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Record No. 1970/94

Deep Crustal Reflection Studies, Amadeus and Ngalia Basins, N.T. 1969

by

A.R. Brown

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SUMMARY

The opportunity was taken to conduct deep crustal reflection studies in the Amadeus and Ngalia Basins during the course of a reflection seismic study of Gosses Bluff and a reconnaissance reflection survey of the Ngalia Basin respectively.

Seismic reflections were recorded at times greater than would be expected of reflections from within the sedimentary section. Fair quality events at about 8 and 12 seconds are considered to be primary reflections from deep within the crust.

It may thus be hoped that a larger-scale seismic survey will shed new light on the deep structure and tectonic history of the Central Australian basins and decide between conflicting theories put forward to explain the anomalous gravity features associated with them.

1. INTRODUCTION

The Amadeus and Yuendumu regional gravity depressions apparently associated with the Amadeus and Ngalia Basins respectively are both considerably displaced to the north of their geologically known basins. Known near-surface structure within and around the basins is not sufficient to explain these gravity anomalies. An explanation may be found in deep structure within the crust and possibly the upper mantle.

The present deep crustal reflection work was carried out by BMR Seismic Party No. 1 during the Gosses Bluff Seismic Survey, 1969, in the Amadeus Basin and the Ngalia Basin Seismic Survey, 1969. The seismic programme was planned to determine if crustal reflections could be recorded in these two areas.

2. Anomalous gravity pattern

The geology of the Amadeus and Ngalia Basins has been described by Wells, Ranford, Cook, & Forman (1967) and Wells et al. (1968). Gravity surveys using helicopters have been conducted over the two basins (Flavelle, 1965; Whitworth, 1970).

Plate 1 indicates the results of these surveys and shows the gravity provinces which have been postulated as well as the outlines of the corresponding sedimentary basins as mapped by surface geology. It can be seen that in both the Amadeus and Ngalia Basins there is a gravity depression which does not lie symmetrically over the basin but is displaced considerably to the north.

Both basins are known to have overthrust faulting along their northern margins and the resultant extension of the sediments under basement rocks would contribute to a northern extension of the basin gravity depressions. However, it is considered that the overthrusting is insufficient to explain the magnitude of the northern extension of the gravity depressions and also the steep Bouguer anomaly gradient north of the MacDonnell Ranges. Thus a more deepseated cause is sought for these features.

Whitworth (1970) and Forman (Wells et al, 1967) discuss the possible structural configurations of the crust which would produce the negative gravity anomaly strip and intense ridge which exist between the two basins. Whitworth favours a fundamental horizontal density change within the crust, as originally suggested by Flavelle (1965), coupled with either southward overfolding of Archaean and Proterozoic rocks on the northern edge of the Amadeus Basin or major faulting bringing ultrabasic rocks close to the surface along the southern flank of the ridge, as originally suggested by Langron (1962).

Forman proposes a major crustal warp as the most probable cause and draws a north-south section through the crust across the northern margin of the Amadeus Basin which fits the gravity profile reasonably well. The depths under the northern part of the basin to the intermediate and Moho discontinuities are given as 24 and 40 kilometres. On the basis of recent geological work, however, Forman (pers. comm.) also has suggested major crustal overthrusting along the basin margin as a possible cause of the gravity pattern.

3. Previous deep crustal reflection studies

Until recently most seismic crustal investigations within Australia have been made using the refraction method. Some were large-scale cooperative experiments, such as project BUMP (Underwood, 1970). However, the reflection method has the advantages of greater resolving power, precision, and the ability to detect discontinuous low velocity layers. Reflection data can yield average vertical velocity using normal moveout formulae if the reflection is recorded over a spread of sufficient length. From knowledge of average velocity, the depth to the reflecting zone is directly deducible. Consideration of the wavelengths of reflections enables conclusions to be drawn regarding the sharpness of discontinuities from which the reflections are obtained.

The Australian Upper Mantle Committee recommended in 1965 that a national project be undertaken to study the earth's crust and upper mantle across the southwest Australian Precambrian shield. This project was called the 'Geo-Traverse'. BMR undertook the seismic survey, which was to be principally a reflection survey, with the aim of mapping the Mohorovicic discontinuity (Moho) and any other discontinuities detected in the crust or upper mantle.

Prior to its work on the Geo-Traverse, BMR conducted several experimental surveys in southeastern Australia to develop techniques for recording deep crustal reflections (Branson & Taylor, 1970a, b).

