailed gravity measurements should be made to define the gravity field with an accuracy required for attempted interpretation in terms of the shape and size of near-surface rock units and the slope of the contacts, as well as the structure deeper in the crust and upper mantle.

A review of the existing geological and geophysical information in the area has been made to provide the necessary background for the proposed geophysical surveys. The area under review occupies about 600 000 km^2 between latitudes 21° and 28°S and longitudes 127°30' and 136°30'E (Plate 1), and covers the southern part of the Northern Territory and adjacent parts of Western Australia and south Australia.

The climate of central Australia is arid and generally pleasant for about half of the year; occasionally it is harsh and subject to violent rain and dust storms. The median annual rainfall is 100 to 250 mm, and the average monthly rainfall is greater in summer than in winter months. Temperatures range from -10°C on some winter nights from June to September to more than 38°C at times in the summer.

Vegetation is generally sparse but varies widely in type and density, depending on the nature and composition of the terrain. The terrain in the greater part of the area is generally flat at an elevation of about 600 m above sea level and covered with sand dunes and ridges. The only significant relief is formed by three east-west mountain ranges - the MacDonnell, Petermann, and Musgrave Ranges - which rise at places to about 1000 m above the general level of the plains.

Access to the survey area and travel in the plains is fair to good using all-wheel drive vehicles on dirt roads and tracks. Alice Springs, to the north of the MacDonnell Ranges, is the main distributing centre and principal town. It is the northern terminus of the railway from Adelaide and is also connected to Adelaide by an unsealed highway and to Darwin by a sealed highway.

In the survey area water is obtainable mainly from bores at the inhabited homesteads and Aboriginal missions, but is scarce elsewhere as lakes and streams are dry except during extremely wet seasons.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Geological studies of most parts of the region have been made and reported: of the Amadeus Basin by Froelich & Kreig (1969) and Wells, Forman, Ranford, & Cook (1970), of the Ngalia Basin by Cook & Scott (1967) and Wells, Evans, & Nicholas (1968), and of the metamorphic areas around the basins by Forman & Shaw (1973) and Shaw & Stewart (in press). The following are the main points from these studies.

Lithology

The main structural units of the area are shown in Plate 1 and the details of the geology, metamorphism, structure and Bouguer anomalies in the region are reproduced in Plate 2 (from Forman & Shaw, 1973). Most of the area consists of Precambrian metamorphic rocks overlain by Late Precambrian and Palaeozoic sedimentary rocks of the Amadeus and Ngalia Basins.

The general relations of the main rock units and the major orogenies are shown in Plate 3 (from Forman & Shaw, 1973). The Precambrian rocks are divided into three major groups.

Older Precambrian - consisting of moderately to highly metamorphosed gneiss and schist intruded by igneous rocks. They are the Arunta Complex in the north of the Amadeus Basin and the Musgrave-Mann Metamorphics and Olia Gneiss in the south of the basin. The metamorphic grade ranges from the lower greenschist to granulite facies.

Younger Precambrian - consisting of several sequences of metamorphosed sedimentary and volcanic rocks which are intruded by granites and unconformably overlie the Older Precambrian.

Adelaidean - consisting of up to 5000 m of sedimentary rocks lying conformably and unconformably beneath Palaeozoic sedimentary rocks in the Amadeus and Ngalia Basins. They are unmetamorphosed in most cases.

Three belts of high-grade granulite and amphibolite facies rocks have been identified (see Plate 2): one north of the Ngalia Basin, and one north and one south of the Amadeus Basin. These belts are flanked on one side by deformed zones, generally of greenschist facies, that are located at or near the margins of the Amadeus and Ngalia basins. Within the low-grade predominantly greenschist facies, belts of the Older Precambrian basement rocks are retrogressively metamorphosed, but the Younger Precambrian basement rocks and the Adelaidean sedimentary rocks are progressively metamorphosed.

In the Amadeus and Ngalia Basins, extensive tracts of up to 9000 m of Precambrian and Palaeozoic sedimentary rocks are present. The stratigraphic successions in the basins and their correlation are shown in Plate 4, which is reproduced from Wells, Moss, & Sabitay (1972). The sequence in the Ngalia Basin is very much thinner and incomplete compared with that in the Amadeus Basin.

Most of the area is overlain by a thin veneer of continental Tertiary and Quaternary sediments.

Orogenies

The region has been subjected to at least three major orogenies which caused reactivation of metamorphic rocks and resulted in complex structures and zones of deformation that are believed to pass through the entire crust into the upper mantle.

Precambrian Orogeny: It has been reported by Forman & Shaw (1973) that the Older Precambrian rocks in the Arunta Complex were strongly folded, metamorphosed, and intruded by granites during Arunta (Plate 3) and other older orogenies before the deposition of Younger Precambrian rocks, and that the minimum age for the high-grade metamorphism would be 1700 m.y. However, A.J. Stewart (BMR, pers. comm.) believes that this date is the age of the 'Unnamed Diastrophism' in Plate 3 as the rocks affected by the high-grade metamorphism include both the Older and Younger Precambrian in the Reynolds Range area.

The Musgrave-Mann Metamorphics have undergone at least two periods of high-grade metamorphism, the younger possibly taking place about 1400 m.y. ago, before the latest granites were intruded. The Olia Gneiss, which is abruptly separated from the Musgrave-Mann Metamorphics by the Woodroffe Thrust, is of much lower metamorphic grade, but isotopic dating suggests that the early folding and metamorphism of the gneiss took place at least 1170 m.y. ago, and probably earlier, at the same time as that of the Musgrave-Mann Metamorphics.

Petermann Ranges Orogeny: During this orogeny, 600 m.y. ago, an easterly-trending zone of the crust was deformed along the southern margin of the Amadeus Basin.

The zone dips to the south, its top is the Woodroffe Thrust, and its base is probably the base of the Petermann Ranges Nappe. Above the deformed zone the granulites of the Musgrave-Mann Metamorphics were uplifted and transported northwards along the Woodroffe Thrust. The Petermann Ranges Nappe, involving the Olia Gneiss and Adelaidean cover rocks, developed near the decollement surface within the deformed zone. All the rocks within the zone were metamorphosed. The Olia Gneiss was deformed and retrogressively metamorphosed within and beneath the zone under the same conditions. The intensity of metamorphism diminishes towards the Amadeus Basin, and only lower greenschist facies rocks occur near the southern margin of the Basin. As the Petermann Ranges Nappe developed, the more competent Adelaidean sedimentary rocks were detached from the underlying incompetent beds and slid northwards on a decollement surface within the Bitter Springs Formation. This folding is preserved in the southwestern Amadeus Basin unconformably beneath the Cambrian sedimentary rocks.

Alice Springs Orogeny: The Arunta Block was folded, thrust, and retrograded in restricted zones along the northern margins of the Amadeus and Ngalia Basins, and the adjacent sedimentary rocks in the basins were folded during the Alice Springs Orogeny in the Carboniferous. Deformation during this orogeny was of similar type to that during the Petermann Ranges Orogeny, but two zones were deformed in the Alice Springs Orogeny and in each the displacements were smaller and southerly and the metamorphism was of lower grade. These zones dip northwards and are also believed to pass through the entire crust. The more prominent zone lies along the northern margin of the Amadeus Basin and includes the Ormiston and Arltunga Nappe Complexes. The southern margin of the deformed retrograded zone coincides approximately with the northern margin of the Amadeus Basin which is a large monocline. To the north the zone is bounded by high-grade, typically granulite facies metamorphic rocks. Within the zone the Arunta Complex is retrograded, at least partly, and in the Nappes the cover of Heavitree Quartzite and Bitter Springs Formation is progressively metamorphosed.

Although the zone of retrograde metamorphism can be traced through the Arunta Complex, thrusts at the base of the Arltunga Nappe Complex cannot be traced very far or connected to those at the base of Ormiston Nappe Complex. Thrust contacts with the overlying granulites are not defined and the partly to completely retrograded core rocks of the upper nappe north of the Arltunga Nappe Complex are suggested to pass northwards into the high-grade rocks without major structural discontinuity.

The deformed zone, north of the Ngalia Basin, is less clearly defined. Its presence is inferred from thrusting along the northern margin of the basin, the presence of granulites to the north, a few greenschist facies rock specimens collected from within it, and a Bouguer anomaly low adjacent to it.

The age of the Alice Springs Orogeny has been deduced as Carboniferous by dating the folding in the basins, and by isotopic dating of metamorphic minerals formed during the orogeny.

Regional Structure

Regional anticlinoria separate the basins which are downwarped areas between them.

Nappe structures, involving both basement rocks and Adelaidean cover sedimentary rocks, occur within the low-grade metamorphic rocks in the southwestern, northern, and northeastern margins of the Amadeus Basin. All the nappes front towards the basin. The largest, the Petermann Ranges Nappe on the southwestern margin, extends for at least 300 km in an easterly direction, and has moved about 50 km northwards, by overthrusting and overturning. The nappes in the northern and northeastern margin of the basin are smaller and have moved southwards for about 13 to 24 km in a similar manner. Two nappes are piled one on the other in the Arltunga and Ormiston Nappe Complexes.

The sedimentary rocks in the Amadeus Basin are strongly folded and this deformation is of the Jura or Appalachian type. There are two major unconformities in the sedimentary sequence (Plate 3). A folded unconformity between Adelaidean and Cambrian sedimentary rocks implies one period of folding late in the Adelaidean, about 600 m.y. ago. The second unconformity between folded sedimentary rocks of Devonian to ?Carboniferous age and flat-lying Permian and Mesozoic sedimentary rocks is dated as Carboniferous.

The Adelaidean or early Cambrian folds in the south of the Amadeus Basin are poorly exposed and probably formed over a decollement within the Bitter Springs Formation during their northwards tectonic transport while the Petermann Range Nappe developed. In the northern part of the basin, the Carboniferous folds are well exposed. Numerous folds of great regularity and length can be seen. Many folds have a core of isoclinally-folded Bitter Springs Formation and some a core of highly sheared, brecciated gypsum and blocks of Carbonate rocks. The folding of the sedimentary rocks above the Bitter Springs Formation does not extend downwards to the Heavitree Quartzite or basement rocks.

There are two surfaces of decollement or detachment in the northeastern part of the Amadeus Basin, one in the Bitter Springs Formation and the other in the Lower Cambrian unit (Chandler Limestone). The sedimentary strata have been folded over both surfaces and the thrust surface connecting the lower and upper decollement is itself folded and imbricated. The folds over the lower decollement surface have a larger (3000 m) amplitude than those over the upper surface (500 - 1000 m). Two periods of folding affected the sedimentary rocks of the Ngalia Basin. A folded angular unconformity near the base of the Cambrian sedimentary rocks is correlated with the older, Adelaidean or early Cambrian, unconformity within the Amadeus Basin. Gentle folds of Carboniferous age in the Devonian to Carboniferous sediments of the Ngalia Basin are related to overthrusting of crystalline basement rocks onto the sedimentary cover along the northern margin of the basin.

Faults occur within the anticlinoria of basement rocks. A thrust of continental proportions, the Woodroffe Thrust, trends easterly near the Northern Territory border south of the Amadeus Basin. It has a gentle southerly dip, which in some areas is nearly flat. Beneath the thrust is a zone of more plastic deformation exemplified by the thrusting and recumbent folding in the Petermann Ranges Nappe to the north. South of the Woodroffe Thrust, other major faults can be seen, one of which is probably older and the other of the same age or younger than the Woodroffe Thrust. A thrust zone occurs north of the Amadeus Basin and includes the Ormiston and Arltunga Nappe Complexes. A third thrust or thrust zone occurs to the north of the Ngalia Basin but its easterly or westerly extensions are uncertain. South of this zone, thrusting has forced crystalline basement rocks over and onto the sedimentary cover along the northern margin of the Ngalia Basin.

PREVIOUS GEOPHYSICAL INVESTIGATIONS

The areas covered by previous geophysical surveys are outlined in Plate 1. All of the area under review has been covered by regional gravity surveys. Aeromagnetic and seismic surveys have been confined to the Ngalia and Amadeus Basin areas and their margins. Summaries of geologic and geophysical studies of the Ngalia and Amadeus Basins have been made by Wells, Moss, & Sabitay (1972) and Froelich & Krieg (1969), respectively.

Aeromagnetic Studies

The results of aeromagnetic surveys have been reported by Carter (1960), Hartman (1963a) and Wells et al. (1972) for the Ngalia Basin area, by Hartman (1963b) and

Young & Shelley (1966) for the Amadeus Basin area, and by Tipper (1969) for the Strangways Range area northeast of Alice Springs. The depths to the magnetic basement in the basin areas are shown in Plate 5. The interpretation of the magnetic data has been quantitative in the basin areas, but only qualitative where the basement rocks crop out at the edge of the basins. The probable error in depths is about 10 per cent.

Ngalia Basin Area: Although the magnetic field on both sides of the northern boundary of the basin shows easterly trends parallel to the basin margin, the margin is well defined by a change in the character of the field. The field is disturbed with several short-wavelength features over the Arunta Complex on the northern side, but is smooth and uniform over the basin where it increases at a rate equal to about twice the normal regional gradient i.e. at about 6 gammas per km. The increase in gradient over the sediments is probably caused by an increase in the magnetic content of the basement rocks. In the Arunta Complex area, a zone of small anomalous features shows a southeasterly trend which parallels the Reynolds Range and coincides with a zone of amphibolite facies rocks.

The basement depth contours in Plate 5 indicate that the Ngalia Basin consists of two sub-basins containing sediments 5300 to 6000 m thick separated by a southerly trending linear ridge. These sub-basins are asymmetrical, with their deepest parts lying closest to the northern margin.

