BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

1981/2

CRUSTAL SEISMIC INVESTIGATIONS IN

NORTHERN AUSTRALIA, 1979: OPERATIONAL REPORT

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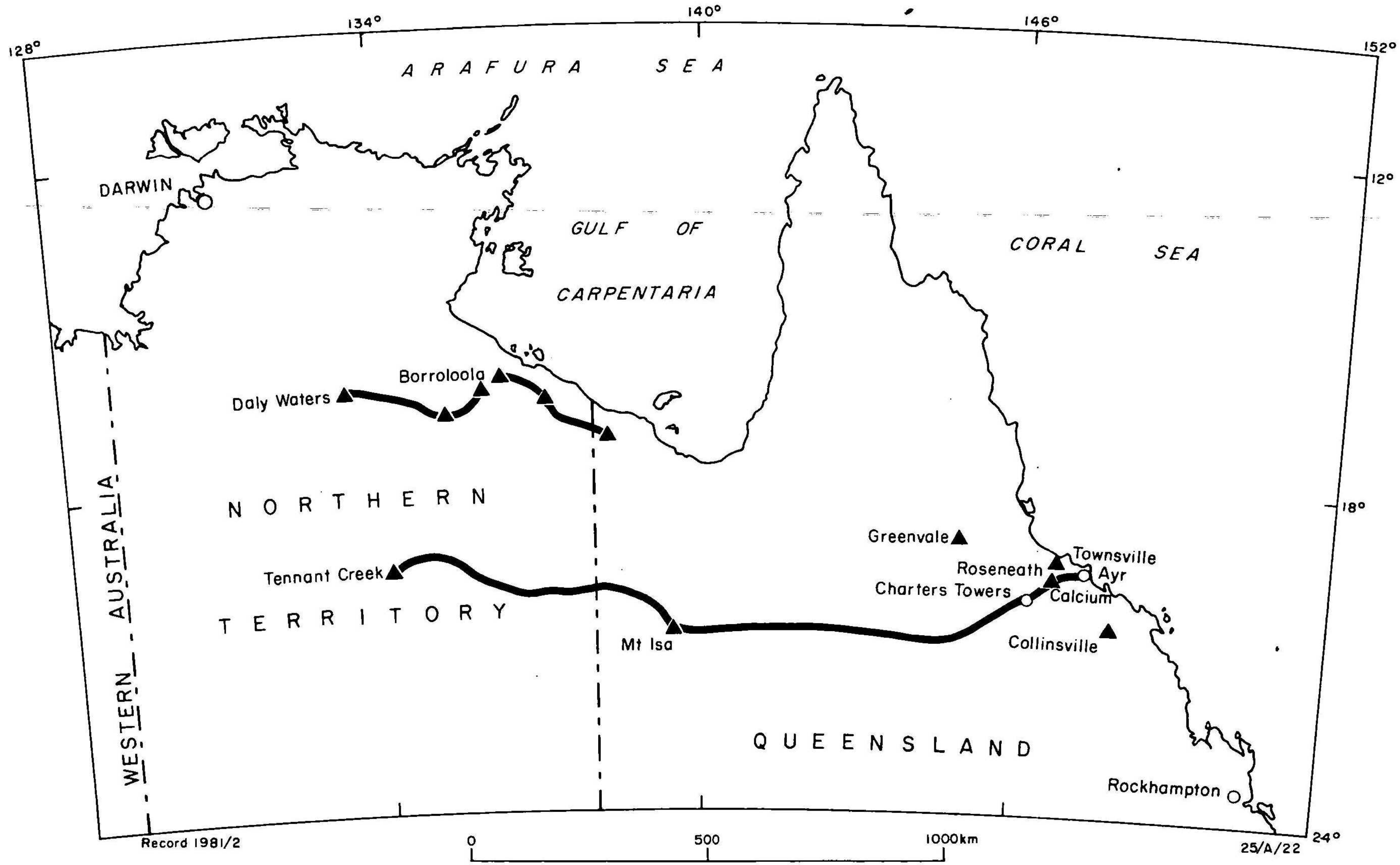
SUMMARY

During 1979 BMR, in cooperation with the Australian National University (ANU), undertook three seismic surveys in northern Australia (Fig. 1) as part of a research program into the structure of the Australian continental crust and upper mantle. This Record describes the survey operations and provides data required for subsequent interpretations.

In the first survey (June-July), recordings were made along two long-range seismic lines in the McArthur Basin to investigate the crustal structure east and west of the Emu Fault. Each line was about 300 km long with 15 km station spacing, reduced to 5 km station spacing near the fault. Altogether, 71 stations were occupied; four 2000 kg and four 400 kg shots were fired during the recording period.

In the second survey (July-August), recordings were made at 21 sites between Nobles Nob and Warrego mines, Tennant Creek, a distance of 57 km, as part of an investigation of the relation between ore bodies and geological structure in the Tennant Creek area. To record deeper information, a 5 tonne shot was detonated by BMR at the Skipper Extended mine southwest of the township, and recorded along an eastward line to Barry Caves by BMR recorders, and beyond that to Julia Creek by ANU recorders. BMR station spacing was 10-20 km; ANU station spacing was 40-50 km. This was reversed by a 40 tonne quarry blast at Mount Isa. A similar recording scheme was adopted with BMR recorders deployed between Mount Isa and Barry Caves, and ANU recorders westward beyond that to Tennant Creek, and eastwards to Julia Creek. Apart from the deeper crustal structures of the Tennant Creek Block, this line will provide information on the Mount Isa Block and the intervening structure beneath the Georgina Basin.

Finally, BMR recorders were deployed for two weeks in August between Julia Creek and the coast south of Townsville. With the ANU recording stations, a continuous recording line extended 1330 km from Tennant Creek to the coast. The purpose of this line was to record earthquakes in the Fiji-Tonga and Banda Sea regions as part of an investigation of the upper mantle. Mine-blasts at Greenvale, at Collinsville, and around Townsville were recorded to provide information on the local crustal structure.



▲ *Shot location*

▬ *Recording line*

○ *Town*

Fig. 1 Location of seismic recording lines in 1979

PART 1: McARTHUR BASIN

INTRODUCTION

The McArthur Basin in the Northern Territory contains a number of economically important ore deposits, and has potential for further discoveries. The search for new deposits requires an understanding of the structural history of the Basin and its effect on the genesis of the deposits.

The main feature of the southern McArthur Basin, where this survey was conducted, is the Batten Trough, which is about 60 km wide, flanked by the Bauhinia Shelf on the west and the Wearyan Shelf on the east. The Emu Fault defines the eastern boundary of the Batten Trough (Fig. 2). One objective of the investigation was to define the major tectonic differences between the Batten Trough and the Bauhinia and Wearyan Shelves, and the nature of their boundaries. A possible difference in crustal structure is evidenced by flood basalts on the shelves and their absence in the trough.

The major faults which bound the Batten Trough may have acted as channels for ore solutions; a study of their present structure, such as the depth and throw, is important in understanding the history of the ore deposits. In particular, the Emu Fault was to be investigated because of its proximity to the H.Y.C. ("Here's Your Chance") lead-zinc deposit and its structural control of the Bulburra Depression which hosts this deposit. Other important questions which need to be answered are whether the major faults antedate the McArthur Basin succession and whether the thickness of rock units changes abruptly at the fault or gradually over tens of kilometres.

Further objectives were to delineate the basement of the McArthur Basin, derive velocities and structures beneath the Mesozoic-Cainozoic cover west of the Mallapunyah Fault (Fig. 2), and identify any marker horizons.

Two long-range seismic refraction traverses were recorded during June-July 1979, west and east of the Emu Fault. Deep vertical reflection recordings were made at each of the six shot-points (Fig. 3). Each traverse was about 300 km long, and comprised 34 recording stations. The first traverse was between Daly Waters and H.Y.C. mine, along the Carpentaria Highway. Two large shots of 2000 kg each were located at Daly Waters and H.Y.C. respectively. Two smaller shots of 400 kg each were fired at H.Y.C. and 100 km west of H.Y.C., near O.T. Downs. For the larger shots, the station spacing was about 15 km, while for the smaller shots, the spacing was about 5 km. A similar pattern was recorded along the second traverse, east of the Emu Fault, with large shots at Borroloola and Westmoreland, and smaller shots at Borroloola and Robinson River. Figure 4 shows the shot/station configuration for each traverse.

GEOLOGICAL SUMMARY

The McArthur Basin is a Proterozoic Basin situated in the Northern Territory and covering an area of 170 000 km^2. It extends around the western side of the Gulf of Carpentaria, from the Alligator River area in the north to the Queensland border in the south. It includes the greater part of Arnhem Land and the western Gulf of Carpentaria drainage system. The geology of the area has been described by Plumb & Derrick (1975) and Plumb (1977).