Criteria for recognition of deep crustal reflections.

A late event recorded on a seismic record, for example between times of 8 to 15 seconds, may or may not be a reflection from within the crust or mantle. Kanasewich & Cumming (1965) established the criteria for recognizing primary reflected energy:

(1) The reflected energy arrives at near-vertical incidence. To prove this it is necessary to record the event at essentially the same record time with geophone spreads mutually at right-angles.

(2) Enough data should be available so that the average vertical velocity can be calculated from the surface to the reflecting layer. The event must, therefore, be recorded over a continuously expanding spread of sufficient length. The average velocity calculated will be characteristic of either the deep crust, the mantle, or the sedimentary section, indicating that the event is a primary reflection from within the crust or mantle or a multiple of a reflection from within the sedimentary sequence.

(3) Every reflected event should be suspected as being of multiple origin unless the data are sufficiently unambiguous to exclude this possibility.

(4) Relative amplitude is useful in identifying reflections. A particularly strong late event, which is not at a time close to a simple multiple of another event, is likely to be a primary crustal reflection. However, the absolute amplitude of an event varies widely from location to location because of near-surface irregularities of velocity, variations in seismometer placement, and differences in shot environment.

Dohr & Fuchs (1967) state that the appearance of deep crustal reflections differs considerably from that of reflections from shallow sedimentary beds. They correlate only over short distances, seldom more than a few kilometres. The reflections are usually broad, that is of many phases or legs.

For these reasons it is normally concluded that deep crustal reflections do not have sufficient character to allow correlation of individual phases across considerable gaps between records.

It has been possible by use of the criteria mentioned above to identify primary deep crustal reflections in the BMR work in southeastern Australia (Branson & Taylor, 1970a, b) and also in the current work on the Geo-Traverse (Branson & Harrison, 1970). Good deep crustal reflections have recently been recorded in Canada (Clowes, Kanasewich, & Cumming, 1968).

4. Objectives and programme

Objectives

The overall objective of deep crustal reflection work in the region of the Amadeus and Ngalia Basins of the Northern Territory will be to investigate the deep structure and tectonic history of the area and in so doing to explain the anomalous gravity depressions and gradients associated with these two basins.

The detailed objective of the work in 1969 was to determine whether deep crustal reflections can be recorded in these areas.

Programme - Amadeus Basin

The deep crustal reflection work in the Amadeus Basin was planned as part of Gosses Bluff Seismic Survey, 1969 (Brown, 1970a). Records obtained during Gosses Bluff Seismic Survey, 1962 (Moss, 1964) indicated that energy transmission through the crust would probably not be a major problem in the region of SP 110 on traverse L. Thus it was decided to conduct the crustal reflection work in 1969 along that part of Traverse L between Gosses Bluff and the MacDonnell Ranges (Pl. 1). This location was as close as convenient to the northern margin of the basin and thus to the anomalous gravity gradient.

It was planned that a short traverse of about six shot-points would be recorded. If late events were obtained, their identity as primary crustal reflections would be checked by shooting a short cross-traverse and by shooting some form of expanded spread.

Information on the techniques likely to produce the best results was to be supplied by BMR Seismic Party No. 2 working at the time on the Geo-Traverse in Western Australia.

It was also planned that, during the Gosses Bluff Survey, some normal reflection records would be allowed to run on to about 20 seconds in order to determine if deep crustal reflections could be recorded in this vicinity without the use of specially designed shots and recording conditions.

Programme - Ngalia Basin

The deep crustal reflection work in the Ngalia Basin was planned as part of Ngalia Basin Seismic Survey, 1969 (Jones, 1970). The site was to be on one of the surveyed traverses where conditions for drilling and energy transmission were reasonable. Furthermore the site had to be as close to the northern margin of the basin as possible.

One shot using a large charge would be recorded. If this revealed late events, and if time and explosive permitted, another shot would be recorded into a geophone spread at right-angles. It was not expected to have time or explosive for a suitably large scale expanded spread to measure crustal velocities in this area.

5. Techniques and results

Amadeus Basin

Continuous reflection coverage was recorded on traverse GB/L between SPs 3110 and 3100 (Pl. 2). The shot at SP 3110 was recorded by a geophone spread laid out between SPs 3108 and 3112. SP 3110, traverse GB/L, coincided with SP 110, traverse L, of the Gosses Bluff Seismic Survey, 1962. SP 3106, namely the intersection of traverses GB/L and GB/LA, is at latitude 23°42.5', longitude 132°18.0'.