The area of intense local anomalies along the southern margin may be caused by block-faulting or igneous plugs. The characteristics of other larger anomalies within the basin suggest combination of faulting, basement highs and/or susceptibility changes.

Amadeus Basin Area: An abrupt change in the character of the magnetic field also defines the northern (magnetic) boundary of the Amadeus Basin which is in good agreement with that geologically mapped. The southern boundary, however, is not so well defined owing to the presence of minor magnetic anomalies within the basin probably caused by dyke swarms and/or volcanic rocks. It is generally to the north of the basement exposures.

North of the basin, the magnetic field over the rocks of Arunta Complex show predominantly an easterly strike parallel to the geologic trends. Increase in the magnetic disturbance northwards from the basin margin reflects an increase in the basic content and hence the density of the metamorphic rocks. Southwest of the basin, the magnetic anomalies show generally ill defined northerly trends which may result from interbedded lavas or faulting.

Based on their character and amplitude, three anomaly zones, A, B, and C have been identified in both the northern and southern areas of metamorphic basement outcrops. These zones are generally parallel to the geological trends. In the north, zones of low anomaly, A, appear to correlate with the Ormiston and Arltunga Nappe Complexes and their character is interpreted as evidence for acidic basement rocks in the cores of nappes. Zone B, of medium amplitude anomaly, has been correlated with outcrops of basalt, and zone C of high anomaly with ultrabasic bodies or zones of mineralization.

A low susceptibility contrast is indicated at the basin's northern margin. A much larger contrast is associated with the contact between Zones B and C in the outcrops to the north, indicating a much greater northerly increase in the magnetic mineral content and therefore rock density across this contact than at the boundary of the basin. In the south, Zone A corresponds to a region of lower Proterozoic sedimentation.

The magnetic basement underlying the basin has been interpreted to be of Arunta age on the basis of a major difference in the magnetic trend orientation within the basin as compared to the surrounding basement outcrop. The southerly trends in the basin are considered to be due to susceptibility contrasts between crystalline rocks and result from the effects of the Arunta Orogeny, whereas the easterly trends over the northern basement result from the Alice Springs Orogeny. The anomalies suggest that the magnetic basement underlying the basin represents plutonic bodies within or at the basement surface of the Arunta Complex. The surface and sub-surface structures in the basin area seem to have no appreciable magnetic expression, implying that they were formed without significant deformation of the basement, as also suggested by the presence of decollement surfaces within the sediments near the basement.

The depth contours in Plate 5 show that the deepest part of the basin lies along the northern border and that the maximum depth to the magnetic basement is 38 000 ft (about 11 500 m) below sea level in the areas south of the western MacDonnell Ranges. Near the southwest margin of the basin, the depths reflect the presence of a deep magnetic basement, which may be Archaean, underlying the exposed or near-surface Lower Proterozoic rocks.

Gravity Studies

The results of regional gravity surveys by the BMR on an 11-km grid in the area are reproduced here as a Bouger anomaly map in Plate 6.

The most striking feature of the map is the series of slightly arcuate easterly elongate gravity lows separated by similar trending highs. The lows reach a minimum of about -140 mGal in the Amadeus Basin, whereas the highs reach a maximum of about +40 mGal in the Arunta Block north of the Amadeus Basin. The highs, viz., the Papunya Regional Gravity Ridge, Olga Regional Gravity Ridge, and Blackstone Regional Gravity Ridge occur over areas of metamorphic rocks of Arunta and Musgrave Blocks. But the lows, viz., Yuendumu, Amadeus and Ayers Rock Regional Gravity Lows, on the other hand, occur slightly offset from the exposed basin areas, either to the north or to the south. The minima of the Yuendumu and Amadeus Lows centre along or close to the northern margin of the Ngalia and Amadeus Basins respectively, whereas that of the Ayers Rock Low lies along the southern margin of the Amadeus Basin.

The main characteristics of the gravity features and their possible causes have been studied by Marshall & Narain (1954), Langron (1962), Flavelle (1965), Lonsdale & Flavelle (1968), Darby & Vale (1969), Whitworth (1970), and Wells et al. (1972).

Yuendumu Regional Gravity Low: The low is similar in shape to, but much greater in extent than, the Ngalia Basin. It is bounded on the north and south by steep gravity gradients that decrease gradually to the west.

The Ngalia Basin lies on the southern flank of the low and its northern boundary, a thrust-nappe zone, lies roughly along the axis of the low. The eastern lobe of the minima has been correlated with granitic outcrops north of the basin. Various hypotheses have been proposed to explain the low: overthrusting from the north of a thin basement sheet over a thick sedimentary section, lateral variation in the deepest sedimentary rocks, or large masses of lower-density acidic intrusions.

Papunya Regional Gravity Ridge: It is a sharp anomaly ridge situated between the Ngalia and Amadeus Basins. The maximum anomaly value along its axis is +40 mGal, whereas the minimum values to the north and south are -100 and -140 mGal. The elevation contrast between these extremes is 60-90 m. The maximum gravity gradient on the northern margin is about 3 mGal/km.

The axis of the ridge occurs over the metamorphic rocks of the Arunta Complex. An analysis of the anomaly pattern by Whitworth (1970) indicates that the source of the anomaly may be an uplifted block of denser crustal rocks between the two basin areas and the top of the source body may not be deeper than 13 km.

Amadeus Regional Gravity Low: The gravity depression covers a large area of the northern part of the Amadeus Basin. The minimum reaches a value of -140 mGal in the north-central part of the basin. The gradient on the northern flank of the feature is much steeper than that on the southern flank.

The axis of the gravity trough coincides with the thickest part of the sediments in the Amadeus Basin as indicated by magnetic basement depths in Plate 5. The gravity pattern over the major part of the basin is in general agreement with the magnetic basement configuration.

Olga Regional Gravity Ridge: It consists of two units which form a continuous broad and low easterly ridge south of the Amadeus Gravity Low. The maximum anomaly values on the ridge are about -60 mGal. Its western part, the Bloods Range Gravity Ridge, occurs over an outcrop of Upper Proterozoic Dean Quartzite that rests unconformably on Lower Proterozoic meta-sediments, granite, and thick basalt. Its eastern part, the Angas Downs Gravity Ridge, on the other hand, is located over southern part of the Amadeus Basin sediments. It is therefore possible that the gravity ridge reflects a sub-surface basement ridge of Lower Proterozoic rocks similar to those associated with the Bloods Range Gravity Ridge. The gentle gravity gradient between the Amadeus Low and the ridge would indicate a gradual southward thinning of the basin sediments.

Ayers Rock Regional Gravity Low: It is a broad low with minimum anomaly values of about -120 mGal along the southern margin of the Amadeus Basin. Granites of the Musgrave Ranges crop out immediately to the south of the negative culmination.

The cause of this anomaly feature has been suggested to be thick less-dense acidic igneous rocks and the likely presence of thick sediments of the basin in this area.

Blackstone Regional Gravity Ridge: This feature is centred over the major part of the Musgrave Block which separates the Amadeus and Officer Basin areas. The steep gradient on the north of the ridge coincides approximately with the Woodroffe Thrust zone, whereas that on the south follows the northern margin of the Officer Basin which is also considered to be a thrust zone by Milton & Parker (1973). The axial highs on these features roughly correspond to the granulite facies of metamorphic rocks in the Musgrave Block.

Arltunga Nappe Detailed Gravity Survey: A detailed gravity traverse at 1 km spacing across the Arltunga Nappe in the eastern part of the Arunta Complex, was made by the BMR in 1973 (Anfiloff, in prep.). The resulting Bouguer anomaly profile across the eastern end of the Papunya Regional

Gravity Ridge is essentially similar to that obtained from the reconnaissance survey. The maximum difference between the measured values and those interpolated from the regional survey is 10 mGal. The smoothness of the detailed gravity profile implies that density variations are either deep-seated or near-surface but gradual. A wide variety of rocks from acid to basic and several faults have been mapped in the area, and no gradual surface density changes are in evidence. It follows that the long wavelength variations in the profile are likely to arise from horizontal density changes deep in the crust or upper mantle.

Seismic Studies

Several seismic surveys have been made by BMR as well as by private companies to investigate the structure and thickness of the sediments in the Amadeus and Ngalia Basins. In general, the seismic reflection data recorded in undisturbed areas of the basins are of good quality and the reflection character is remarkably consistent down to the level of the Bitter Springs Formation. However, usually poor data were recorded over outcrops and the disturbed areas. The reflection method has been suitable only for investigating sections above the high-velocity refractors within the sediments and not the crystalline basement.

Amadeus Basin: The results of seismic surveys along a southerly line close to the railroad across the eastern part of the basin have been reported by Moss (1962, 1966). They indicate that the hinge line of the southeastern margin lies along the Black Hill Range, and that the sediments are about 3000 m thick in the area of Mount Charlotte and attain a thickness of about 6000 m in synclinal areas both north and south of Ooraminna Anticline. The seismic evidence also suggests that the uplift at Deep Well and the Ooraminna Anticline are the results of movement of plastic material in the sedimentary section, most likely the Bitter Springs Formation, and not the result of deep-seated crustal movement. The penetration of the refraction method was limited to a refractor of high velocity (about 6100 m/s) tentatively identified as the Jay Creek Limestone (Cambrian).

A refraction survey in connection with the search for water in the Alice Springs Farm Area (Moss, 1963) located a refractor of 3170 m/s velocity at a depth of 300-450 m, which is considered to be the Palaeozoic basement surface on which the Mesozoic sediments were deposited.

The seismic survey in the Palm Valley-Hermannsburg Area (Turpie and Moss, 1963) showed that the Palm Valley anticlinal structure existed at depth, that the thickness of the Pertnjara-Mereenie Complex (Lower Carboniferous/Upper

Silurian) was about 1200 m on a flank of the anticline, and that the thickness of the sediments in the Missionary Plain exceeded 7600 m. The refraction results were limited to a shallow high-velocity (5430 m/s) refractor.

The results from a regional seismic traverse by BMR (Moss, 1964) across the Missionary Plain, from the MacDonnell Ranges in the north through Gosses Bluff to the Gardiner Range in the south, indicated that the maximum thickness of sediments under the plain was at least 10 000 m, that Gosses Bluff was probably a diapiric structure of the salt-dome type and that the Gardiner Range Fault was an overthrust from the south. Subsequent detailed studies of Gosses Bluff (Brown, 1971; 1973) aimed at testing the hypothesis that it was an astrobleme, however, discounted its diapiric origin and it was concluded that it is a structure formed by the impact of an extra-terrestrial body, an astrobleme, during the Cretaceous.

Seismic surveys by Magellan Petroleum (Geophysical Associates, 1965; 1967) have provided extensive reconnaissance coverage which has been integrated with surface geology (Froelich & Krieg, 1969) along most of the northern part of the Amadeus Basin. The most important information from these surveys is the direct evidence of 'thin skin' deformation owing to plastic flowage, diapirism, and thrust-faults and the absence of consistent reflections deeper than the Bitter Springs Formation. Velocity surveys indicate little consistency for the Ordovician and overlying section where large variations and inversions in velocity are present. The velocities in the Cambrian are more consistent, averaging about 5330 m/s, and are in general agreement with the values (5490-6100 m/s) measured by BMR. The seismic sections show that the thickest sedimentary section lies in the north-central Missionary Plain south of the MacDonnell Ranges, and that the section thins and shallows towards east, south, and west away from this trough.

In summary, the seismic results indicate that the Missionary Plain is a broad, east-trending synclinorium plunging into a trough south of the central MacDonnell Ranges which form the steep homoclinal north flank of the trough. The south flank of the Missionary Plain synclinorium either dips gently from the flanks of bordering anticlines, as at the James Ranges and Palm Valley structure, or is abruptly dislocated as along the Gardiner Fault. The seismic data provide little information about the section below the Bitter Springs Formation or the crystalline basement.

During the seismic survey at Gosses Bluff in 1969, about 4 km of deep crustal reflection coverage was also obtained north of the Bluff (Plate 7), using a shot pattern of three 30-m holes at 23 m spacing, 3 x 158 kg of Geophex and a geophone pattern of 32 per trace in 2 lines, 6.1 m apart in line (Brown 1970). Several deep events were recorded among which two with large amplitudes at about 8.5 and 12.0 seconds stand out. A cross traverse and two end shots of an expanded spread, with a maximum offset of about 9 km, recorded similar events. The results, shown in Plate 7, though incomplete, strongly suggest that the two events are primary deep crustal reflections. The section on the right also illustrates the consistent good quality of reflections generally recorded in undisturbed areas within the basin. Using average velocities of 5.7 and 6.0 km/s to reflections at similar times obtained at Mildura (Branson, Moss, & Taylor, 1972), the deep events yield depths of 24 and 36 km for the intermediate crustal and Mohorovicic discontinuities.

Ngalia Basin: Extensive seismic coverage has been obtained in the Ngalia Basin by Pacific American Oil Co. (Hudson & Campbell, 1965), by BMR (Jones, 1969; Tucker, 1969; Jones & Moss, in prep.) and by Magellan Petroleum Pty Ltd. The results of these surveys have been summarized by Wells, Moss, & Sabitay (1972).

The results confirmed the magnetic conclusions that the basin was asymmetric with its axis located near the Proterozoic outcrops delineating the northern margin and that it was filled with thick (about 4500-6000 m) sediments and divided into eastern and western lobes. They also provided substantial knowledge about the structure of the basin, viz., unconformities, anticlines, and numerous faults. An example of the seismic section recorded by BMR illustrating the generally good quality of the reflection data recorded within the basin and the major thrusting at its northern margin is shown in Plate 8.