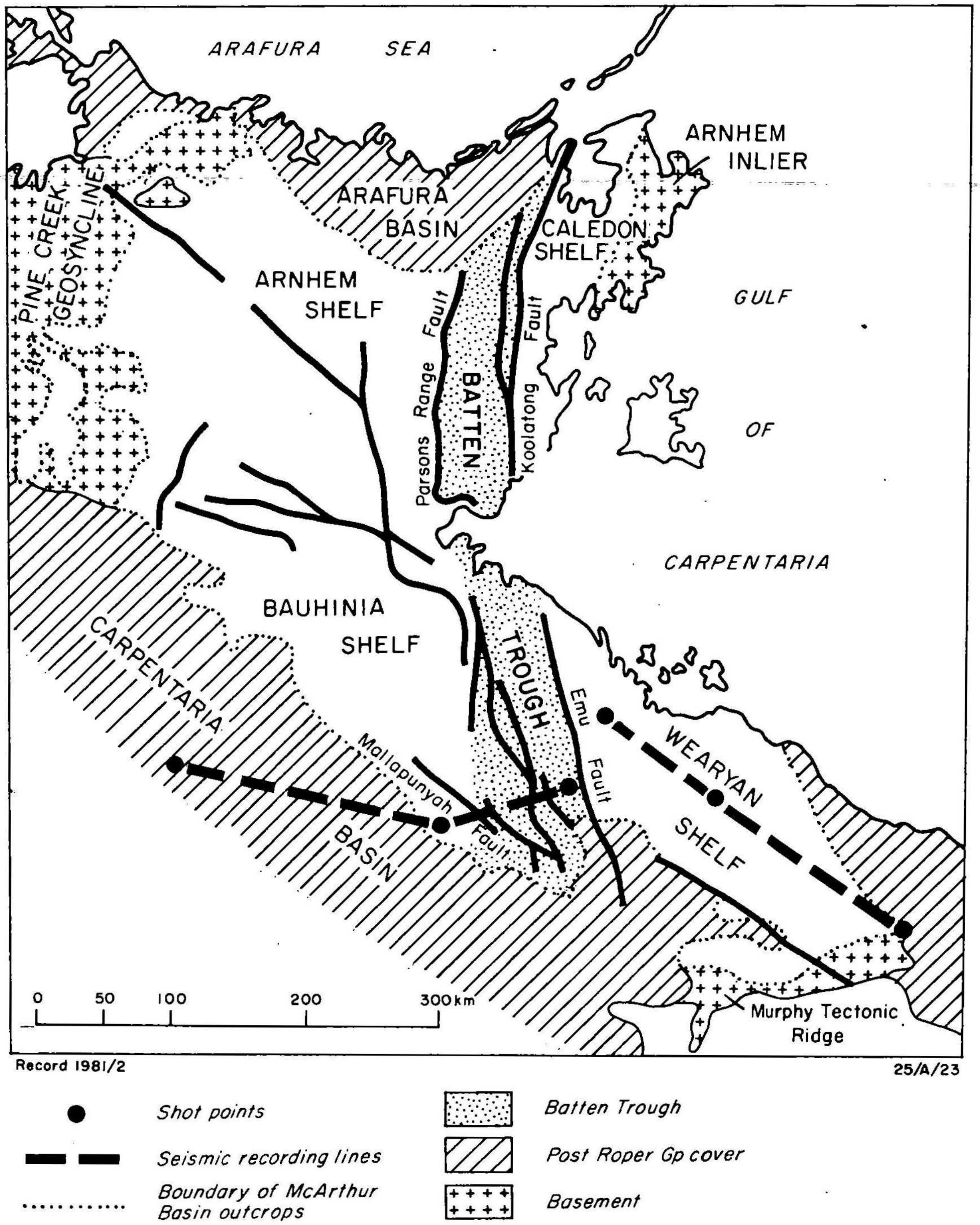


Fig. 2 Major tectonic elements, McArthur Basin (After Plumb and Derrick, 1975)

The McArthur Basin is a relatively undeformed structure of mainly shallow-water sediments (Fig. 2). It is bounded by Early Proterozoic inliers of the Pine Creek Geosyncline in the northwest, the Arnhem Inlier in the northeast, and the Murphy Inlier in the southeast. The Palaeozoic Arafura Basin overlies it in the north, as do the Palaeozoic Georgina and Daly River Basins in the south and northwest respectively; the Mesozoic Carpentaria Basin overlies it in the west. It is unconformable with these basement and cover rocks. The full extent of the McArthur Basin is unknown.

The McArthur Basin succession is up to 12 km thick. Three groups, and their equivalents, are represented: the Carpentarian Tawallah and McArthur Groups and the Carpentarian to Adelaidean Roper Group. The Tawallah Group is up to 6 km thick and consists of sandstones and carbonates. It was deposited between 1750 and 1600 m.y. ago. The McArthur Group, up to 5.5 km thick, comprises predominantly carbonate rocks deposited between 1600 and 1500-1450 m.y. ago. The Roper Group comprises mainly sandstones and lutites up to 5 km thick, deposited between 1450-1300 m.y. ago. The sediments are predominantly shallow-water ones and are often remarkably uniform over large areas.

The fault-bounded north-trending Batten Trough, 50-60 km wide, runs down the axis of the basin and contains a thick Carpentarian succession. It is flanked by the broad, relatively flat-lying Arnhem, Caledon, Bauhinia, and Wearyan Shelves. Development of the Trough began in the north but achieved significance in the south only during McArthur Group times.

The east-bounding Emu and Koolatong Faults were active during deposition, and the Parson's Range Fault on the northwest side was also probably active. In the south, the western boundary of the trough was more or less gradational. Later, during the formation of the Roper Group, the maximum sedimentation shifted westwards to the Bauhinia Shelf. The effect of the Batten Trough faults on Roper sedimentation is unknown.

The sense of the faulting subsequently reversed, and the Batten Trough is now a horst. Deformation within the basin was more intense in the Batten Trough than in the surrounding shelves, and was related to block faulting along pre-existing basement faults. Although the evolution of the McArthur Basin has been dominated by vertical movements of up to 7.5 km along the major faults, it is evident that the overall control was by right-lateral horizontal displacements along the north-trending Batten Fault zone and left-lateral displacements along the north-west-trending faults (Plumb, 1979). Deformation of the McArthur Basin ceased before the development of the Arafura Basin.

LONG-RANGE SEISMIC REFRACTION/REFLECTION RECORDING EQUIPMENT

Recordings were made on 21 BMR automatic tape recording systems. These systems have been described by Finlayson & Collins (1980) and only a brief description is given here.

Four channels were recorded on tape: the seismic signal at two gain levels, a radio time signal from VNG, Lyndhurst, Victoria, and a coded clock signal. Each system consisted of a seismometer, amplifier, modulator, tape recorder, calibrator, clock, and radio receiver, as well as ancillary equipment such as power supplies.

Six systems used Precision Instruments (PI) recorders, recording on ½ inch tape, and fifteen used modified Akai tape decks recording on ¼ inch tape. The PI recording systems were rebuilt before this survey so that all the components of each system were contained in one case, and new radios were installed.

Each system used a single Willmore Mk II or Mk IIIA seismometer set to a free period of 0.75 seconds. The amplifiers were set to 96 dB gain at all recording sites; the low-gain channel on all systems was 24 dB below the high-gain, i.e. 72 dB.

The built-in filters were set to a passband of 0.01-20 Hz. All systems were programmed to record continuously between 0700 and 1800 hours local (Northern Territory) time each day, and remain on standby at other times. All recording systems had the same polarity with respect to the direction of ground motion.

Power was provided from 12 volt 80 ampere-hour lead-acid batteries. Minor problems occurred with some of the recording equipment, and caused the loss of 9 out of a possible 168 records (Fig. 3). Most of the losses were due to battery failure.

The recorded tapes were played back at BMR. A portable field playback system was used to play back some of the initial recordings, but the quality of the playback was very poor. However, it confirmed that the shots were being recorded along the traverse.

Two manual recorders were used for shot-timing at shot sites. Each consisted of a 2 Hz SIE geophone, whose signal was amplified by a TAM5 amplifier and then recorded on a Hellige Hellcoscript chart recorder. VNG radio time signals were recorded alongside the geophone signal so that

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the first break for each shot could be accurately timed. Whenever possible, these recorders were used to record at stations additional to the automatic recorders, and good recordings were made up to 276 km from the shot.

Trial recordings were made with a prototype tape-recording shot-timer. An AWA stereophonic cassette deck was modified to record the seismic signal from a geophone on one channel and VNG radio signals on the second channel. The cassette was later played back with the output recorded on a Sanei Visigraph recorder. Problems were encountered during playback, and further development is needed. However, several shots were timed accurately with this recorder.

Parallax errors occur between the recorded channels of the PI and modified Akai systems owing to head misalignment. These parallax corrections are listed in Table 10.

SHOTS

Description of shots

Shot statistics are listed in Table 1. Eight shots were fired during the survey: four of 2000 kg each and four of 400 kg. Small shots were fired at each shot site to provide weathering corrections for the seismic reflection recordings.

The explosive used was ICI Anzite Blue fired electrically from a shooting truck under radio control from the reflection recording truck. It was loaded into drill holes 27 m deep, with 100 kg in each hole. The large shots were loaded in a pattern of two rows of ten holes, each hole being 15 m from its neighbour. The small shots were loaded into a row