The recommended techniques were modified to the following*:

Shot - hole pattern: 3 in line, spacing 23 metres

Hole depth: 30 metres

Charge: 3 x 158 kg Geophex

Geophones: HS - J, 14 Hz

Geophone spread; 805 - 0 - 805 metres split

Geophone station interval: 67 metres

Geophone pattern: 32 per trace in 2 lines, spacing in line 6.1 metres

Instruments: AGC SS, Final gain FULL or - 10dB, filter L/16 - KK/60

Camera Speed: 15 cm per second

Record length: 30 seconds

Presentation: variable area/wiggle trace

The number of holes was limited by difficult drilling conditions. It was impossible to record on magnetic tape energy arriving after 6 seconds from the shot instant as that is the length of the recording cycle of the PMR-20 tape recorder.

Many late events were recorded using these techniques (Pl. 3). In fact, on most records coherent energy was recorded to 30 seconds. Most of this is undoubtedly of multiple origin, but two events stand out with large relative amplitudes at times of 8.5 and 12.0 seconds. These are not obviously multiples.

One shot was then recorded at SP 3106-50 on traverse GB/LA, which intersects traverse GB/L at SP 3106 at right-angles (Pl. 2). This record (Pl. 3) indicated a similar pattern of events to those from the main traverse. The events at 8.5 and 12.0 seconds occurred at essentially the same record time, proving that they resulted from energy arriving at the geophones at near-vertical incidence.

* During the survey measurements were made in feet and pounds. The specifications here are conversions which have been rounded to the number of digits shown.

In order to prove conclusively that these two events were primary deep crustal reflections rather than multiples of reflections from within the sedimentary section, an attempt was made to record an expanded spread of suitable size. There was little time available, the drilling was difficult and the length of traverse between Gosses Bluff and the MacDonnell Ranges, about 13 km, was considered too short a distance.

However, the two extreme shots of an expanded spread were recorded in the space available. A shot was fired from SP 3110 into a spread laid between SPs 3088 and 3092 and also one from SP 3090 into a spread between SPs 3108 and 3112 (Pl. 2). These both had common subsurface coverage with the split spread recorded at SP 3100. These three records displayed with appropriate sized gaps are on the left in Plate 3.

Correlation of the events at 8.5 and 12.0 seconds between the centre and outside records proved difficult. However, of the many correlations of phases possible some do indicate vertical velocities which are close to those expected for primary crustal reflections.

Thus the evidence, although incomplete, suggests that these two strong events at 8.5 and 12.0 seconds are primary deep crustal reflections. The deeper event is seen to dip to the south, which can be interpreted either as structure deep within the crust or as crustal thickening. We can be optimistic that extension of the line to the north may reveal crustal structure in the critical zone between the two basins.

The average vertical velocities to reflections at similar times to these were deduced by Branson et al. (1970a) at Mildura, Vic., to be 5.7 and 6.0 km/s. Use of these velocities in the Amadeus Basin yields depths to the reflecting layers of 24 and 36 kilometres. These are in fair agreement with the depths used in Forman's model for the intermediate crustal and Moho discontinuities.

Attempts during the Gosses Bluff Survey to record crustal reflections by allowing normal reflection records to run on to about 20 seconds were unsuccessful. No late events were recorded.

Ngalia Basin

Two shots were recorded from the same shotpoint (lat. 22°24.0', long. 131°14.2', see Plate 1) by geophone spreads mutually at right-angles. The shotpoint was SP 6016 on traverse O of the Ngalia Basin Seismic Survey (Jones, 1970). One of the geophone spreads was laid along traverse O which had a bearing of N. 15° W.

The techniques used were based on those found successful in the Amadeus Basin and were:

Shot-hole pattern: 30 holes were drilled in rectangular pattern, othogonal spacings 15 metres.
Shot 1 (spread along traverse O) used 6 holes.
Shot 2 (spread perp. to traverse O) used 15 holes.