The seismic data indicate that the sedimentary pile is about 4900 m thick in the western part of the basin where the thickness of the Palaeozoic sediments is suggested to be greater than that in the eastern lobe.

During the Ngalia Basin Seismic Survey in 1969, two shots were also recorded for deep crustal reflections on spreads laid mutually at right angles (Brown, 1970). The shots used a rectangular pattern of 37-m deep holes with 15 m spacing and 6 x 129 kg and 15 x 109 kg of Geophex. The geophone pattern consisted of 32 per trace in 2 lines with 6.1 m spacing in line. Several late events were recorded and the strong one occurring on both records at a time of about 12.7 s is considered to be a primary reflection from the Moho. Assuming an average velocity of 6.0 km/s, the depth to this boundary is calculated to be about 38 km.

SUMMARY AND REVIEW OF RESULTS

The main geological features in central Australia are the series of regional anticlinoria of Precambrian rocks and the intervening intracratonic depressions filled with Proterozoic and Phanerozoic sediments. The features show a predominant easterly trend, indicating that the region has been subjected to forces in a north-south direction during the periods of tectonism.

In the largest depression, the Amadeus Basin, about 9 km of Precambrian and Palaeozoic sediments are preserved whereas in the small Ngalia Basin the sequence is much thinner, about 6 km, and incomplete. The southern and northern margins of the Amadeus Basin and the northern margin of the Ngalia Basin are marked by thrust and nappe structures involving large movements of overthrust metamorphic rocks and strong folding in the adjacent sediments.

In the Precambrian metamorphics, grades ranging from the low greenschist to high granulite mineral facies of mafic rocks have been mapped, and three zones of highly deformed retrograded crystalline rocks have been delineated. Each zone is flanked on one side by folded thrusted sedimentary rocks of the basins and on the other by granulite and amphibolite facies rocks of the overthrusted, overlapped nappe complexes. The zone along the southwestern margin of the Amadeus Basin was deformed during the Petermann Ranges Orogeny about 600 m.y. ago, whereas the zones along the northern margins of the Amadeus and Ngalia Basins were deformed during the Alice Springs Orogeny in the Carboniferous.

The diagrammatical cross-section by Forman & Shaw (1973), shown in Plate 2, summarizes the possible structure of the crust and upper mantle along a northeast line AB across the major features of central Australia. The sub-surface structure shown is speculative and based primarily on the study of geology and structure mapped on the surface, and only qualitatively on the Bouguer anomalies in the area. The deformed zones are shown as moderately to gently dipping and on the basis of associated gravity gradients are believed to pass through the crust into the mantle beneath. The crust and upper mantle are shown to have been upthrust along each deformed zone bringing granulite facies rocks to the surface.

The geophysical investigations have so far provided much information about the nature and structure of the sedimentary basins, but only a very general picture of the deeper structure in the crust and upper mantle and of the relation between the various structural units in central Australia. The magnetic and gravity data indicate that in general the magnetic and crystalline basements in the Amadeus Basin are identical, that both the Amadeus and Ngalia Basins are asymmetric with the thickest parts closer to their northern margins, and that the higher-grade facies belts in the Arunta and Musgrave-Mann Complexes have greater magnetic content and density than the lower facies belts. The shape of the basins and the thickness of their sediments estimated from the magnetic and gravity data have been confirmed by seismic data where available.

Although there is a general correspondence in shape and location between the gravity lows (Yuendumu and Amadeus) and the Ngalia and Amadeus Basins, the extent and magnitude of the lows are far greater than that produced by the known thickness of sediments. Forman (in Wells et al., 1970) has shown that the density contrast between the sedimentary rocks of the Amadeus Basin and the basement metamorphic rocks in the Arunta Block, assuming their densities to be 2.5 and 2.7 g/cm^3 respectively, would produce an anomaly difference of only 50 mGal compared to the observed difference of 160 mGal. He has also shown that the observed anomaly profile across the northern margin of the basin can be interpreted in terms of folding of a two-layer crust with densities of 2.7 and 3.0 overlying a mantle of density 3.3. The distribution of granulite facies rocks in the Arunta Complex, however, suggests that these lower crustal rocks may have been brought to the surface by major thrusts along Ormiston and Arltunga Nappes at the northern margin of the basin. Forman & Shaw (1973) therefore based their subsurface structure model, illustrated in the section along AB in Plate 2, on a hypothesis of folding and faulting that involved the entire crust and upper mantle.

Seismic refraction profiling has been successful in investigating the sedimentary section above high-velocity refractors in the basin areas but not in mapping the crystalline basement below because of poor energy penetration through these refractors. Reflection surveys have shown that, using relatively simple techniques, it is possible to record good-quality reflections from within the deep crust as well as the sedimentary layers in the undisturbed areas of the Amadeus and Ngalia Basins and even map thrust planes in areas such as the northwestern margin of the Ngalia Basin where the thrust zone is not complex.

North of Gosses Bluff in the Missionary Plain, the depths to the basement of the Amadeus Basin, the intermediate layer in the crust, and the Moho have been estimated from the reflection times to be about 10, 24, and 36 km respectively using average velocities of 5.1, 5.7, and

6.0 km/s to these boundaries. The thickness of the sedimentary rocks in the northwestern part of the Ngalia Basin is estimated to be about 4.5 km for the section down to 2.0 seconds.

Interpretation of Gravity Anomalies

If the gravity anomalies are calculated for the crustal model along line AB in Plate 2, using the densities of 2.5 g/cm^3 for the basin sediments, 2.7 for the upper crustal layer, 3.0 for the lower crustal layer, and 3.3 for the upper mantle - values suggested by Forman (in Wells, et al., 1970) - the anomalies computed for the Arunta and Musgrave-Mann Block areas are found to be about 200-300 mGal higher than those observed. Since the above densities are close to those used in such studies, this indicates that the folding and thrusting under these blocks is probably not as severe as shown in this model section.

To achieve a closer two-dimensional approximation in the interpretation, a more northerly profile (along CD in Plate 6), intersecting the major gravity features at right angles and passing through their maxima and minima, was chosen for analysis. Along this profile, shown in Plate 9, the amplitudes and wavelengths of the features, lows and highs, suggest that the major part of the anomalies is of deep crustal origin. In the model section shown in the lower part of the figure, the basin shapes are based on other geophysical information (Milton & Parker, 1973; Young & Shelley, 1966; Jones & Moss, in prep.). The depths to the crustal layers have been derived from the gravity anomaly remaining after subtracting the effect of the basin rocks from the observed Bouguer values. In this derivation it was assumed that most of the remaining anomaly was of deep crustal origin, the thickness of the second layer was constant, the standard crust parameters found suitable for a similar analysis of the crustal structure in southwestern Australia (Mathur, 1973) were relevant, and the upper mantle density was normal (3.2 g/cm^3) in this area. The match between the computed and the observed anomalies is good everywhere except in the gravity-high areas of Musgrave and Arunta Blocks. In these areas, the match would be better if the gravity effects of the basic granulites, which have been mapped at the surface, could be included in the calculations. However, no specific shapes and densities of such rock bodies are proposed in the model, nor their gravity effects computed, because of inadequate knowledge about their subsurface distribution. The derived depths to the second layer and the mantle under the northern part of the Amadeus Basin are within 2 km of those estimated from seismic reflection data (Brown, 1970).

The crustal structure model shown in Plate 9 is a simple one which is consistent with the major features of the available geological and geophysical information in central Australia. It is also consistent with the observations of Evans & Crompton (1946), Woollard (1948), and Glennie (1951) during their studies of different areas of the Earth that the primary control of the Bouguer anomalies is the thickness of the crust, and with the observation of Skeels (1940) and Woollard (1949) that the large negative anomalies associated with the major basins are mainly the result of local downwarp of the crust as a whole.

A similar interpretation was proposed earlier by Marshall & Narain (1954) along a north-south reconnaissance traverse in the area, between Tennant Creek and Oodnadatta, in terms of crustal deformation and fracture owing to compression in the crust. These authors also showed from theoretical considerations that such a crustal folding with wavelengths of 200 to 400 km and fractures about 85 km apart (cf. 100 km in the Arunta Complex) was possible and that such a localized isostatic disturbance could be maintained by the strength of the crust possibly over long geological periods.

The lack of uniqueness inherent in the gravity interpretation and the poor state of our knowledge of the lithological and density variations with depth make it possible to propose other sub-surface models to explain the observed anomalies at the surface. One such model, incorporating in some detail the lithology and structure observed at the surface, speculating on the shapes, sizes, and densities of rock units at depth and assuming that most of the anomalies are of origin within only the upper 20 km of the crust, has been proposed by Anfiloff & Shaw (1974) as shown in Plate 10.

Although the near-surface lithology, i.e. the sedimarary rocks in the Amadeus and Ngalia Basins and the acidic and basic rock units in the metamorphic areas, does contribute to the gravity anomalies, its contribution is considered to be relatively small, as discussed above. It may be argued in general terms that the results of the results of the detailed gravity survey in the general terms that the results of the detailed gravity survey in the Arltunga Nappe (Anfiloff, in prep - see p.) support this hypothesis, but the considerable differences in the geology between the two areas make the argument rather tenuous.

However, the model in Plate 9 is considered more likely to be representative of the major features of crustal structure in central Australia, and the proposed regional seismic surveys, although general, have been planned in particular to test the validity of this model.

OBJECTIVES AND PROGRAM

Objectives

The broad objective of a deep structure project in central Australia is to investigate the composition and structure of the crust and upper mantle and the relation of such deep-seated structure to surface features such as basins, basin margins, nappes, and faults. The knowledge thus gained would aid in the understanding of the development of the major features and of the mineralized zones within them.

Specifically, the objective of a seismic reflection and refraction survey will be to determine the thickness and structure of the layers in the crust and upper mantle along the northern part of the line AB in Plate 2, which crosses all major structural features approximately at right angles.

The objective of a detailed gravity survey will be to define the gravity field in the area with an accuracy greater than that of the reconnaissance surveys. Such definition is necessary in order to resolve the field into its major components, the amplitudes and wavelengths of which would indicate the size, shape, and depth of the causative mass anomalies.

A combined analysis of the results will then lead to a deep structure model consistent with both the seismic and gravity data and minimize ambiguity in the interpretation.

Program

A program is presented for a seismic survey which would provide the necessary information on the velocities and structure of the crust and upper mantle at the northern margin of the Amadeus Basin.

The recording plan is based on the experience gained during the deep sounding tests in eastern Australia (Branson, Moss, & Taylor, 1972; Taylor, Moss, & Branson, 1972) and the Geotraverse survey in southwestern Australia (Mathur, Branson, & Moss, in prep.).

It is proposed that -

A seismic survey comprising simultaneous recording of reflection and refraction data from the same shots will be made in the northern part of the traverse AB (Plate 6). The survey will consist of three reflection probes in (1) the Gosses Bluff/ Hermannsburg area in the Amadeus Basin, (2) the Mount Chapple area in the Arunta Complex and (3) the Mount Reeling area (south of Tea Tree) north of the Ngalia Basin and that each probe will be about 28 km long and consist of continuous reflection and simultaneous expanded spread recording on 2160-0-2160 m spreads as shown in Plate 11. Refraction data from the same shots will be recorded for about 400 km along the strike of the structural features as well as across them with one set of 10 remote recorders, at 5-km spacing moving towards east (or west) and the other set towards north (or south). Two additional shots, one at each end of the easterly traverse, will be recorded at 10-km intervals for reversing the refraction profiles. The refraction layout at each probe is shown in Plate 12.

The overall seismic coverage proposed is shown in Plate 6. The proposed reflection work is expected to provide reliable information on the velocities and depths to the discontinuities in the crust and upper mantle in the three probe areas which are not affected beydeformation. The refraction data long the east-west profiles should provide additional independent information on the velocities and depths and their variation along the strike of the main features within zones which are also undisturbed by the complex deformation along the margins of the basins. The information from the undisturbed areas would then be used in the relatively difficult interpretation of the refraction data along the north-south profiles in order to determine the nature of variation and the correlation of the various crustal layers across the deformed zones. Detailed gravity surveys along the seismic traverses, particularly across the deformed zones and the Arunta Complex area, may help in determining the nature and slope of contacts between different rock types.

A maximum offset of about 28 km in expanded spread recording is suggested because it would provide large enough (about 800 ms) moveout for a t^2-x^2 velocity analysis of the reflections from the expected Moho depths in the area. The refraction profiles along the strike are necessary as they should be less complicated by the structure in the thrust zone and should be easier to interpret. The difficulties in the interpretation of north-south profiles across the structure are illustrated in Plate 13 which shows the theoretical complex travel paths and the computed time-distance curves for a likely crustal model based on the structure shown in Plate 9. Here the inverse problem of deriving the structure from these refraction data alone appears to be almost impossible as there is no way of distinguishing between the arrivals of waves following different paths.

The length of refraction profiles has been chosen on the basis of time-distance curves (Plates 14 and 15) computed for the simple postulated structural models in the Amadeus Basin and the Arunta Block such that the arrivals from the intermediate boundary and the Moho would be separated enough to be picked without much ambiguity.

The details of the operational requirements for each probe are given in Table 1. The total duration of the survey would be controlled by the drilling requirements and is estimated to be a maximum of 5 months. The time interval between shots would be large enough for a normal-size line crew to move the recording spreads and remote recorders into position for each shot.

It is proposed that the operations start with the probe in Gosses Bluff/Hermannsburg area of the Amadeus Basin where the earlier surveys have already shown that good reflection data is obtainable from within the sedimentary section as well as from deep in the crust and upper mantle. It may be necessary to experiment with different recording parameters to arrive at optimum techniques for each probe area and to continually assess the results for any modification of the program as the survey progresses northwards into the unknown area.