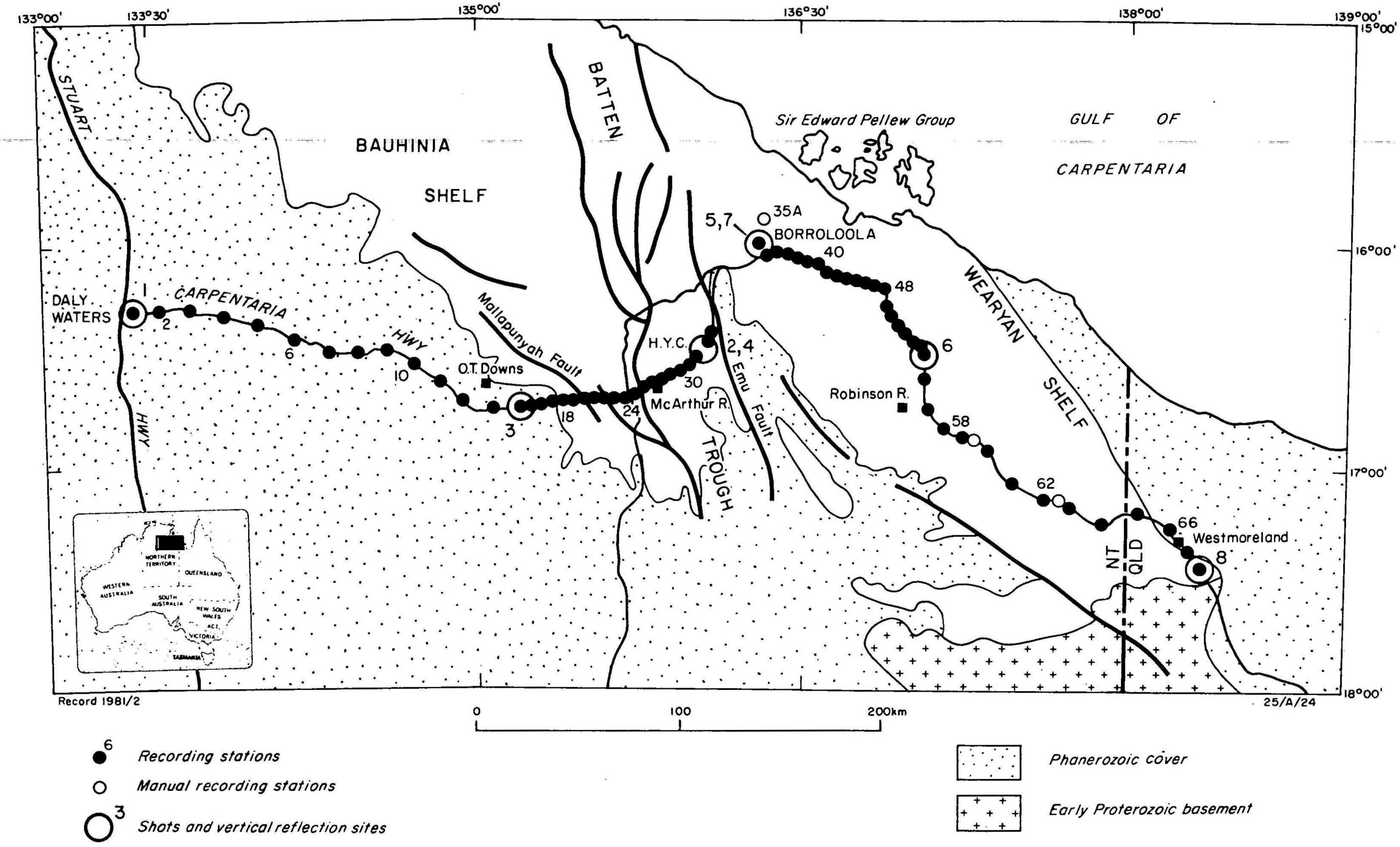

Fig.3 Locations of shots and recording stations and simplified geology, McArthur Basin.

of 5 holes, 15 m apart. In some cases, where drilling was difficult owing to unconsolidated rock and water, it was necessary to reduce the depth of each hole. Surface damage was minimal owing to the depth and dispersion of the charge.

The first two weathering shots were timed so that the distance to which these small shots could be recorded would be later established. These shots were 25 kg each, and from Daly Waters were recorded only as far as station 2 (14 km). However, they would probably be recorded farther from the other shot locations because Daly Waters proved to be the least favourable site for the larger shots.

Shot positions

The shot-hole patterns for all shots were surveyed by staff from the Australian Survey Office. The approximate positions of the shots, and the seismic reflection spreads, were chosen before the start of the survey. Accessibility and density of vegetation were final considerations in choosing the location. The latitudes and longitudes were scaled from 1:100 000 topographic maps using the Survey Office descriptions to position the shots on the maps (Table 1).

Shot timing

All shots were timed on site relative to VNG radio time signals by shot-timing recorders (see Equipment). Most shots were timed using two recorders, one located as near as possible to the shot, and the other 1.5 km away at one end of the seismic reflection spread. Past experience has shown that the radio signal sent from the recording truck to actuate the firing circuit on the shooting truck can interfere with the shot-timing recorder and produce a spurious first arrival on the record. For this reason, the timing was done at the ends of the spread cable, so the equipment was remote from the shooting truck. The time correction required because of the distance from the shot was determined accurately by using the travel-time to the nearest reflection geophone.

An experimental cassette recorder shot-timer was used at some shot sites. Unlike the chart-recording shot timers, this system can be left running for half an hour or more, depending on the length of the cassette. This is an advantage when communication with the shot-firer is difficult, as is the case when radio interference must be avoided.

RECORDING STATIONS

Station description

Altogether, 71 recording stations were occupied, 68 by automatic tape recorders and 3 by manually operated recorders (see Equipment).

Two traverses approximately 300 km long were surveyed (Fig. 3). The traverses were mirror images of each other, and the following description refers to the western traverse. The recording scheme is illustrated in Figure 4. The two large end shots were recorded at 21 equally spaced stations along the traverse, with a station spacing of approximately 15 km. The small shot (shot 3) 100 km from the eastern end was recorded to the west by 7 recorders at a 15 km station spacing, and to the east by 14 recorders at a station spacing of 5 and 10 km (Fig. 4). The small shot at the eastern end was recorded 100 km westward by 21 recorders at 5 km station spacing. A similar scheme applied to the eastern traverse.

Wherever possible, the seismometer was placed on rock outcrop, but at most sites it was buried in soil. Most sites along the eastern traverse were in very sandy soil. The recording equipment and batteries

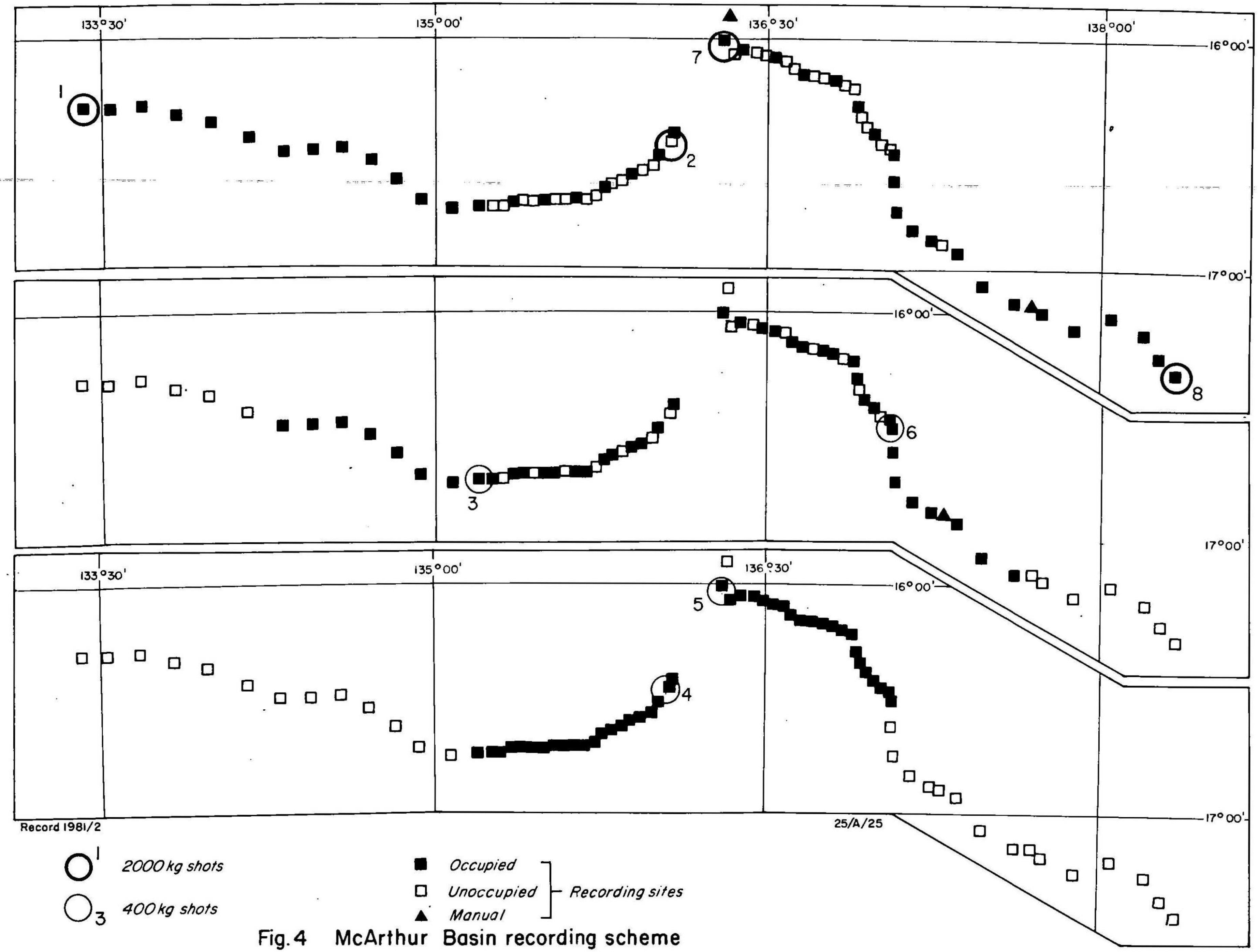

Fig. 4 McArthur Basin recording scheme

were protected by means of an aluminium coated "space blanket" as a shield from the sun, to reduce daytime temperatures within the recorders.

Station positions

All recording stations on the western traverse were along the Carpentaria Highway and, on the eastern traverse, along the Borroloola-Burketown road. The approximate station locations were flagged along the road prior to commencement of the survey; the actual recording sites were placed between 50 and 400 m off the road to avoid vandalism and minimise traffic noise.

The final positions were marked on 1:100 000 topographic maps by identifying features on the maps and measuring distances from the road, except for stations 58-61. Whenever possible, stations were located near prominent features on the map such as fence junctions and creek crossings. The latitudes and longitudes of the stations were then scaled off the maps to within 0.1 minutes of arc (i.e. approximately 200 m). Elevations were interpolated from the contours on the maps. These range between 40 and 310 m on the western traverse and 20 and 220 m on the eastern traverse.

Sites 58-61 could not be located on the 1:100 000 maps because of changes to the Borroloola-Burketown road. These sites were surveyed by staff of the Australian Survey Office using star observations.

A list of station latitudes and longitudes is given in Table 2. The start and stop times of recording at each station are also listed. This could be useful if, for instance, recordings of earthquakes occurring during this survey are required.

VERTICAL REFLECTION RECORDING

Vertical reflection recordings were made at the six refraction shot-points, and at a site near Starvation Hill between Borroloola and Westmoreland.

At each site a 3-km recording spread was laid along the road, i.e. along the same azimuth as the long-range refraction lines, centred on the refraction shot. A short cross-spread 1 km long was laid at one end of the long spread, either making a "T" shape with it or an "L" shape with it, depending on access. The main spread had 36 recording stations at 83.33 m intervals; the short spread had 12 stations, and the same interval. Each recording station had 8 geophones per trace, in line, 5 m apart.