Hole depth: 37 metres

Charge: shot 1 - 6 x 129 kg (774 kg) Geophex
shot 2 - 15 x 109 kg (1630 kg) Geophex

Geophones: HS-J, 14 Hz

Geophone spread: 1100-0-1100 metres split

Geophone station interval: 91 metres

Geophone pattern: 32 per trace in 2 lines, spacing in line 6.1 metres

Instruments: AGC SS, final gain FULL, filter L/16 - KK/60

Camera speed: 15 cm per second

Record length: 30 seconds

Presentation: variable area/wiggle trace

Many late events were recorded (Pl. 4), but not as many as were recorded in the Amadeus Basin. One particularly strong, broad event occurs on both records at a time of 12.7 seconds. It is not obviously a multiple. Assuming this is a primary deep crustal reflection and assuming an average velocity to the reflecting layer of 6.0 km/s, the depth of the layer would be 38 kilometres, which is not an unreasonable depth for the Moho discontinuity.

6. Conclusions

It has been demonstrated that fair quality reflections can be obtained from deep within the crust in particular areas of the Amadeus and Ngalia Basins, and it may be hoped that a larger-scale seismic survey will shed new light on the deep structure and tectonic history of these basins and decide between conflicting theories put forward to explain the anomalous gravity features associated with them.

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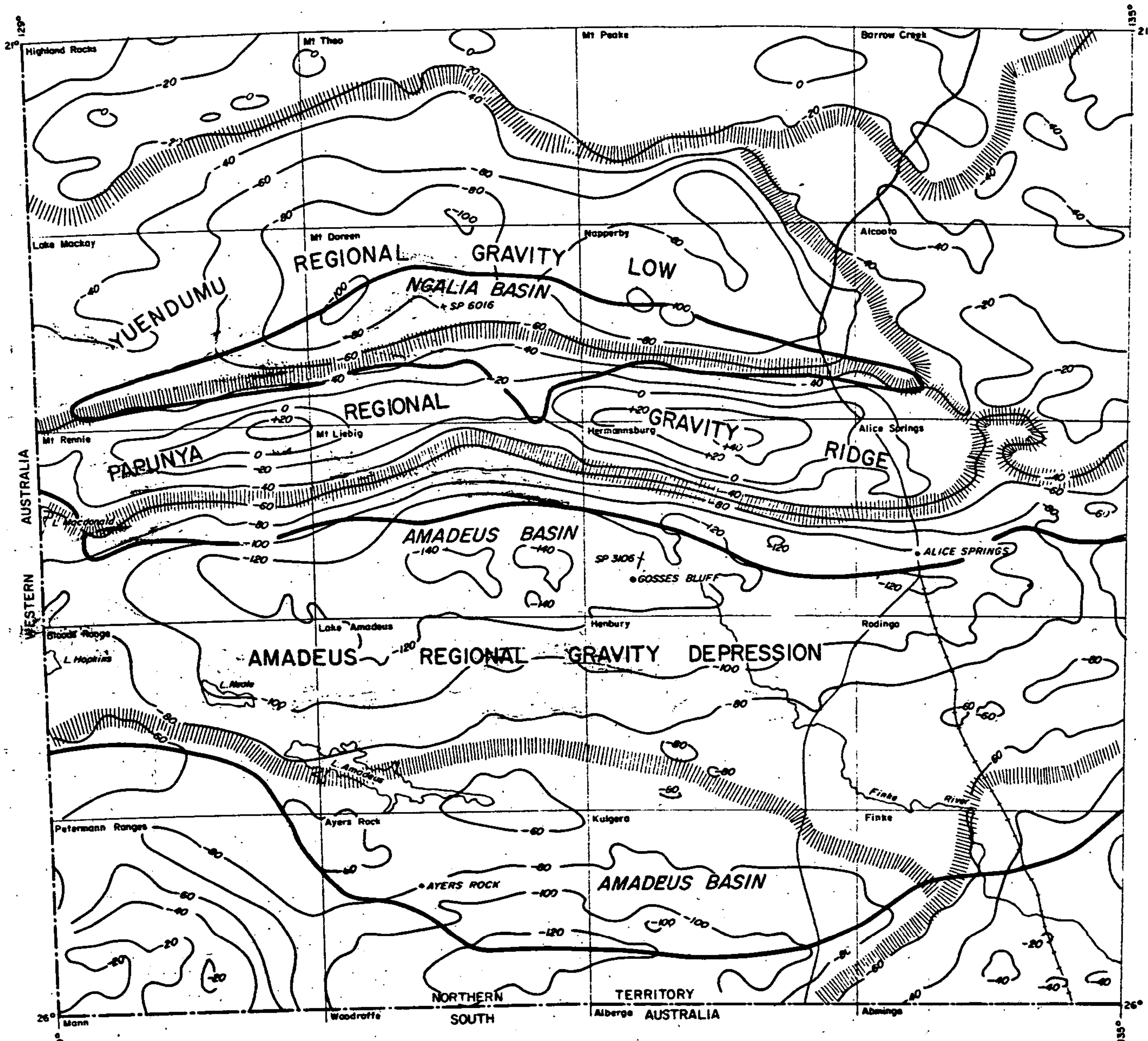
PLATE I