It is also proposed to measure gravity at 1-km intervals along about 2000 km of seismic traverses. The gravity measurements will be made using mostly ground transport except in the MacDonnell Ranges area where about 25 hours of helicopter support will be required because of the difficult terrain. The elevation of the stations will be determined by optical methods. The accuracy of the gravity values so obtained is expected to be better than 1 mGal.

The staff, equipment, and vehicle requirements for the survey are listed in Appendixes I and II. Most of these requirements are normal for a BMR seismic and gravity combined party working on sedimentary basin surveys. The additional recording equipment necessary is already available in BMR. The seismic and gravity operations in the field are designed to make maximum use of the personnel, vehicles, and equipment.

In summary, the seismic and detailed gravity survey herein proposed would require a normal-size party to operate at normal cost for up to 5 months and provide a valuable contribution to the investigation of the structure of the crust and upper mantle in the northern part of the Amadeus Basin and the adjacent metamorphic areas to the north. Depending on the success of the proposed survey, further surveys may be planned to investigate the structure in the other complex areas to the south.

REFERENCES

ANFILOFF, W., in prep. - Arltunga Nappe detailed gravity survey, N.T., 1973. Bur. Miner. Resour. Aust. Rec. (unpubl.).

ANFILOFF, W., & SHAW, R.D., 1974 - The gravity effects of three large uplifted granulite blocks in separate Australian shield areas. Bur. Miner. Resour. Aust. Rec. 1974/4 (unpubl.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD., 1965 - Aeromagnetic survey, Pollock Hills area PE 152 H and PE 153 H, Western Australia. Part I, operational report - Aeroservice Ltd., Part II, Interpretation - Geophysical Associates Pty Ltd. Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1965/4619 (unpubl.).

BRANSON, J.C., MOSS, F.J., & TAYLOR, F.J., 1972 - Deep crustal reflection seismic test survey, Mildura, Victoria and Broken Hill, N.S.W. 1968. Bur. Miner. Resour. Aust. Rec. 1972/127 (unpubl.).

BROWN, A.R., 1970 - Deep crustal reflection studies, Amadeus and Ngalia Basins, N.T., 1969. Bur. Miner. Resour. Aust. Rec. 1970/94 (unpubl.).

BROWN, A.R., 1971 - Gosses Bluff seismic survey, Northern Territory, 1969. Bur. Miner. Resour. Aust. Rec. 1971/4 (unpubl.).

BROWN, A.R., 1973 - A detailed seismic study of Gosses Bluff, Northern Territory. Bur. Miner. Resour. Aust. Rep. 163.

CARTER, R.M., 1960 - Mt Hardy region airborne magnetic and radiometric survey, N.T., 1958. Bur. Miner. Resour. Aust. Rec. 1960/117 (unpubl.).

COOK, P.J., & SCOTT, I.F., 1967 - Reconnaissance geology and petrography of the Ngalia Basin, N.T. Bur. Miner. Resour. Aust. Rep. 125.

DARBY, F., & VALE, K.R., 1969 - Progress of the reconnaissance gravity survey of Australia. Bur. Miner. Resour. Aust. Rec. 1969/110 (unpubl.).

EVANS, P., & CROMPTON, W., 1946 - Geological factors in gravity interpretation illustrated by evidence from India and Burma. Quart. J. geol. Soc., 102, 211-249.

FLAVELLE, A.J., 1965 - Helicopter survey by contract, N.T. and QLD., 1965. Part 1. Bur. Miner. Resour. Aust. Rec. 1965/212 (unpubl.).

FORMAN, D.J., & SHAW, P.D., 1973 - Deformation of the crust and mantle in central Australia. Bur. Miner. Resour. Aust. Bull. 144.

FROELICH, A.J., & KRIEG, E.A., 1969 - Geophysical-geologic study of northern Amadeus Trough, Australia. Bull. Amer. Ass. petrol. Geol., 53(9), 1978-2004.

GEOPHYSICAL ASSOCIATES PTY LTD, 1965 - Missionary Plain seismic and gravity survey, Oil Permits 43 and 56, Northern Territory. Rep. for Magellan Petroleum (N.T.) Pty Ltd, Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1965/11013 (unpubl.).

GEOPHYSICAL ASSOCIATES PTY LTD, 1967 - Mount Rennie-Ooraminna seismic and gravity survey 1966, Oil Permits 43 and 56, N.T. Rep. for Magellan Petroleum (N.T.) Pty Ltd, Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1966/11074 (unpubl.).

GLENNIE, E.A., 1951 - The Cuddapah Basin in India and crustal warpings. Roy. Astr. Soc. Mon. Notices, geophys. Suppl. 6, 168-176.

HARTMAN, R.R., 1963a - Interpretation report on airborne magnetometer survey over portion of Oil Permit No. 81, Ngalia Basin, N.T. Rep. by Aeroservice Ltd for Pacific American Oil Co., Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1963/1702 (unpubl.).

HARTMAN, R.R., 1963b - Interpretation report of airborne magnetometer survey over Oil Permit No. 72 and portion of Oil Permit No. 78 (Amadeus Trough, N.T.). Rep. by Aeroservice Ltd for Exoil (N.S.W.) Pty Ltd., Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1963/1701 (unpubl.).

HUDSON, H.B., & CAMPBELL, J.A.B., 1965 - Napperby seismic survey, Oil Permit 81, Northern Territory of Australia. Report by Geophysical Associates Pty Ltd for Pacific American Oil Co., Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Rep. 1964/4543 (unpubl.).

JONES, P., 1969 - Ngalia Basin seismic survey, Northern Territory, 1967. Bur. Miner. Resour. Aust. Rec. 1969/69 (unpubl.).

JONES, P., & MOSS, F.J., in prep. - Ngalia Basin seismic survey, Northern Territory, 1967-1969. Bur. Miner. Resour. Aust. Rec. (unpubl.).

LANGRON, W.J., 1962 - Amadeus Basin reconnaissance gravity survey using helicopters, Northern Territory, 1961. Bur. Miner. Resour. Aust. Rec. 1962/24 (unpubl.).

LONSDALE, G.F., & FLAVELLE, A.J., 1968 - Amadeus and south Canning Basins gravity survey, Northern Territory and Western Australia, 1962. Bur. Miner. Resour. Aust. Rep. 133.

MARSHALL, C.E., & NARAIN, H., - Regional gravity investigations in the eastern and central Commonwealth. Univ. Sydney, Dep. Geol. Geophys. Mem. 1954/2.

MATHUR, S.P., 1973 - Crustal structure in southwestern Australia from seismic and gravity data. Bur. Miner. Resour. Aust. Rec. 1973/63 (unpubl.).

MATHUR, S.P., BRANSON, J.C., & MOSS, F.J., in prep. - Geophysical investigations along the Goetraverse, Western Australia. Bur. Miner. Resour. Aust. Rep.

MILTON, B.E., & PARKER, A.J., 1973 - An interpretation of geophysical observations on the northern margin of the eastern Officer Basin. Quart. geol. Notes, Geol. Surv. S. Aust., 46, 10-14.

MOSS, F.J., 1962 - Amadeus Basin (southern margin) seismic survey, Northern Territory, 1961. Bur. Miner. Resour. Aust. Rec. 1962/167 (unpubl.).

MOSS, F.J., 1963 - Alice Springs (Farm Area) seismic refraction survey, N.T., 1961. Bur. Miner. Resour. Aust. Rec. 1963/6 (unpubl.).

MOSS, F.J., 1964 - Gosses Bluff seismic survey, Amadeus Basin, Northern Territory, 1962. Bur. Miner. Resour. Aust. Rec. 1964/66 (unpubl.).

MOSS, F.J., 1966 - Ooraminna seismic survey, Amadeus Basin, Northern Territory, 1962. Bur. Miner. Resour. Aust. Rec. 1966/57 (unpubl.).

QUILTY, J.H., & MILSOM, J.S., 1964 - Simpson Desert aeromagnetic survey, Northern Territory, 1962. Bur. Miner. Resour. Aust. Rec. 1964/115 (unpubl.).

SHAW, R.D., & STEWART, A.J., in press - Regional geology of the Precambrian Arunta Block. In Knight, C.L. (Ed.) - Economic Geology of Australia and Papua New Guinea. Aust. Inst. Min. & Metall., Melbourne.

SKEELS, D.C., 1940 - Gravity in sedimentary basins. Amer. geophys. Un. Trans. 21, 182-201.

TAYLOR, F.J., MOSS, F.J., & BRANSON, J.C., 1972 - Deep crustal reflection seismic test survey, Tidbinbilla, A.C.T. and Braidwood, N.S.W., 1969. Bur. Miner. Resour. Aust. Rec. 1972/126 (unpubl.).

TIPPER, D.B., 1969 - Strangways Range detailed aeromagnetic survey, Northern Territory, 1965. Bur. Miner. Resour. Aust. Rep. 136.

TUCKER, D.H., 1969 - Ngalia Basin seismic survey, Northern Territory, 1968. Bur. Miner. Resour. Aust. Rec. 1969/70 (unpubl.).

TURPIE, A., & MOSS, F.J., 1963 - Palm Valley-Hermannsburg seismic survey, Northern Territory, 1961. Bur. Miner. Resour. Aust. Rec. 1963/5 (unpubl.).

WELLS, A.T., EVANS, T.G., & NICHOLAS, T., 1968 - The geology of the central part of the Ngalia Basin, Northern Territory. Bur. Miner. Resour. Aust. Rec. 1968/38 (unpubl.).

WELLS, A.T., FORMAN, D.J., RANFORD, L.C., & COOK, P.J., 1970 - Geology of the Amadeus Basin, central Australia. Bur. Miner. Resour. Aust. Bull. 100.

WELLS, A.T., MOSS, F.J. & SABITAY, A., 1972 - The Ngalia Basin, Northern Territory, - Recent geological and geophysical information upgrades petroleum prospects. APEA J. 1972, 144-151.

WHITWORTH, R., 1970 - Reconnaissance gravity survey of parts of Northern Territory and Western Australia, 1967. Bur. Miner. Resour. Aust. Rec. 1970/15 (unpubl.).

WOOLLARD, G.P., 1948 - Gravity and magnetic investigations in New England. Amer. geophys. Un. Trans. 29, 306-317.

WOOLLARD, G.P., 1949 - Gravity anomalies and the nature of the Earth's crust. Amer. geophys. Un. Trans. 30, 189-201.

WOOLLARD, G.P., 1959 - Crustal structure from gravity and seismic measurements. J. geophys. Res., 64, 1521-1544.

YOUNG, G.A., & SHELLEY, E.P., 1966 - Amadeus Basin airborne magnetic and radiometric survey, Northern Territory 1965. Bur. Miner. Resour. Aust. Rec. 1966/230 (unpubl.).

APPENDIX I

PROPOSED SEISMIC SURVEY REQUIREMENTS

STAFF

Supervising geophysicist	1 (halftime)
Party leader	1
Geophysicist	1
Party clerk	1
Observer	1
Asst. Observer	1
Shooters	2
Mechanic	1
Cook, Cook's offsider	2
Field Hands	15
(Ex Petroleum Technology section)	
Toolpusher	1
Drillers	3
Asst. Drillers	2
Mechanic	1
Field Hands	3

EQUIPMENT

Seismic amplifiers	SIE PT700 TI 8000
Cameras	SIE TRO6 SIE VRO6 GSC1301
Magnetic recorders	SIE PMR20 SIE PMR500 ElectroTech DS77
Geophones (reflection)	HSJ 14Hz GSC20D 8Hz
Remote recorders (refraction)	BMR units (20)
Cables	SCG1 2000ft. (24) SCW4 450ft. (2)
Transceivers	Traeger TM3 Pye Cambridge FM10D Codan SSB

VEHICLES

Recording trucks	Bedford 5 ton 4x4 (1) International C1300 4x4 (1)
Shooting trucks	Bedford 5 ton 4x4 Water Tanker (2)
Geophone carriers	Land Rover Ute LWB (5)
Workshop truck	International 5 ton 4x4 (1)
Flat Top trucks	Bedford 5 ton 4x4 (2)
Personnel Carriers	Land Rover Station Wagon (3)
Stores run	International C1300 1 ton 4x4 (1)
Office caravan	4-wheel trailer (1)
Kitchen caravan	4-wheel trailer (1)
Ablutions caravan	4-wheel trailer (1)
Workshop trailer	4-wheel trailer (1)
Generator trailer	4-wheel trailer (special) (1)
General purpose trailers	4-wheel trailer (2)
Explosives Magazine	4-wheel trailer (1)
Drill trailer	4-wheel trailer (1)
Drilling rigs	Mayhew 1000 (3)
Water tankers	Bedford 5 ton 4x4 Water tanker (3)