Reflections were recorded from the large refraction shots at each site, as well as the small weathering shots. The large shots were offset 15 to 30 m from the centres of the main spreads; the weathering shots were fired at each end of the main spreads. Details of these shots have been discussed earlier.

Digital recordings were made by BMR's DFS IV recording system, on tape; analogue records were produced in the field for monitoring purposes. Recordings were made at a sampling interval of 4 ms and the records were run for a total of 16 s.

The tapes were sent to Geophysical Services International, Sydney, for processing. This included true-amplitude recovery, time variant scaling, correction for datum statics, normal move-out corrections, muting, and whitening deconvolution. At H.Y.C. and Borroloola, the two small weathering shots produced excellent reflections, so a 4-fold stack could be performed on the data. A time-varying filter was applied, with a 20-50 Hz passband at 0 s varying to an 8-30 Hz passband at 16 s. The processed section was produced as a variable area display, 6 cm/s and 6 traces/cm.

Good vertical reflections from depths between 2 and 45 km were recorded at all locations except Daly Waters and O.T. Downs. At these two sites the shallow subsurface conditions probably attenuated the reflections.

PART 2: TENNANT CREEK-MOUNT ISA

INTRODUCTION

A number of gold and copper mines have been worked in the Tennant Creek area for many years. Some are still active, and others are being developed. To assist in understanding the relationship of these orebodies to the local geological structure, it is necessary to map the deeper structures in the area, such as fault and shear zones, and relate these to the surface geology.

A request for BMR to carry out a reconnaissance seismic refraction survey in the vicinity of Tennant Creek township was made by the Northern Territory Department of Minerals and Energy. In July 1979, BMR recorded a traverse between the Nobles Nob and Warrego mines. This traverse was 57 km long and was expected to delineate the structure of the outcropping granites and sediments, and provide velocity information about these rocks (Fig. 5).

To investigate the deep crustal structure of the Tennant Creek Block, BMR detonated 5 tonnes of explosive in the Skipper Extended mine, an abandoned mine shaft southwest of Tennant Creek (Fig. 5). Recordings were made by BMR and the Australian National University (ANU) recorders along the Barkly Highway to Mount Isa, and further east as far as Julia Creek by ANU recorders alone (Fig. 6). This line was reversed by recording a mine-blast at Mount Isa with a similar station deployment as above. This traverse was shot to provide information on structures between the Tennant Creek Block and the Mount Isa Orogen, beneath the intervening Georgina Basin, and provide some details of structures in the Mount Isa region.

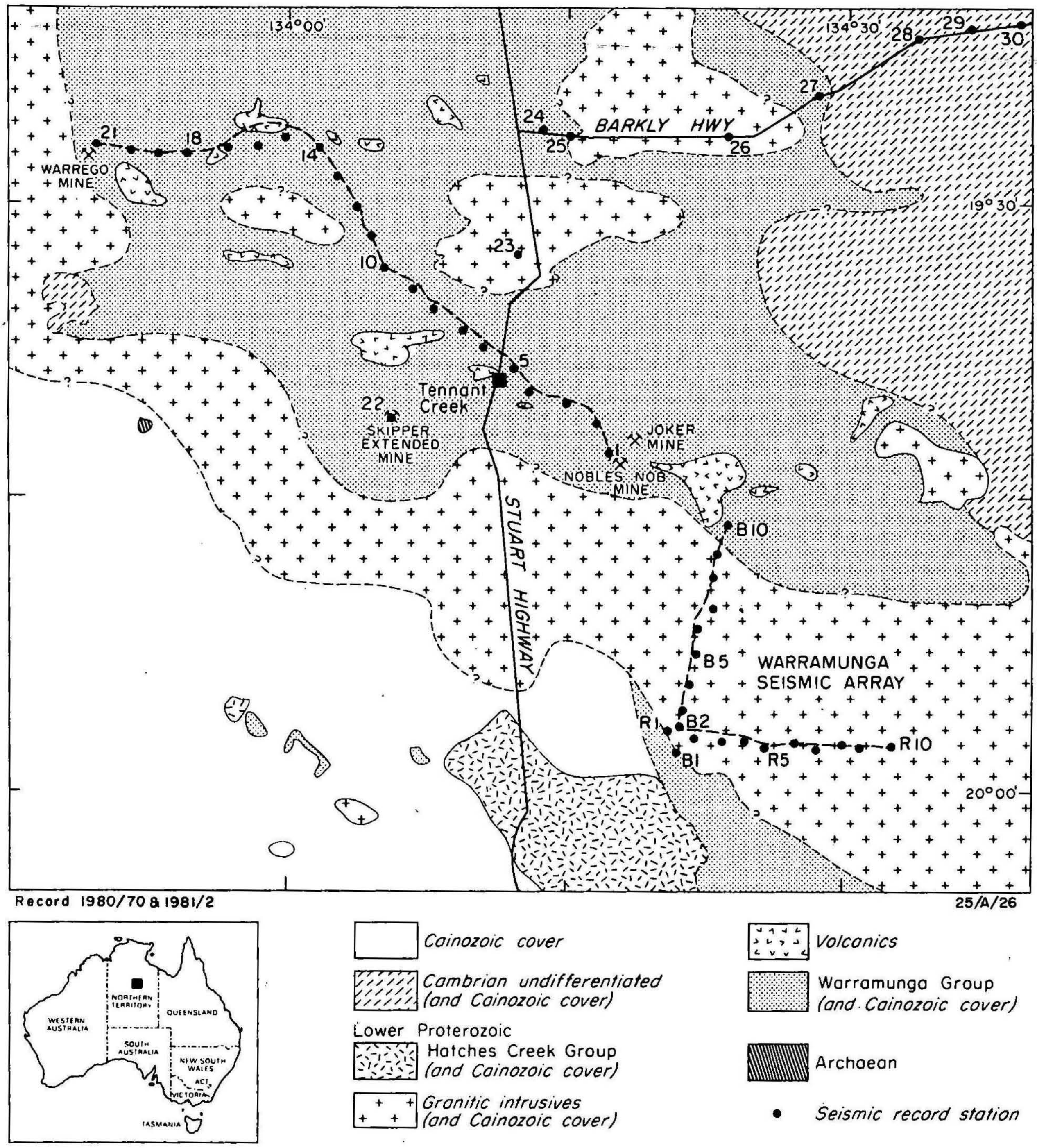

Fig. 5 Location of Shot and Recording sites and General Geology Tennant Creek Block

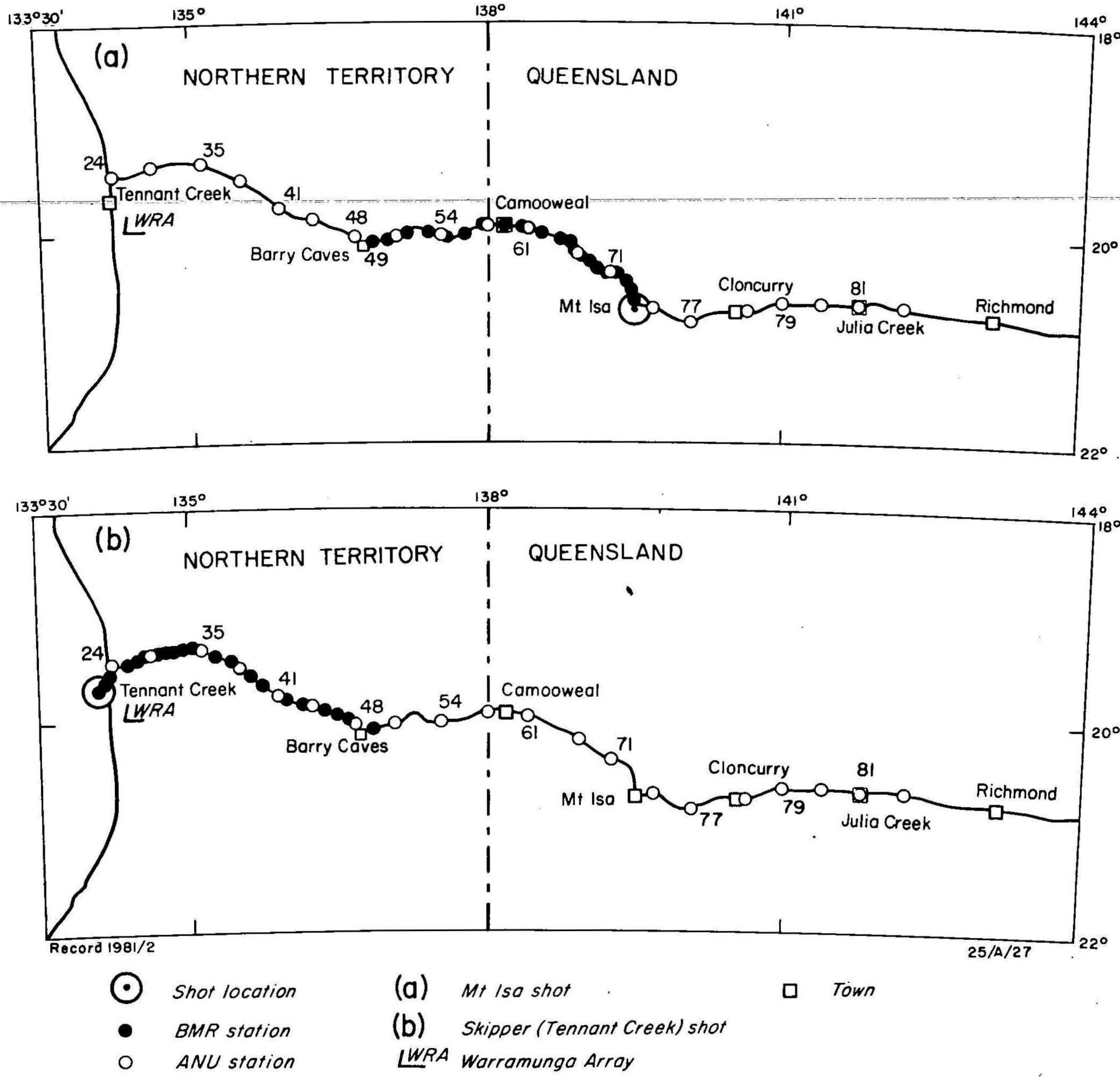

Fig. 6 Tennant Creek — Mount Isa location diagram

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The shots in the Tennant Creek area and at Mount Isa were recorded also at the ANU Warramunga seismic array, southeast of Tennant Creek (Fig. 5).