To accompany Record No 1970/94

LEGEND

Bouguer anomaly contours (20 milligal interval)

Gravity province boundary

Sedimentary basin boundary

Road

Railway

+ SP6016 Crustal reflection probe

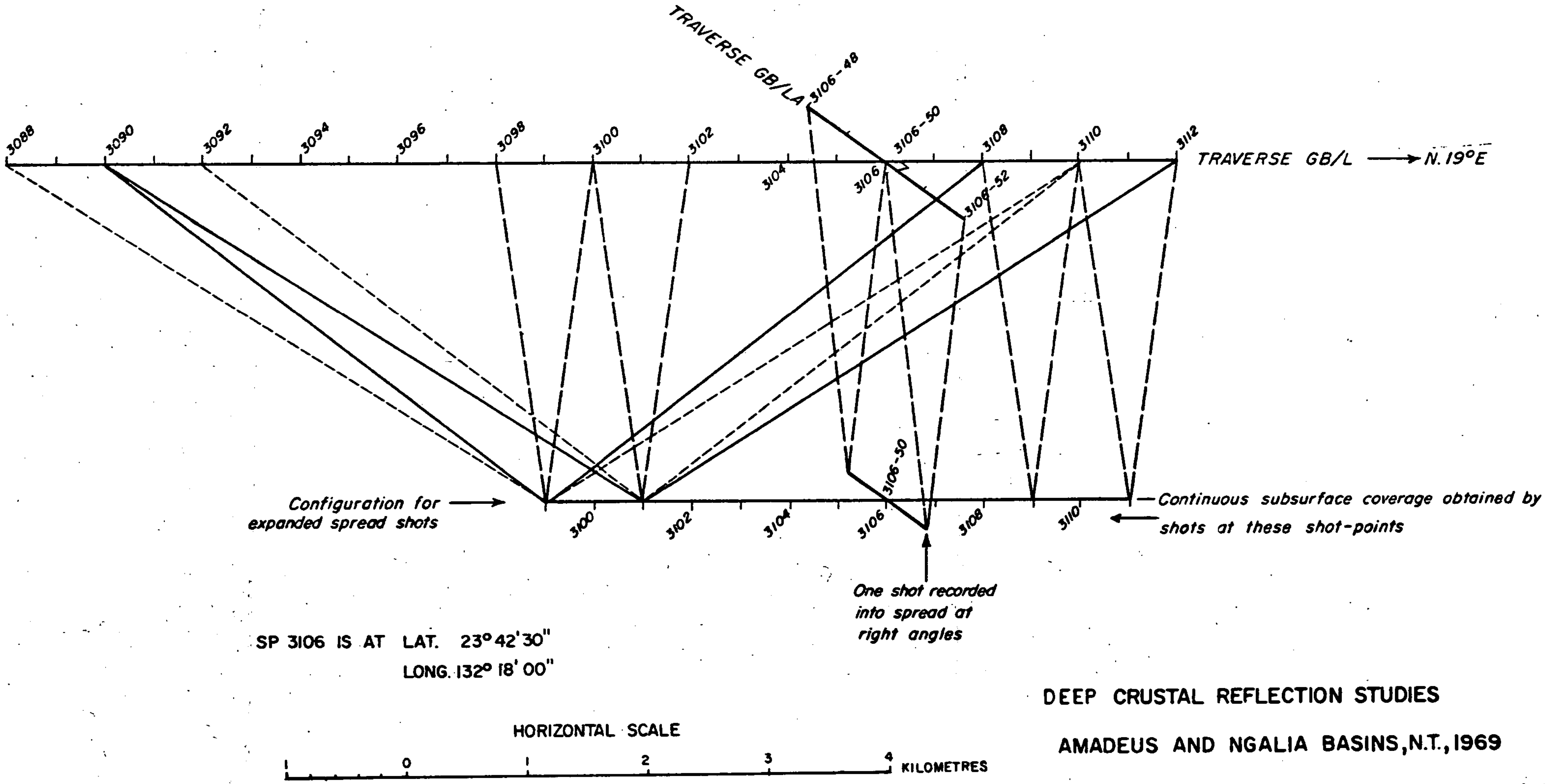
KILOMETRES

50 0 50 100 150

DEEP CRUSTAL REFLECTION STUDIES AMADEUS AND NGALIA BASINS, N.T., 1969

GRAVITY FEATURES ASSOCIATED WITH AMADEUS AND NGALIA BASINS