APPENDIX II

PROPOSED GRAVITY SURVEY REQUIREMENTS

STAFF

Geophysicist	1
Observer (T.O.)	1
Field Hands	2

EQUIPMENT

Gravity meter	1
Microbarometers	2
Radio Transceivers	2

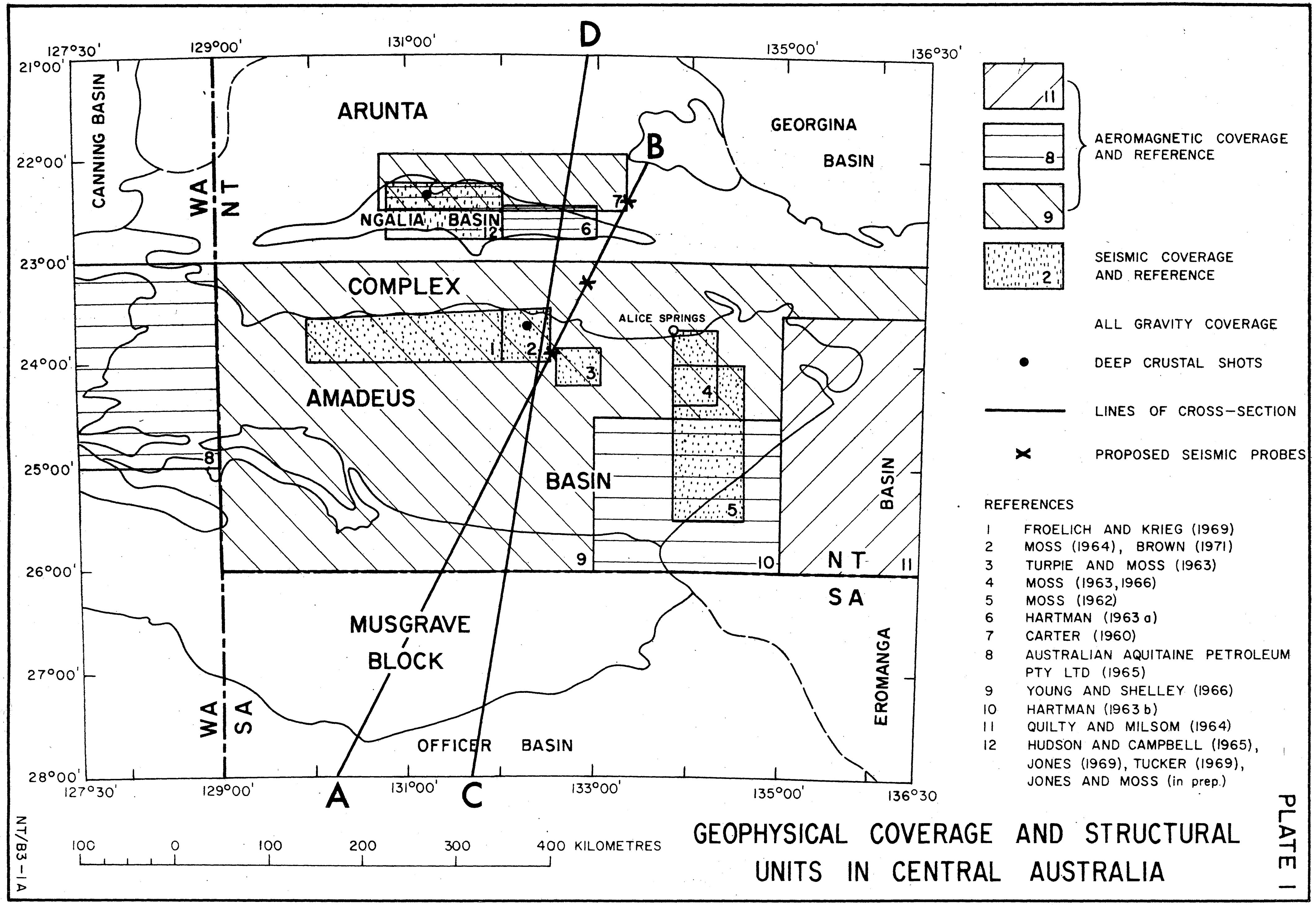
VEHICLES

Landrover LWB	1
International C1300	1

TABLE 1. OPERATIONAL REQUIREMENTS FOR THE SEISMIC SURVEY

ITEM	BASIN AREA (1 probe)	METAMORPHIC AREA (2 probes)	REMARKS
Length of probe	28 km	28 km	
No. of shots/probe	15	15	
Explosives/shot/probe	1500 kg	5000 kg	) Geophex and Amm. Nitrate)
Total explosives/probe	22 500 kg	75 000 kg	) to be shared 1:4
No. of shot holes & depth	10 holes @ 40 m	50 holes @ 30 m	
No. of drilling rigs	3	3	
Drilling time/probe	2.5 weeks	9.4 weeks	based on av. rate of 20 m/hr/rig
Total explosives	1 x 22 500 + 2 x 75 000 = 172 500 kg		)
Total drilling footage	1 x 6000 + 2 x 22 500 = 51 000 m		) For the whole survey)
Total drilling time	1 x 2.5 + 2 x 9.4 = 21.3 weeks		)

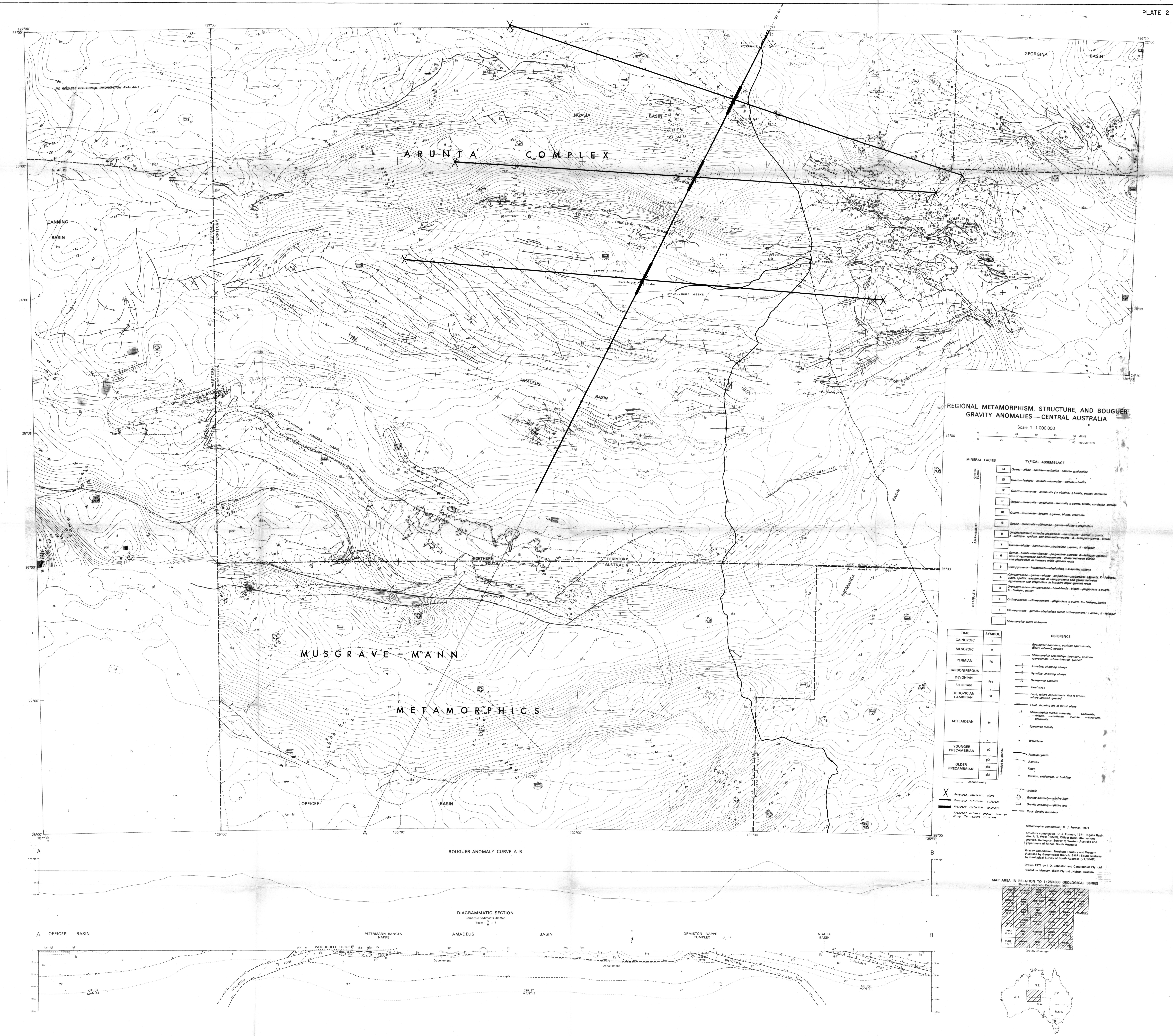
Record No. 1974/69



GEOPHYSICAL COVERAGE AND STRUCTURAL UNITS IN CENTRAL AUSTRALIA

PLATE 1

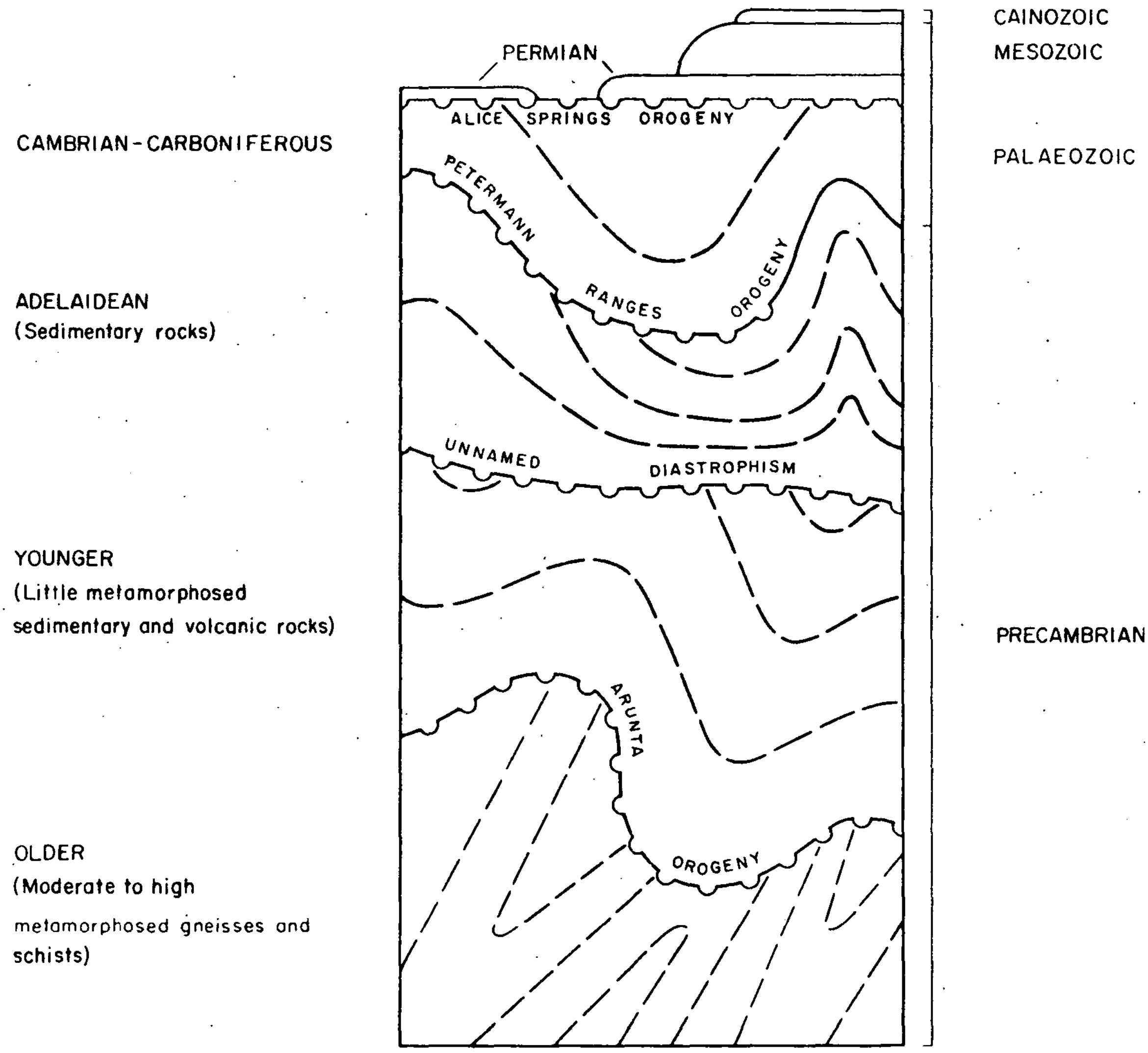
PLATE 2



Record No. 1974/69

NT/B3-2

PLATE 3



(AFTER FORMAN & SHAW, 1973)