GEOLOGICAL SUMMARY

The recording traverses discussed in this section are located over the Tennant Creek Block, the Georgina Basin, the Mount Isa Orogen, and the northern Eromanga Basin (Figs. 5, 7).

The geology of the Tennant Creek area has been summarized by Crohn (1965, 1975). The major rock group in the Tennant Creek area is the Lower Proterozoic Warramunga Group, which consists of greywackes and shales, including a distinctive group of hematite shales, with some tuffs and acid volcanics, and a total thickness of over 4000 m. It is folded about eastwest axes, with the intensity of folding decreasing away from the centre of the outcropping area. A major northwest trending fault zone runs through the area, but of greater importance to the location of mineralization are two sets of less well exposed west-northwest and northeasterly trending shear zones.

The basement below the Warramunga Group is not exposed, but drilling shows it is probably Archaean quartz-feldspar-garnet gneiss and amphibolite.

Granites, both massive and foliated, and adamellite, granite porphyry and quartz-feldspar porphyry, intrude the Warramunga group. Ignimbrites in volcanic plugs and lack of strong contact metamorphism show that the emplacement was at a high level. These intrusive bodies were probably not directly responsible for the mineralization, but may have provided the conditions for remobilization and concentration. Basic intrusions which occur at numerous localities post-date the granites and ore bodies.

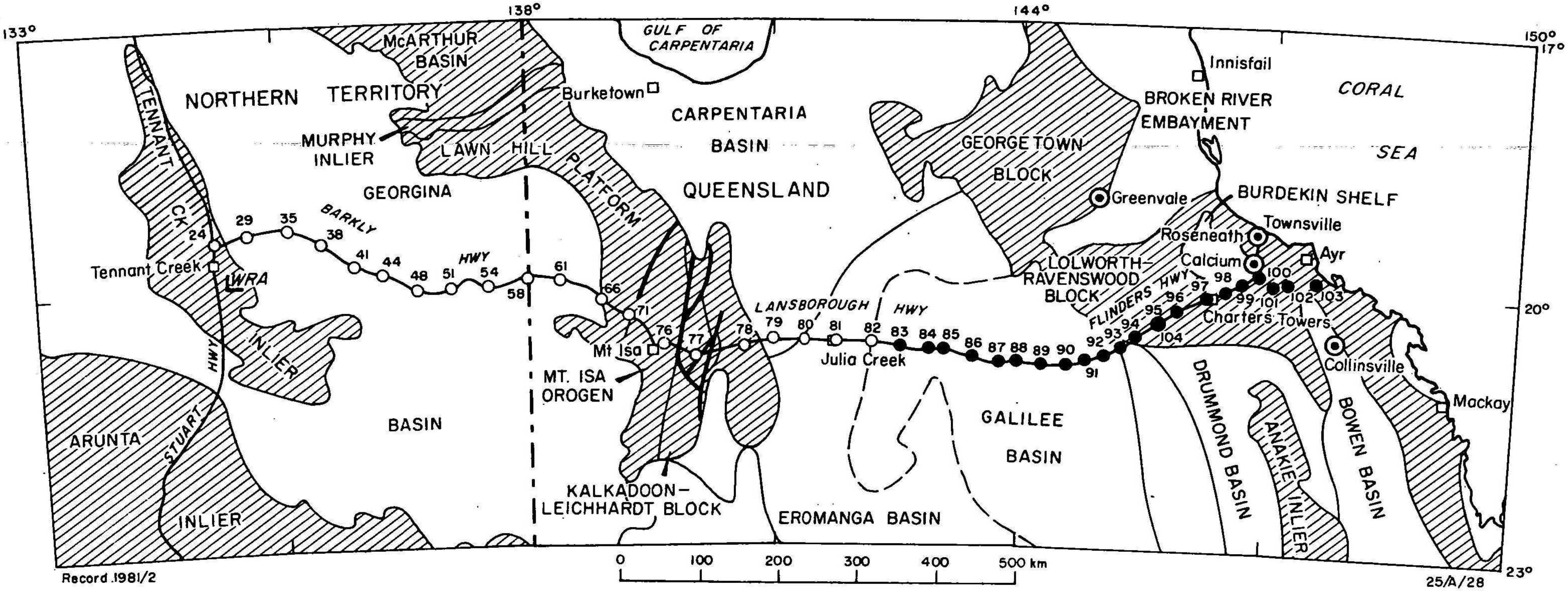
Ironstones and copper/gold/bismuth deposits are confined to the Warramunga Group. They developed preferentially at the intersections of shear zones, or at the intersection of shear zones and favourable sedimentary beds such as the hematite shale beds.

The Warramunga Group is unconformably overlain by the Carpentarian Hatches Creek Group south of the Tennant Creek area. Upper Proterozoic conglomerates and mudstones occur in a small synclinal structure south of Nobles Nob. Lower Cambrian sediments and volcanics are flat-lying over all other rocks in the area, and therefore the evolution of the Tennant Creek rocks was completed by the Cambrian.

The Georgina Basin overlies the Tennant Creek Block to the east. It is an elongated northwesterly trending sedimentary terrain of dominantly Middle Cambrian to Middle Ordovician age. It is generally flat-lying with a maximum thickness of 2.7 km; carbonates dominate the sequence. The basement to the east is comprised of sediments of the McArthur Basin and Mount Isa Orogen.

The geology of the Mount Isa region is summarized by Henderson (1980) and Plumb & others (1980). Various names have been applied to the tectonic elements of the region; the terminology used by Plumb & others (1980) will be used here (i.e. Mount Isa Orogen/Lawn Hill Platform).

The Proterozoic Mount Isa Orogen lies on the eastern edge of the North Australian Craton. It is considered to have been a continental margin belt, while the penecontemporaneous McArthur Basin represented a linear marine embayment. The Mount Isa Orogen contains three major palaeogeographic units; the sedimentary sequences in these units are



Shot location

BMR station

ANU station

WRA Warramunga array

Town

Fig.7 Tennant Creek to Townsville recording line

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similar to those of the McArthur Basin, but are usually thicker and contain more volcanics. They have also been more deformed, metamorphosed and intruded by granite. A central north-trending granitic and volcanic basement inlier, the Kalkadoon-Leichhardt Block, was an elevated block during the early history of the orogen. It separates the moderately thick and intensely folded sequences of the Mary Kathleen Fold Belt to the east from the thicker sequences of the Leichhardt River Fault Zone to the west.

The Mary Kathleen Fold Belt was a shelf of mainly shallow-water sediments which has undergone extensive regional metamorphism, complex folding, and granitic intrusion. The Leichhardt River Fault Zone was a similar feature to the Batten Trough in the McArthur Basin, but contains vast quantities of basalt. The sedimentation, vulcanism and basin development have been controlled largely by major long-acting north-trending lineaments, some of which have controlled post-depositional faulting, metamorphism, and intrusion in the orogen.

The Lawn Hill Platform sequences to the north are less deformed than those of the Mount Isa Orogen. They thin abruptly towards the Murphy Inlier, which separates them from the contemporaneous McArthur Basin sediments.

The Eromanga Basin is a flat-lying Mesozoic sedimentary basin overlying the Proterozoic Mount Isa Orogen on its western margin and the Carboniferous-Triassic Galilee Basin towards the east. It contains marine and freshwater sediments which are generally flat-lying; the maximum thickness is about 2.7 km.

FIELDWORK

The BMR recording equipment and procedures were the same as those in the McArthur Basin (Section 1). Shot timing was also similar, and because the approximate detonation times of the shots were known, the recorders were run for short periods only.

Tennant Creek area

Recordings were made at 21 stations along a traverse between Nobles Nob open-cut gold mine and Warrego underground gold/copper mine, using the blasting at these mines as seismic sources (Fig. 5). The traverse was 57 km long and station spacing averaged 3 km (Table 6). One shot from each of these mines was recorded and shot details are listed in Table 4. An attempt was made to record a Warrego shot along a line south of the mine, over the Cabbage Gum granite, to obtain the seismic velocity of the granite directly. Unfortunately the shot was postponed and lack of time precluded a further attempt.

Both shots were recorded at the ANU Warramunga seismic array. The array comprises ten short-period vertical seismometers along a roughly north-south line (the Blue line) and another ten seismometers along an east-west line (the Red line). Each arm of the array is approximately 20 km long.

Tennant Creek-Mount Isa

Thirteen ANU recording systems were deployed along the Barkly Highway between Tennant Creek and Mount Isa, and 7 more between Mount Isa and Julia Creek. The station spacing was between 40 and 50 km. These stations were deployed primarily to record earthquakes (see Section 3) and were run continuously for the duration of the BMR recording period.

The ANU systems are direct-write tape recorders which record vertical seismic at 3 gain levels, clock and radio signals (Muirhead & Simpson, 1972). Owing to their low power requirements and low speed, they were able to operate unattended during the whole of the recording period.

To record a quarry blast at Mount Isa, 21 BMR recorders were placed along the eastern half of the Tennant Creek-Mount Isa line, between Barry Caves and Mount Isa, a distance of 280 km (Fig. 6a). Within 100 km of Mount Isa the BMR station spacing was about 10 km; beyond 100 km the station spacing was about 20 km. Six ANU stations were within this distance range from Mount Isa, and 7 were between Barry Caves and Tennant Creek. Seven ANU stations recorded along the Lansborough Highway east of Mount Isa to Julia Creek, and the shot was recorded at the Warramunga array.

The Mount Isa shot was a 40-tonne blast at the Kennedy siltstone minefill open-cut quarry operated by Mount Isa mines northwest of the township (Table 4). The blast was detonated in 18 rows of drillholes with a 25 ms delay between each row. The charge detonated per row was between 250 kg and 4460 kg, with 1674 kg in the first row.