F53/B3-147



To accompany Record No 1970/94

DEEP CRUSTAL REFLECTION STUDIES

AMADEUS AND NGALIA BASINS, N.T., 1969

SHOOTING DIAGRAM, AMADEUS BASIN

PLATE 2

F53/B3-148

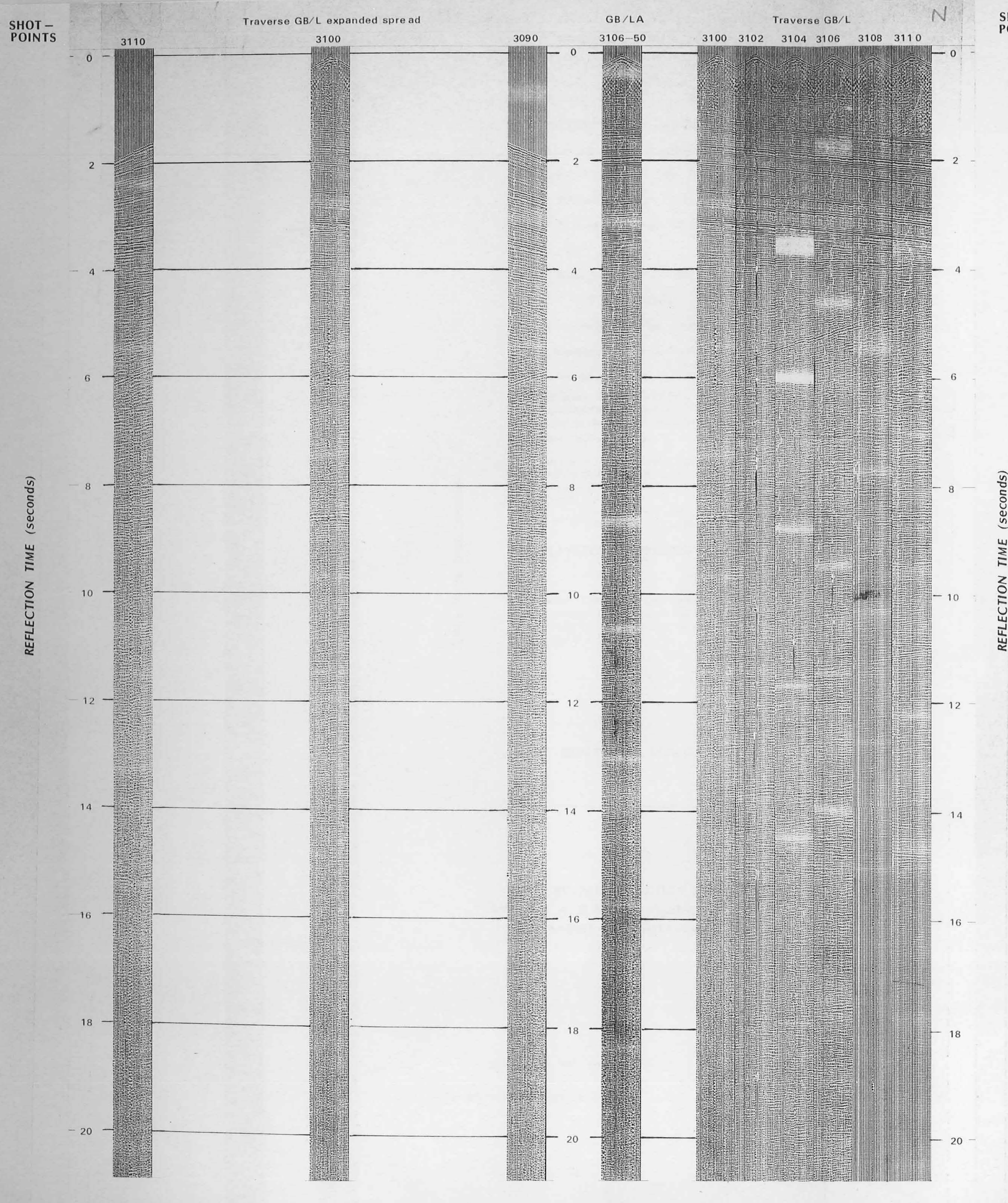


PLATE 3

RECORD SECTION

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 was not recorded on magnetic tape and thus no playback was possible.