GENERAL LITHOLOGY, OROGENIES AND THEIR RELATIONS

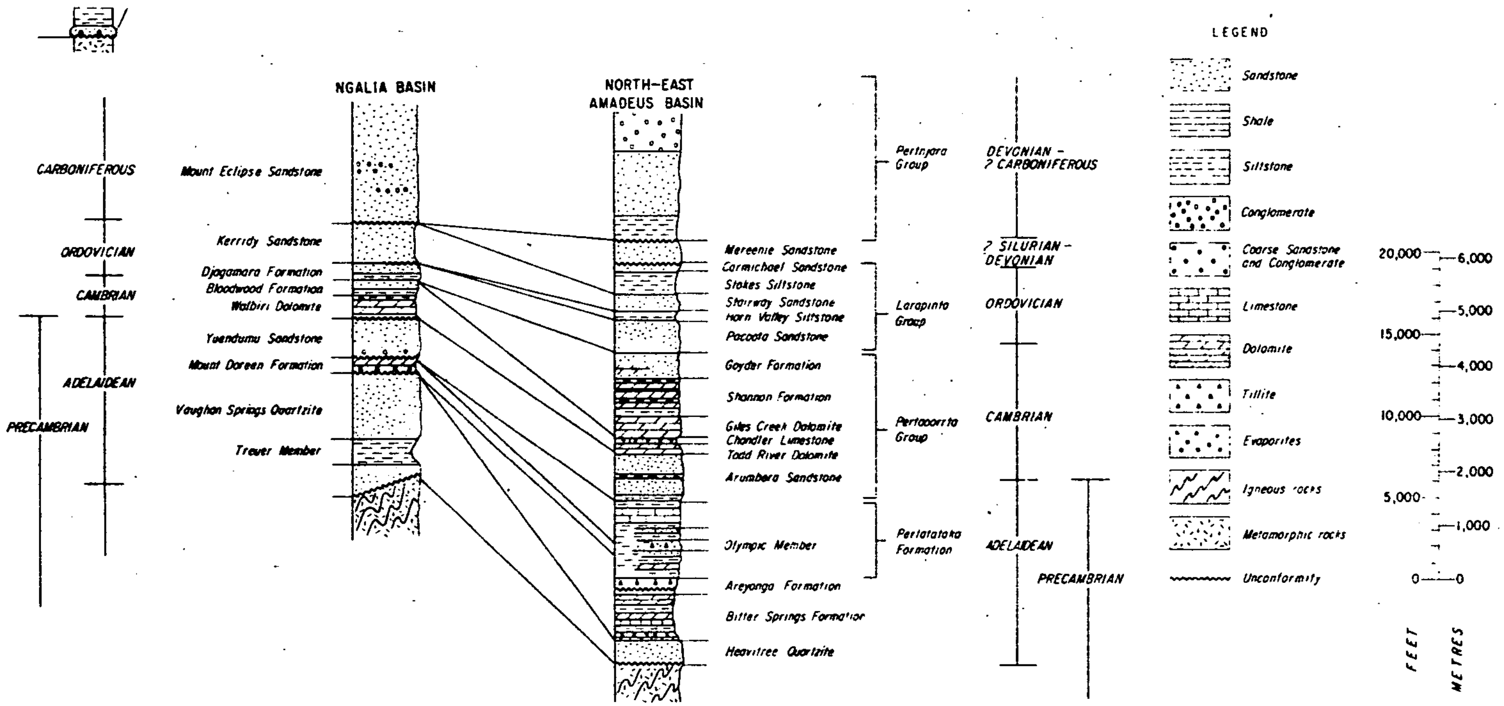


PLATE 4

CORRELATIONS OF FORMATIONS BETWEEN NGALIA AND AMADEUS BASINS

After Wells, Sabitay, and Moss (1972)

Basement depth contour (feet below sea level)

Fault

Magnetic zone and zone boundary

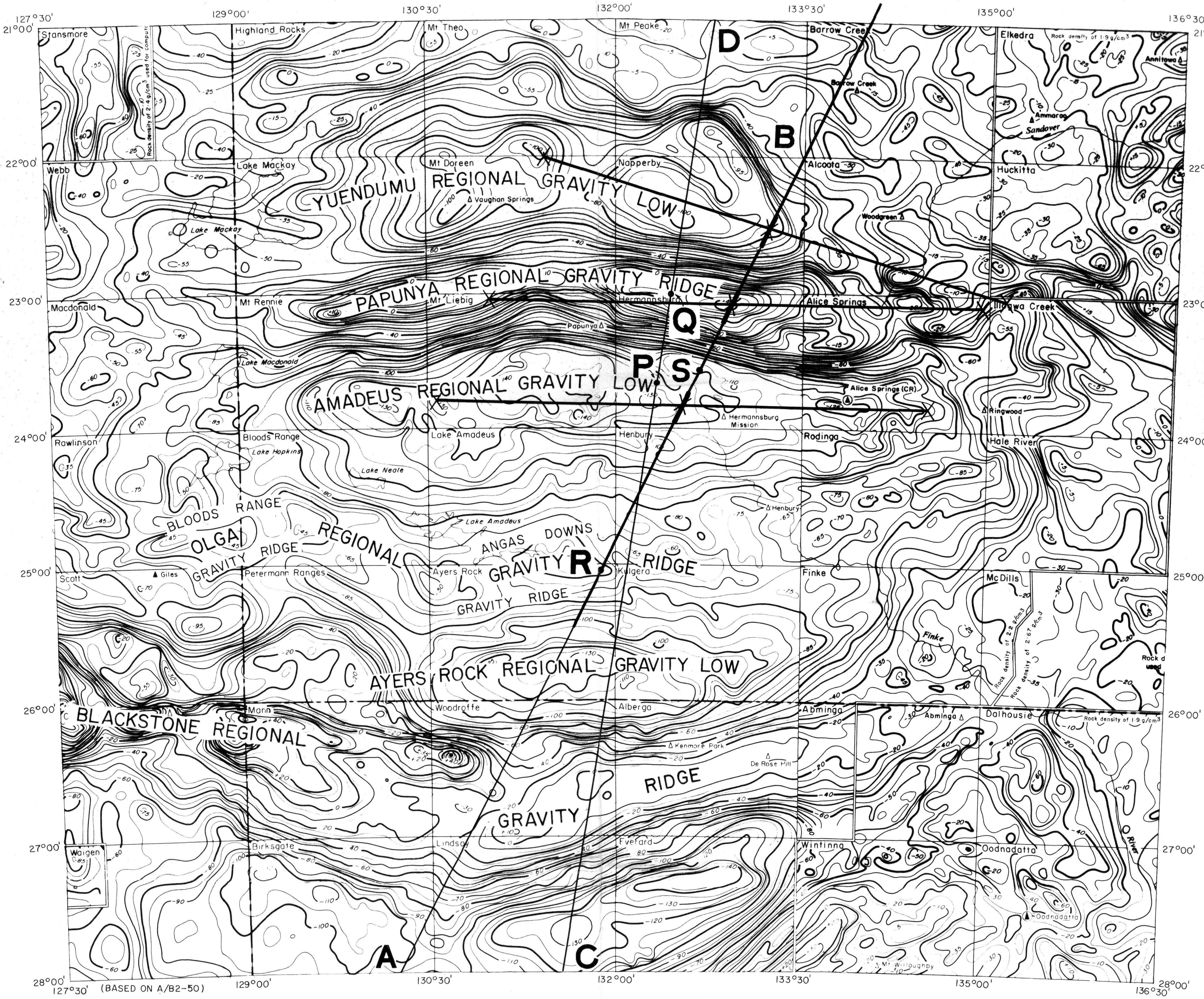
Boundary between surveys

Reference : Wells, Forman, Ranford, & Cook (1970)

Record No. 1974/69

MAGNETIC BASEMENT DEPTH CONTOUR MAP

NT/B3-4



X Proposed refraction shot-points

Proposed refraction coverage

Proposed reflection and expanded spread coverage

A —— B Line of cross-section (Plate 2)

C —— D Line of gravity profile (Plate 9)

Detailed gravity coverage will be along the seismic traverses

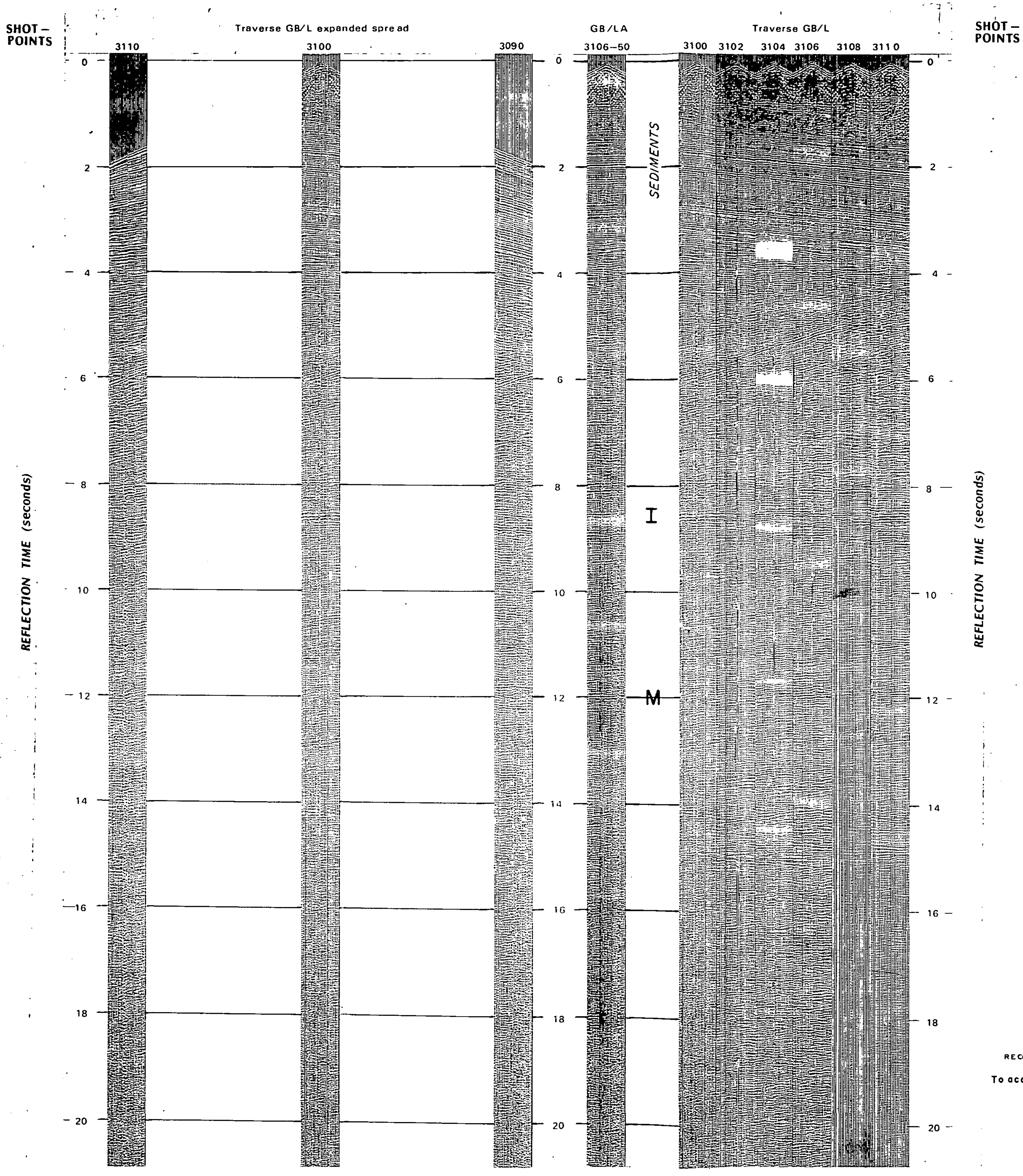
From the Preliminary Anomalies Map of Australia, 1:2,534,400 scale, published by the Bureau of Mineral Resources, Geology & Geophysics

50 0 50 100 150 200 km

BOUGUER ANOMALY MAP SHOWING GRAVITY FEATURES

PLATE 7

RECORD SECTION



DEEP CRUSTAL REFLECTIONS-AMADEUS BASIN

RECORDING INFORMATION

Magnetic Recorder : PMR-20

Amplifiers : PT-700

Prefilters : Nil

Filters : L/16 - KK/60

AGC : SS

Gain Initial : -70/-60dB

Final : FULL (except 3108,3110: -10dB)

Geophones : Hs-J, 14Hz

Geophone Station Interval : 67m

Geophone Pattern :

32/ trace in 2 lines of 16
spacing in line 6.1m
spacing between lines 9.1m

Shot Hole Pattern :

3 in line, spacing 23m
Depth: 30m
Charge: 470kg Geophex per shot

PLAYBACK INFORMATION

Note: These are reductions of monitor records. The data were not recorded on magnetic tape and thus no playback was possible.

I = Intermediate reflection

M = Moho reflection

HORIZONTAL SCALE

(Km)