This shot was reversed by an especially detonated shot near Tennant Creek. The BMR recorders were re-deployed at the western end of the line, between Tennant Creek and Barry Caves, a distance of 290 km (Fig. 6b). Within 100 km of Tennant Creek the station spacing was about 10 km, and beyond 100 km, about 20 km. Seven ANU stations were within this distance range from Tennant Creek, and 13 others as far east as Julia Creek.

The shot was fired in the Skipper Extended mine, an abandoned gold mine. The mine consisted of a vertical shaft from the surface, 40 m deep, with a drive 40 m long at the bottom (Fig. 8). Smaller drives occurred halfway down the shaft and at the bottom. Five tonnes of Ammonium Nitrate-Fuel Oil mixture (ANFO) were detonated at the end of the long drive at the bottom of the shaft, in a small gallery sufficiently large to hold the charge. The ANFO was mixed underground and stacked in bags. Little stemming was used, but the force of the blast was contained to a certain extent by the right-angle change in direction from the gallery to the drive, and from the drive to the shaft. The entire charge was fired instantaneously by electric detonators in gelignite boosters.

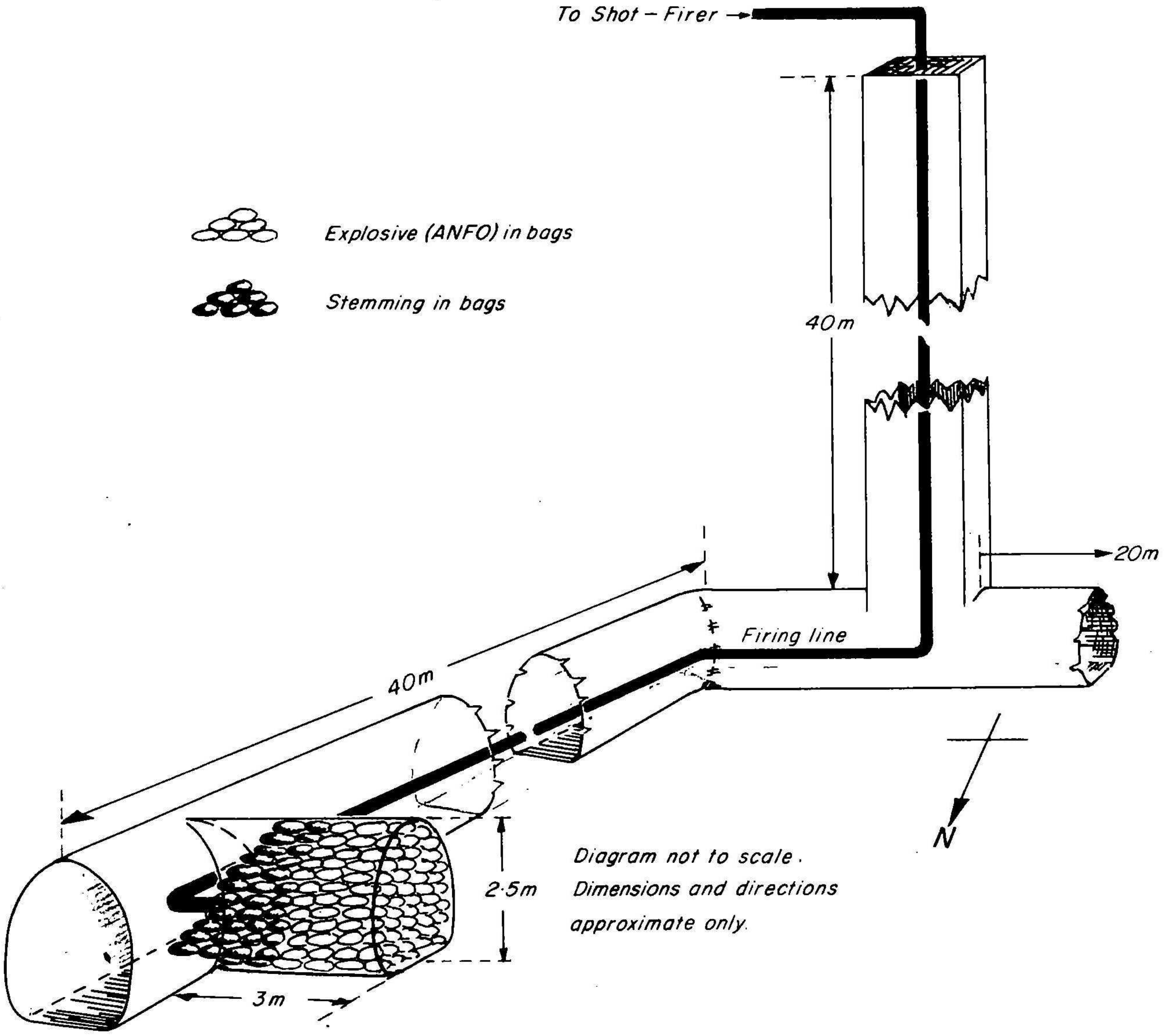

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Fig.8 Diagrammatic sketch of Skipper Extended mine, Tennant Creek

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PART 3: EARTHQUAKE RECORDING, TENNANT CREEK-TOWNSVILLE

INTRODUCTION

As part of a cooperative project with ANU, BMR deployed 21 recording systems between Julia Creek and the coast, south of Townsville. With the ANU stations already deployed between Tennant Creek and Julia Creek, a continuous recording line, 1330 km long with station spacing of between 25 and 50 km, extended between Tennant Creek and the coast (Fig. 7). The purpose of this line was to record earthquakes in the Fiji-Tonga region to the east and Banda Sea to the northwest, as part of an investigation of the upper mantle.

While the BMR stations were deployed, quarry blasts were timed at Collinsville, Greenvale and Roseneath (Fig. 7, Table 7), and additional blasts were detonated at Calcium. Though not ideally placed with respect to the recording line, these shots should provide some information on the velocity-depth structures in the area.

GEOLOGICAL SUMMARY

The geological provinces crossed by the western half of the traverse have been discussed in Section 2. The eastern half, occupied by BMR stations between Julia Creek and Ayr on the coast, was situated over the sub-surface Galilee Basin in the west and the Lolworth-Ravenswood Block in the east.

The Carboniferous-Triassic Galilee Basin is covered almost entirely by the Jurassic-Cretaceous sediments of the Eromanga Basin in the survey area. The Galilee Basin sediments are mainly terrigenous and

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are relatively undisturbed. The basement is not known, but Devonian sequences are continuous beneath the Carboniferous in one area.

The Lolworth-Ravenswood Block is a remnant of a once-extensive metamorphic terrain of Pre-Cambrian or Lower Palaeozoic age. It was intruded by Middle Ordovician and Late Silurian granitoids, which now form the major part of the block.

The traverse passes south of the Burdekin Shelf, a thick, partially marine, blanket of Middle Devonian-Early Carboniferous age, unconformable on the Lolworth-Ravenswood Block. The most easterly stations are situated on the Coastal Ranges Igneous Province, a Late Palaeozoic igneous suite which forms an almost continuous sequence between Townsville and Cairns.

The Collinsville coal mine is situated in the northern tip of the Permo-Triassic Bowen Basin. The Greenvale nickel mine is a lateritic deposit on Devonian serpentinites on the northern edge of the Broken River Embayment. The Calcium limestone quarry is situated on the southern edge of the Burdekin Shelf.

FIELDWORK

The BMR recorders were deployed for 15 days and were run continuously during this period (Table 8). Batteries were changed every two days, or when unavoidable, every three days. In some cases the recorder had stopped after three days. The ¼ inch tapes were changed half-way through the recording period. 3600-foot tapes were used on the ¼-inch recorders (normally 1800-foot tapes are used). One 7200-foot tape was used on each of the ½-inch tape recorders. Otherwise the field procedures were the same as previously (see Sections 1 and 2).

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Shots were timed at Greenvale, Collinsville and Roseneath. Earthquakes and local blasts were monitored at the Queensland University seismic observatory at Charters Towers.

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COMMENTS ON 1979 OPERATIONS

To date, most events recorded have been played back and digitised at BMR, except shots in the Townsville area. The shots at Daly Waters and OT Downs were not recorded well, probably due to near-surface effects at the shot-sites such as deep weathering. This is borne out by the lack of useful vertical reflections at Daly Waters and OT Downs. The quality of the recordings from the eastern traverse in the McArthur Basin was much better than the western traverse, despite the fact that the majority of the stations were on very sandy soil, whereas many on the western side were on rock. The 400 kg shots were too small for the required 100 km recording range; the arrivals at the farthest stations were too small and emergent to allow much confidence in arrival times and velocities derived from them. The 2000 kg shots on the western traverse were inadequate also at the farther stations, but on the eastern side were well recorded, even at the farthest stations. Because so many unknown factors are involved in designing a survey such as this it would be advisable to use larger shots in the future unless prior experience in the area dictates otherwise.

Good vertical reflections were obtained, even with the small weathering shots, at all localities except those already mentioned above. Large charges do not improve the records in these cases because the reflections are masked by reverberation noise, rather than being absent owing to insufficient energy.

The 5-tonne Skipper shot at Tennant Creek was much better recorded than the 40-tonne shot at Mount Isa. This is probably mainly due to the fact that the Skipper shot was detonated instantaneously, and at 40 m depth, in contrast to the Mount Isa blast, which was fired with delays and designed to break rock on the surface. The local geological conditions may also have been a contributing factor, as well as the orientation of the shot pattern at Mount Isa, which may have given a certain degree of directionality to the seismic energy.

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APPENDIX: BMR Personnel and Vehicles

The total fieldwork period was between 24/5/79-6/9/79. The fieldwork was undertaken by the following personnel -

D.M. Finlayson	(11/7 - 21/8)
C.D.N. Collins	
J.W. Williams	
D.P. Pownall	(8/6 - 20/7)
H. Hughes	(20/7 - 6/9)

Vehicles used were three International D1310 30 cwt trucks and one short-wheelbase Landrover. Seven recording systems, plus 24 80 ampere-hour batteries were carried in each truck. In addition, spare batteries, equipment and vehicle spares, and camping equipment were carried. Normally, one operator deployed and serviced seven recording systems.