HORIZONTAL SCALE

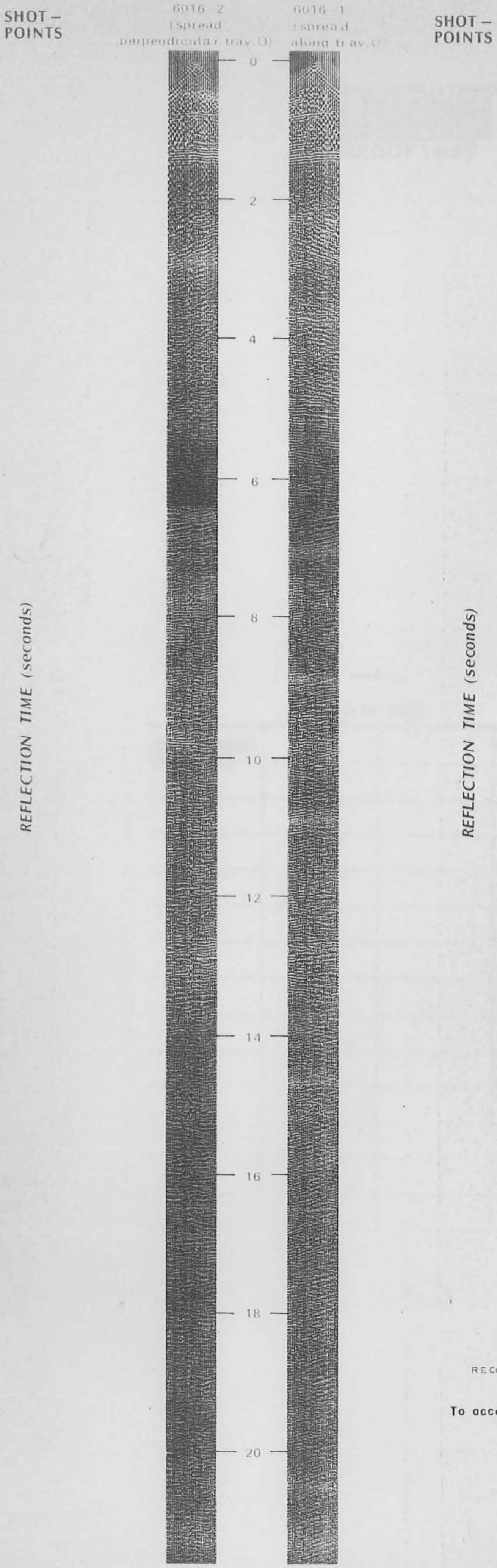
(Km)

0 1 2 3 4

DEEP CRUSTAL REFLECTION STUDIES
AMADEUS AND NGALIA BASINS NT, 1969
TRAVERSE GB/L AND GB/LA, AMADEUS BASIN

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

To accompany Record No 1970/94



RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: PMR – 20

Amplifiers : PT – 700

Prefilters : Nil

Filters : L/16 – KK/60

AGC : SS

Gain Initial : – 80 dB

Final : FULL

Geophones : Hs – J, 14 Hz

Geophone Station Interval : 91m

Geophone Pattern :

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

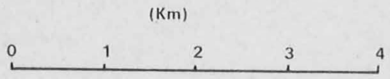
Shot Hole Pattern :

30 holes in rectangular pattern,
orthogonal spacings 15m
6016 – 1 used 6 holes, 6016 – 2 used 15 holes
Depth: 37m
Charge: 6016 – 1 6 x 129kg Geophex
6016 – 2 15 x 109kg Geophex

PLAYBACK INFORMATION

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

HORIZONTAL SCALE



DEEP CRUSTAL REFLECTION STUDIES
AMADEUS AND NGALIA BASINS NT, 1969
TRAVERSE O, NGALIA BASIN

RECORDED BY: SEISMIC PARTY NO. 1

F52/B3–40A

To accompany Record No 1970/94