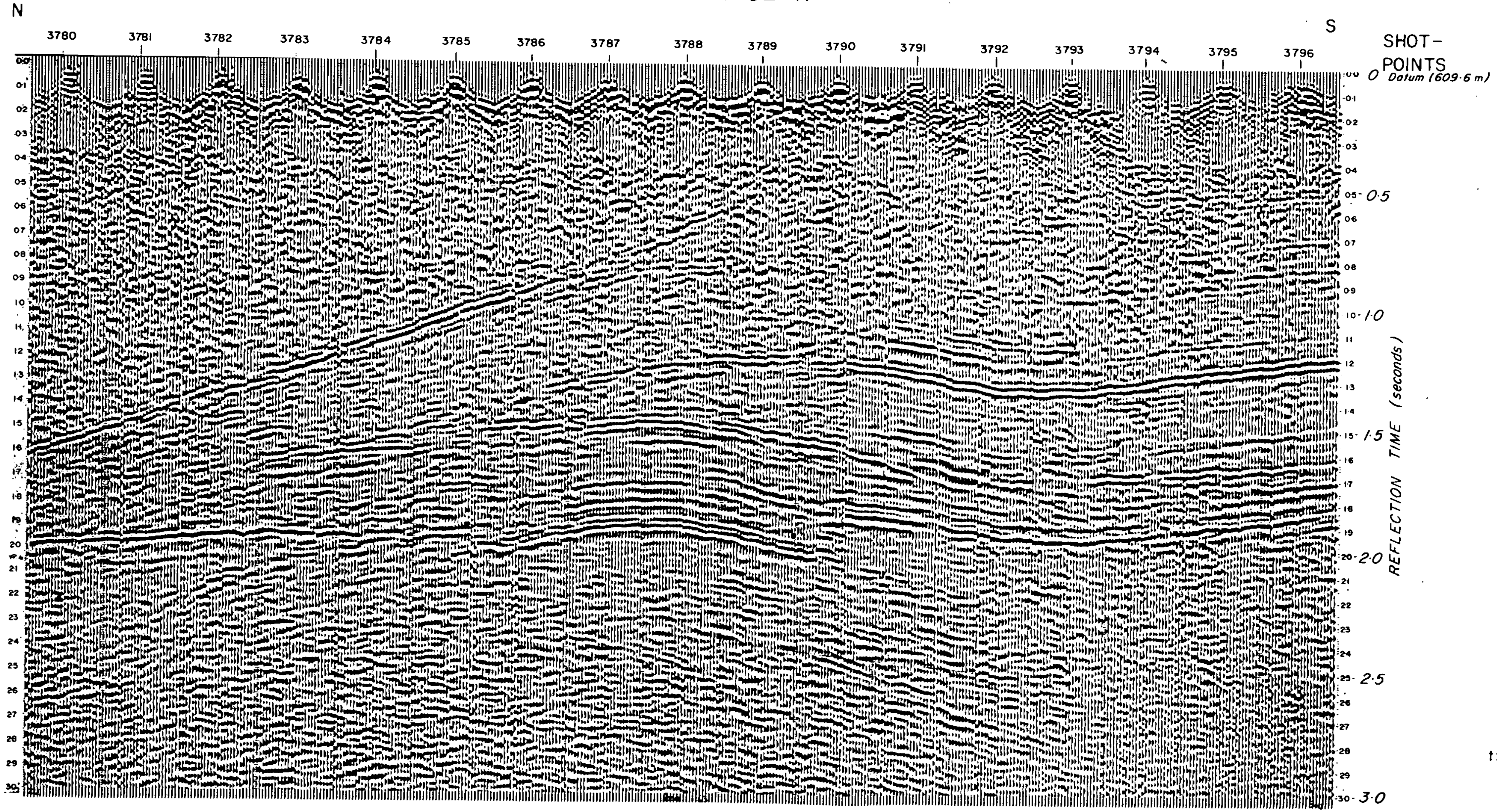
0 1 2 3 4

REFERENCE: BROWN, 1970

RECORDED BY: SEISMIC PARTY NO. 1 F52/B3-39

To accompany Record No. 1970/94
and Record No. 1973/78
and Record No. 1974/69

TRAVERSE K



CORRECTED RECORD SECTION

PLATE 8

RECORDING INFORMATION

Magnetic recorder : PMR-20

Amplifiers : PT-700

Prefilters : —

Filters : L 20-K 135

AGC : Med

Gain Initial: Various

Final : 0 to -10

Geophone station interval : 46m

Geophones : HSJ-14 Hz

Geophone pattern :

24 /trace,. 6·1m apart in line

Shot-hole pattern :

3 holes, 15·2m apart in line

Depth 36·5m

Charge 3 x 13·6kg to 3 x 22·7kg

PROCESSING INFORMATION

Analog to digital conversion

Sampling rate : 4ms

Datum statics

Time varying deconvolution

NMO and static corection

Display filters: 15-50 Hz

(Digitally processed by GSI)

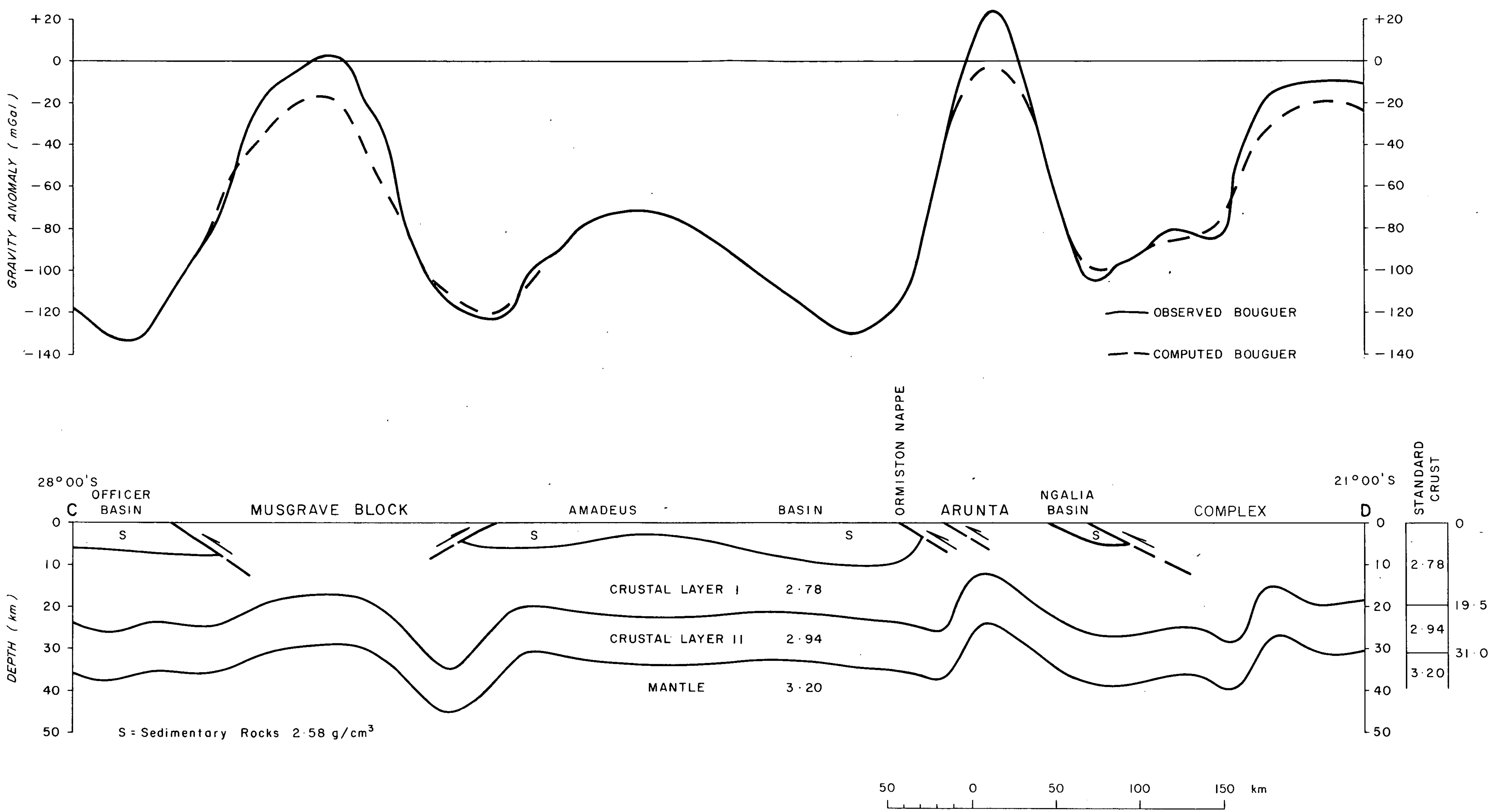
VELOCITY INFORMATION

t:Δt and Expanded Spread at SP 3800

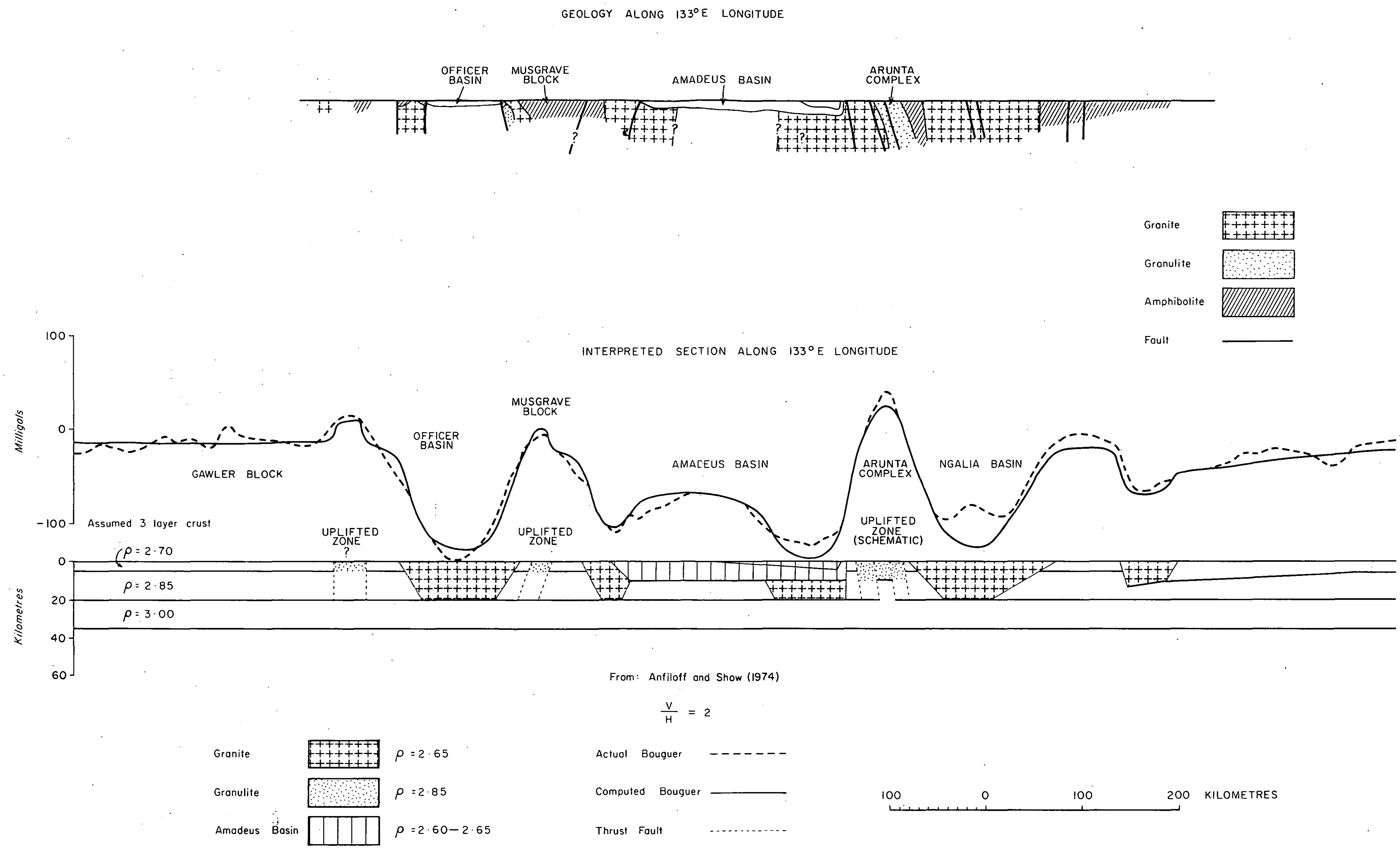
HORIZONTAL SCALE (metres)