TABLE: 1 SHOT STATISTICS: MCARTHUR BASIN

No.	DATE 1979	SIZE (KG)	TIME D	H	M	S	LAT Deg	Min	LONG Deg	Min	ELEV M	LOCATION
			(NT local time)									
1	14/6	2000	14	08	29	30.41	16	18.50	133	24.89	215	Daly Waters
2	15/6	2000	15	16	42	10.46	16	27.95	136	02.78	40	H.Y.C.
3	19/6	400	19	13	23	03.26	16	44.02	135	11.90	246	O.T. Downs
4	20/6	400	20	13	54	42.63	16	27.95	136	02.78	40	H.Y.C.
5	27/6	400	27	12	18	39.24	16	01.62	136	18.23	16	Borroloola
6	29/6	400	29	12	27	53.62	16	31.10	137	03.63	60	Robinson River
7	5/7	2000	35	12	00	10.36	16	01.62	136	18.23	16	Borroloola
8	7/7	2000	37	12	10	59.74	17	27.43	138	21.30	75	Westmoreland

TABLE 2

RECORDING STATIONS - McARTHUR BASIN

NO.	LATITUDE DEG	LATITUDE MIN	LONGITUDE DEG	LONGITUDE MIN	ELEV. M	SET NO.	TAPE NO.	ON D	ON H	ON M	OFF D	OFF H	OFF M	NOTES
1	16	18.22	133	24.89	220	002	1	13	09	59	17	16	23	
2	16	18.22	133	32.00	260	001	1	13	09	27	17	16	52	
3	16	17.39	133	40.54	240	017	1	12	14	23	17	17	23	
4	16	19.76	133	49.78	240	003	1	12	13	15	17	(S)		5
5	16	21.90	133	59.10	280	010	1	12	12	47	18	(S)		5
6	16	26.05	134	09.26	300	016	1	12	12	08	18	10	44	
7	16	29.68	134	18.69	310	011	1,2	12	11	32	18	(S)		5
								18	11	37	19	15	06	
8	16	29.30	134	26.69	280	006	1,2	12	09	49	18	(S)		5
								18	10	03	19	15	51	
9	16	28.86	134	34.79	270	019	1	12	10	17	18	10	29	
								18	10	33	19	15	32	
10	16	32.25	134	42.46	280	004	1,2	12	10	38	18	11	01	
								18	11	01	19	15	08	
11	16	36.94	134	49.48	240	012	1,2	12	11	04	18	11	31	
								18	11	31	19	14	43	
12	16	42.55	134	56.05	270	018	1	12	11	30	14	11	20	
								18	11	55	19	14	14	
13	16	44.73	135	04.46	260	005	1,2	12	11	56	18	12	26	
								18	12	29	19	13	47	
14	16	44.19	135	11.94	240	013	1	12	12	34	18	(S)		5
								18	12	50	20	17	19	
15	16	44.02	135	15.36	250	010	1	18	14	10	20	17	40	
16	16	43.94	135	17.88	240	011	2	19	17	16	20	17	24	
17	16	42.88	135	20.77	240	017	1	12	10	57	18	(S)		5
								18	11	15	20	17	35	
18	16	42.49	135	23.50	210	001	1	18	15	12	20	(S)		5
19	16	42.82	135	26.52	190	019	1	19	17	58	20	16	40	
20	16	42.58	135	29.46	180	007	1,2	12	12	16	18	(S)		5
								18	12	27	20	17	05	
21	16	42.31	135	32.22	160	016	1	18	15	55	20	16	21	
22	16	42.17	135	35.35	140	006	2	20	09	08	20	16	09	
23	16	41.99	135	37.68	140	008	1	12	12	57	18	(S)		5
								18	13	-	20	16	33	
24	16	42.34	135	40.86	140	003	1	19	12	21	20	15	52	
25	16	41.16	135	43.73	80	012	2	20	10	02	20	15	44	
26	16	39.09	135	45.69	80	020	1	12	13	39	18	13	35	
								18	13	50	20	15	58	
27	16	37.96	135	47.92	80	002	1	18	18	13	20	15	23	
28	16	37.17	135	50.81	80	018	1	20	11	06	20	15	07	
29	16	35.70	135	53.06	80	009	1	12	14	50	20	15	27	
30	16	34.76	135	56.20	60	017	1	18	17	17	20	14	43	
31	16	33.42	135	59.18	60	004	2	20	11	45	20	14	40	
32	16	30.70	136	00.71	50	014	1	12	15	15	18	(S)		5
								18	14	55	20	14	57	

TABLE 2 (contd)

NO.	LATITUDE DEG MIN	LONGITUDE DEG MIN	ELEV. M.	SET NO.	TAPE NO.	ON D H M	OFF D H M	NOTES
33	16 26.90	136 03.71	40	005	2	20 12 21	20 14 19	
34	16 24.78	136 04.52	40	015	1,2	12 15 45	18 (S)	5
						18 16 14	20 14 28	
35A	15 59.15	136 19.70	20	-	-	MANUAL	RECORDER	
35	16 00.75	136 18.16	20	001	2,3	26 12 13	32 (S)	5
						34 16 32	37 12 42	
36	16 04.08	136 20.74	40	007	2	26 11 50	27 14 08	
37	16 02.64	136 23.32	20	011	2,3	26 13 34	34 17 44	
						34 17 44	37 13 37	
38	16 03.42	136 26.61	20	008	1	26 12 48	27 14 40	
39	16 04.43	136 28.97	20	006	2	26 11 44	27 14 45	
						28 16 35	32 (S)	5
40	16 05.26	136 31.93	20	003	1,2	26 14 40	34 18 20	
						34 18 20	37 14 09	3
41	16 05.86	136 35.05	20	020	1	26 13 53	27 15 07	
42	16 08.06	136 36.81	20	018	1	26 12 35	29 16 07	
43	16 09.25	136 39.52	20	017	1	26 15 40	37 14 46	
44	16 09.78	136 42.02	20	009	2	26 14 53	28 17 10	
45	16 10.04	136 45.18	20	005	2	26 13 30	29 16 09	
46	16 10.73	136 47.87	20	010	1,2	26 16 36	34 19 40	
						34 19 40	37 15 35	
47	16 12.05	136 50.60	30	014	1	26 15 45	27 15 40	
48	16 12.83	136 53.13	30	019	1	26 14 36	29 15 35	
49	16 17.55	136 54.08	30	002	2,3	26 17 15	34 20 20	
						34 20 20	37 16 09	
50	16 20.52	136 55.10	40	021	1	26 16 45	27 16 22	
51	16 23.11	136 56.63	40	013	2	26 15 32	29 15 06	
52	16 25.13	136 58.50	50	016	1	26 17 55	37 16 42	
53	16 27.23	137 00.65	60	004	2	26 16 30	27 17 01	
54	16 28.30	137 03.03	40	012	2	26 16 49	29 17 01	
55	16 30.28	137 03.71	60	015	2,3	27 08 00	33 (S)	5
						35 08 43	37 15 32	
56	16 37.17	137 03.95	80	008	1,2	29 08 45	33 (S)	5
						35 09 25	37 15 00	
57	16 45.21	137 04.84	120	020	1	29 09 22	33 15 52	
						35 09 53	37 14 27	
58	16 49.95	137 09.28	140	009	2,3	29 09 58	33 15 35	
						35 10 23	37 14 01	2
59	16 52.80	137 14.92	160	007	2,3	29 11 38	33 15 20	
						35 10 50	37 13 30	2
59A	16 53.42	137 17.85	160	-	-	MANUAL	RECORDER	2
60	16 56.07	137 21.69	100	014	2,3	28 17 54	33 14 40	
						35 11 18	37 12 58	2
61	17 04.70	137 28.34	180	021	1	28 16 56	33 14 16	

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TABLE 2 (Contd)

NO.	LATITUDE DEG MIN	LONGITUDE DEG MIN	ELEV. M	SET NO.	TAPE NO.	ON D H M	OFF D H M	NOTES
						35 11 46	37 12 19	2
62	17 09.08	137 37.24	200	004	2,3	28 15 42	35 (S)	4,5
						35 09 30	37 17 04	
62A	17 09.29	137 41.82	220	-	-	MANUAL	RECORDER	
63	17 11.25	137 44.58	170	006	2	35 08 44	37 16 25	4
64	17 15.52	137 53.25	60	019	1	34 17 15	37 15 42	4
65	17 12.52	138 03.25	50	012	3	34 16 27	37 14 56	4
66	17 16.73	138 12.29	60	013	3	34 15 51	37 14 19	4
67	17 22.55	138 16.53	63	018	1	34 15 17	37 13 35	4
68	17 26.90	138 20.48	60	005	2	34 14 25	37 13 02	4

NOTES

1. On/off times given in Days, Hours, Minutes. Days commence at 1st June.

2. Position surveyed by Department of Administrative Services surveyors.

3. Date on recorder 11 days slow.

4. Date on recorder 1 day fast.

5. (S) indicates recorder had stopped when station was visited (flat battery, etc.).