0 300 600 900 1200
0 549 1097

SEISMIC SECTION ACROSS THE NORTHERN MARGIN OF THE NGALIA BASIN

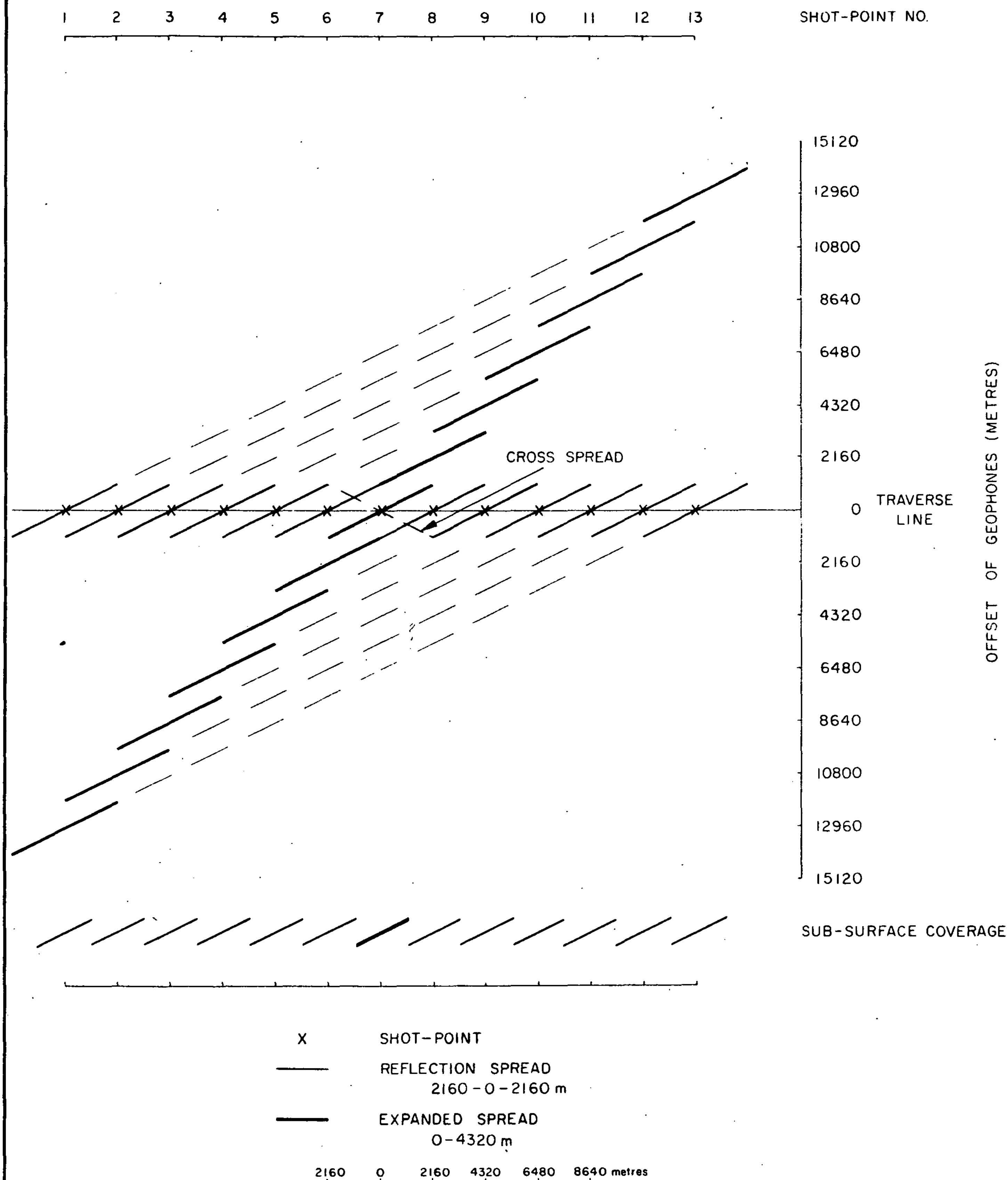


GRAVITY PROFILES AND INTERPRETATION OF CRUSTAL STRUCTURE
ALONG LINE CD ACROSS CENTRAL AUSTRALIA

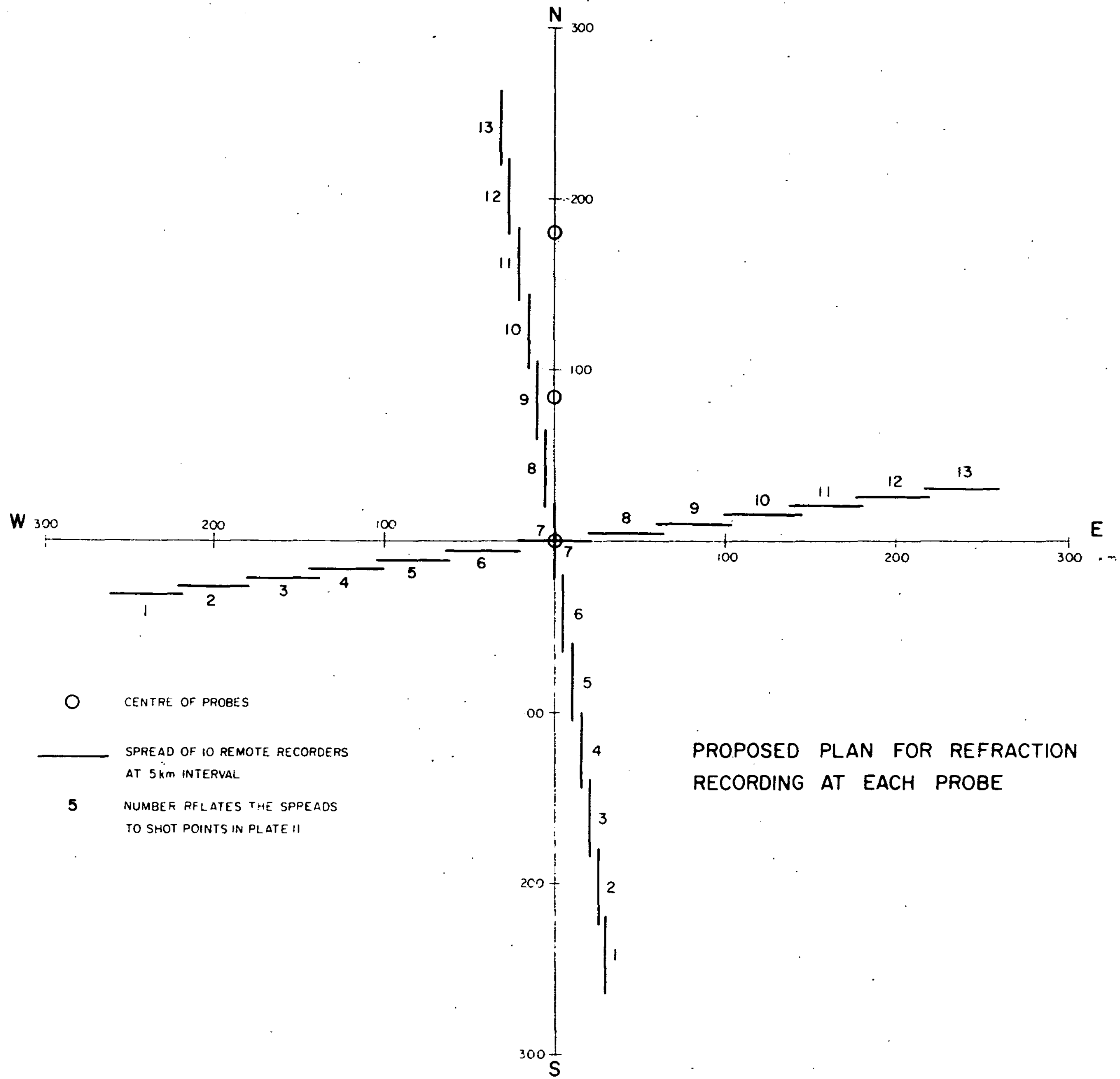


GEOLOGY, GRAVITY PROFILES, AND INTERPRETED SECTION ALONG 133°E LONGITUDE IN CENTRAL AUSTRALIA

PLATE 11



PROPOSED PLAN FOR REFLECTION AND EXPANDED SPREAD SHOOTING AND RECORDING AT EACH PROBE



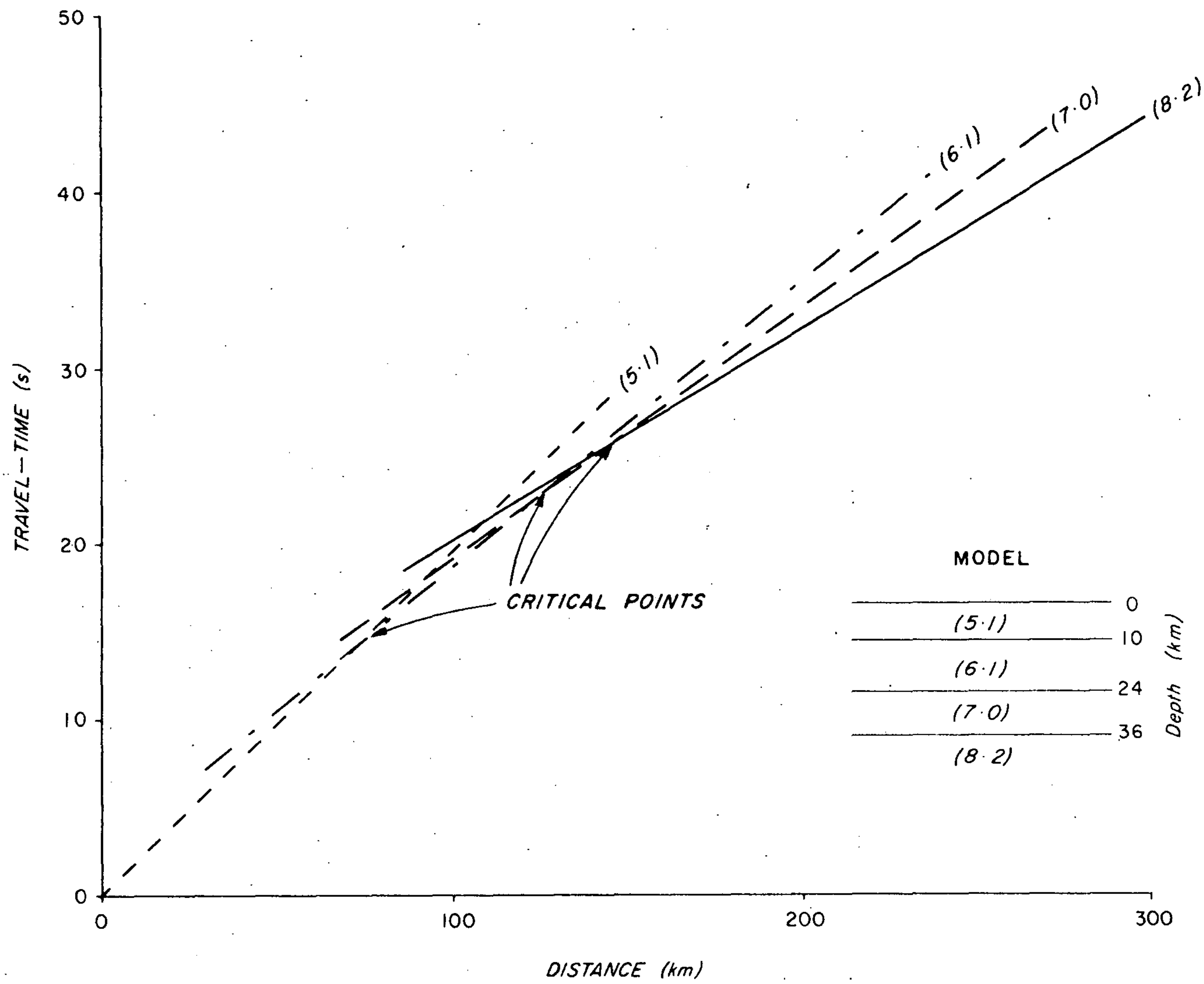
PROPOSED PLAN FOR REFRACTION RECORDING AT EACH PROBE

PLATE 12

THEORETICAL REFRACTION PATHS AND TRAVEL-TIME CURVES FOR A NE-SW TRAVERSE (RSB) ACROSS AMADEUS BASIN AND ARUNTA COMPLEX

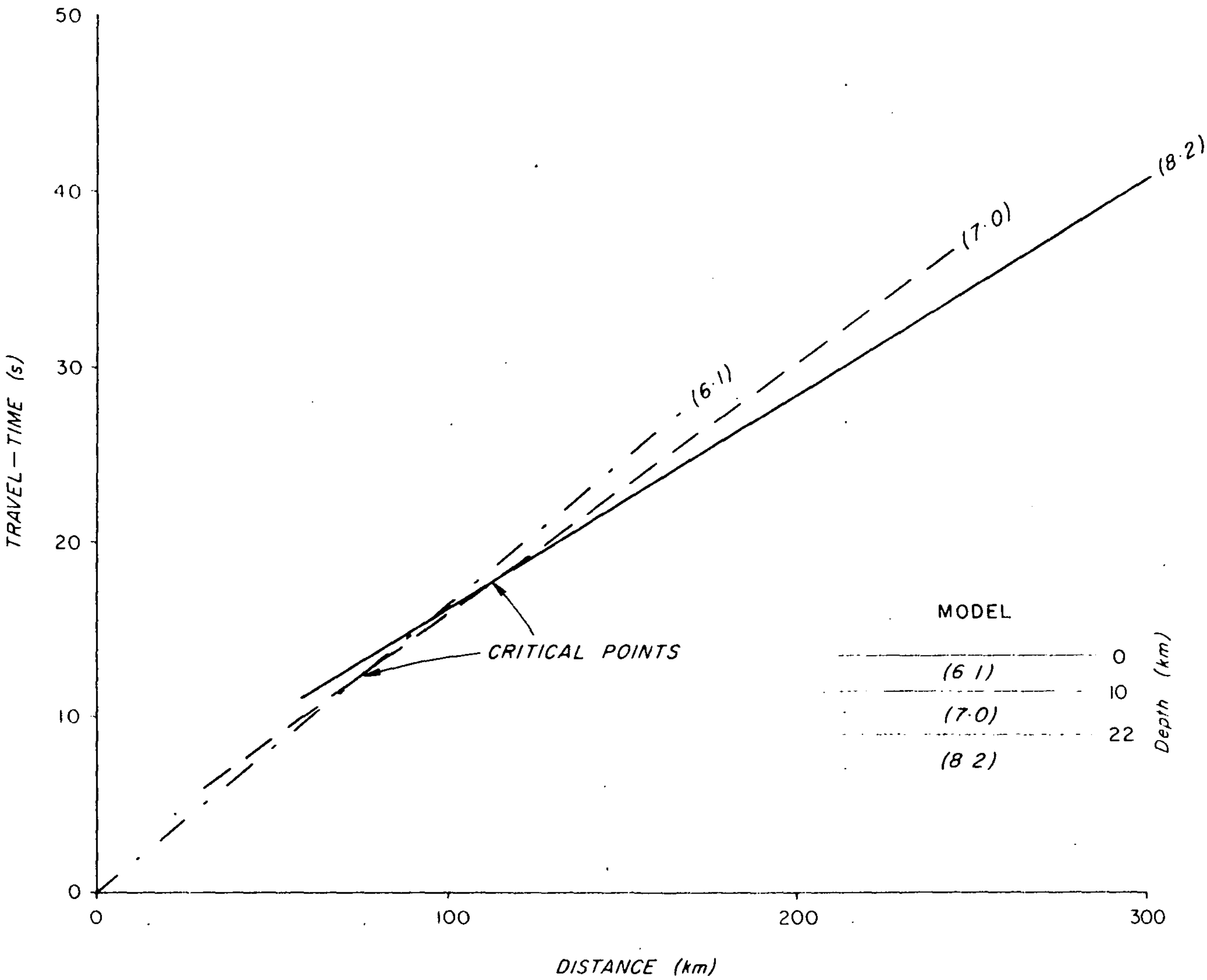
Record No. 1974/69

NT/B3-10



THEORETICAL REFRACTION TIME—DISTANCE CURVES FOR AN APPROXIMATELY E—W TRAVERSE AT P IN THE AMADEUS BASIN

PLATE 15



THEORETICAL REFRACTION TIME–DISTANCE CURVES FOR AN APPROXIMATELY E–W TRAVERSE AT Q IN THE ARUNTA COMPLEX