TABLE 3: DISTANCE VS FIRST ARRIVAL TIMES: MCARTHUR BASIN

TRAVERSE 1

STATIONS	SHOT 1		SHOT 2		SHOT 3		SHOT 4	
	D km	T s	D km	T s	D km	T s	D km	T s
1	0.52	0.30	281.69	-				
2	12.67	2.93	269.05	-				
3	27.95	5.99	254.01	40.07				
4	44.39	8.93	237.27	37.40				
5	61.25	-	220.45	-				
6	80.22	14.84	202.08	33.32				
7	97.97	17.83	185.26	31.25	98.25	18.77		
8	111.81	20.35	171.02	29.85	84.86	16.05		
9	125.91	22.63	156.60	27.06	71.68	13.12		
10	140.39	24.75	143.14	25.34	56.67	10.74		
11	154.34	26.47	131.45	23.35	41.94	8.06		
12	168.16	28.72	121.70	21.17	28.30	5.73		
13	183.64	30.77	108.24	18.98	13.29	3.00		
14	196.27	32.43	95.25	16.47	0.32	0.19	95.25	16.57
15					6.15	1.60	89.39	15.54
16							85.13	15.19
17	211.03	34.43	79.63	-	15.90	3.24	79.63	-
18					20.81	4.29	74.83	-
19							70.08	12.25
20	226.09	36.21	65.08	11.23	31.36	5.91	65.08	11.34
21					36.25	6.64	60.46	10.47
22							55.39	9.48
23	240.22	37.82	51.61	8.99	45.97	8.39	51.61	8.94
24					51.57	7.87	47.16	8.21
25							41.73	5.82
26	253.43	39.18	36.69	6.37	60.75	10.74	36.69	6.33
27					65.00	11.52	32.24	5.81
28							27.25	—
29	265.62	40.67	22.44	—	74.77	12.93	22.44	4.03
30					80.59	14.53	17.17	3.13
31							11.95	2.09
32	278.03	—	6.27	1.16	90.21	15.97	6.27	1.10
33							2.55	0.47
34	284.48	43.24	6.62	1.14	100.10	17.46	6.62	1.13

TABLE: 3 DISTANCE VS FIRST ARRIVAL TIMES

TRAVERSE 2

STATIONS	SHOT 5		SHOT 6		SHOT 7		SHOT 8	
	D km	T s	D km	T s	D km	T s	D km	T s
35A							276.28	41.95
35	1.61	0.50	98.47		1.61	0.51	271.02	41.40
36	6.37	1.32						
37	9.35	1.78	88.73	15.68	9.35	1.81	261.34	40.15
38	15.31	2.92						
39	19.84	3.63	78.94	14.02				
40	25.34	4.70	73.89	12.98	25.34	4.66	246.45	38.49
41	31.00	5.66						
42	35.20	6.47	63.93	11.48				
43	40.49	7.34	58.89	10.58	40.49	7.35	231.27	36.32
44	45.68	8.19						
45	50.50	8.98	50.88	9.24				
46	55.45	9.79	46.90	8.44	55.45	9.89	218.08	34.73
47	60.83	10.73						
48	65.57	11.49	38.54	7.10				
49	70.33	12.26	30.23	5.68	70.33	12.27	201.51	32.50
50	74.39	12.99						
51	79.08	13.73	19.30	3.73				
52	83.84	14.52	14.30	2.81	83.84	14.46	186.58	30.52
53	89.13	15.81						
54	93.77	16.23	5.27	1.15				
55	96.74	16.75	1.52	0.37	96.74	—	173.43	28.88
56			11.21	2.26	104.54	17.85	165.62	27.73
57			26.11	4.96	115.54	19.56	156.39	26.27
58			36.19	6.78	127.29	21.55	145.23	24.57
59			44.77	7.94	138.17	23.42	133.92	22.96
59A			48.31	8.52				
60			56.14	9.95	151.13	25.41	12[illegible].48	20.59
61			75.95	13.26	170.56	28.28	102.8[illegible]	17.68
62			91.81	15.84	187.43	30.74	85.42	14.84
62A					194.11	31.52		
63					200.19	32.33	71.58	12.39
64					217.08	—	54.33	9.50
65					227.99	36.31	42.18	7.46
66					245.60	38.17	25.38	4.78
67					257.87	39.82	12.34	2.37
68					268.22	41.08	1.75	0.44

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TABLE 4. SHOT STATISTICS: TENNANT CREEK-MOUNT ISA

No.	DATE 1979	SIZE (KG)	TIME H M S		LAT (S) Deg	Min	LONG (E) Deg	Min	ELEV. m	LOCATION
1	17/7	700	16 12 38.81	C	19	26.68	133	49.20	260	Warrego
2	19/7	2 000	11 59 42.65	C	19	43.00	134	17.50	350	Nobles Nob
3	26/7	40 000	11 59 50.41	EST	20	42.40	139	28.27	360	Mount Isa
4	9/8	5 000	16 15 00.93	C	19	40.66	134	05.50	320	Skipper

NOTES

1. C = Central Time.
   EST = Eastern Standard Time.
   Central Time = Eastern Standard Time - 30 minutes.

2. The Warrego shot was detonated underground at a depth of 643 m. The Skipper shot was detonated underground at a depth of 40 m. Nobles Nob and Mt Isa are open-cut operations.

3. The Mount Isa blast comprised 18 rows with a 25 ms delay between each row. Charge per row varied between 250 and 4460 kg. Row 1 was 1674 kg.

Quarry/Mine Details

Quarry	Operator	Type
Mount Isa	Mount Isa Mines	Siltstone mine-fill
Warrego	Peko-Wallsend	Gold/copper
Nobles Nob	Australian Development	Gold

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TABLE 5

RECORDING STATIONS - NOBLES NOB TO WARREGO, TENNANT CREEK

NO.	LATITUDE DEG	LATITUDE MIN	LONGITUDE DEG	LONGITUDE MIN	ELEV. M	SET NO.	TAPE NO.	ON D H M	OFF D H M	NOTES
1	19	42.43	134	17.30	350	004	3	17 10 35	18 10 48	
								19 11 11	19 12 32	
2	19	40.91	134	16.48	340	006	3	17 10 23	18 10 54	
								19 11 00	19 12 51	
3	19	39.93	134	14.90	335	012	3	17 10 11	18 11 01	
								19 10 53	19 13 05	
4	19	39.22	134	12.98	360	018	1	17 09 56	18 11 08	
								19 10 43	19 13 17	
5	19	37.90	134	12.31	380	013	3	17 08 55	18 11 15	
								19 10 35	19 13 30	
6	19	36.98	134	10.26	400	005	3	17 08 42	18 11 22	
								19 10 14	19 13 43	
7	19	36.02	134	9.43	360	019	1	17 08 14	18 11 32	
								19 10 04	19 13 57	
8	19	35.02	134	7.70	350	015	3	17 11 40	18 10 22	
								19 10 21	19 15 04	
9	19	34.02	134	6.54	360	014	3	17 11 58	18 10 12	
								19 10 32	19 14 48	
10	19	33.17	134	5.20	360	020	1	17 12 11	18 10 02	
								19 10 42	19 14 26	
11	19	31.58	134	4.42	360	009	3	17 12 32	18 09 46	
								19 10 54	19 14 11	
12	19	29.97	134	3.61	350	008	3	17 12 55	18 09 40	
								19 11 08	19 13 53	
13	19	28.50	134	2.68	350	013	1	17 13 09	18 09 27	
								19 11 23	19 13 28	
14	19	27.02	134	1.73	360	007	3	17 13 24	18 09 15	
								19 11 50	19 12 49	
15	19	26.62	133	59.92	360	002	3	47 11 42	48 09 25	
								49 10 39	49 15 06	
16	19	26.89	133	58.35	340	016	1	47 11 57	48 09 33	
								49 10 49	49 14 46	
17	19	26.90	133	56.73	350	003	3	47 12 16	48 09 43	
								49 11 00	49 14 28	
18	19	27.22	133	54.70	340	017	1	47 12 34	48 09 55	
								49 11 11	49 14 00	
19	19	27.30	133	53.10	340	011	3	47 12 53	48 10 07	
								49 11 27	49 13 37	
20	19	27.04	133	51.67	340	010	3	47 13 09	48 10 17	
								49 11 41	49 13 17	
21	19	26.75	133	49.80	340	001	3	47 13 29	48 10 26	
								49 11 50	49 13 00	

NOTES

1. On/off times are in Days, Hours, Minutes (Central Time).

2. Recording period was 17-19 July. 47 days = 17 July, etc.

TABLE 6 - Shot-to-Station distances : Tennant Creek-Mount Isa

Warrego				Nobles Nob			
Station	Distance	Station	Distance	Station	Distance	Station	Distance
1	57.09	105	79.55	1	1.11	105	27.68
2	54.46	106	78.58	2	4.25	106	25.98
3	51.17	107	77.39	3	7.26	107	24.00
4	47.59	108	76.22	4	10.54	108	22.06
5	45.42	109	74.94	5	13.07	109	19.72
6	41.45	110	73.40	6	16.84	110	17.45
7	39.36	111	73.47	7	19.10	111	16.76
8	35.84	112	71.84	8	22.59	112	14.47
9	33.22	113	70.73	9	25.33	113	12.94
10	30.45	114	70.10	10	28.13	114	12.19
11	28.12	115	77.68	11	31.09	115	25.70
12	25.94	116	79.91	12	34.17	116	26.84
13	23.83	117	81.73	13	37.24	117	27.74
14	21.94	118	83.38	14	40.37	118	28.74
15	18.76	119	85.48	15	43.11	119	30.42
16	16.02	120	87.41	16	44.78	120	31.52
17	13.18	121	89.23	17	46.92	121	32.93
18	9.68	122	91.26	18	49.37	122	34.55
19	6.92	123	92.59	19	51.57	123	35.70
20	4.37	124	94.85	20	53.92	124	37.67
21	1.06			21	56.97		

1. Distances in kilometres
2. Stations 105-124 are Warramunga Array stations.

TABLE 6 (contd)

Mount Isa				Skipper			
Station	Distance	Station	Distance	Station	Distance	Station	Distance
24	31.98	63	466.47	22	0.06	42	196.67
29	52.38	64	475.29	6	10.74	43	215.03
35	97.72	65	480.62	23	19.59	44	224.33
38	129.71	66	485.15	24	30.35	45	238.70
41	167.03	67	488.51	25	30.95	46	251.72
44	203.06	68	497.74	26	40.84	47	265.63
48	250.82	69	506.38	27	50.04	48	272.20
49	269.43	70	516.13	28	60.55	49	290.82
50	284.91	71	521.87	29	65.06	51	314.20
51	292.85	72	528.24	30	69.47	54	361.74
52	306.54	73	540.36	31	78.72	58	410.40
53	325.43	74	546.27	32	87.99	61	452.58
54	340.42	75	551.64	33	97.75	66	506.49
55	346.30	76	571.85	34	107.27	71	543.26
56	366.77	77	613.85	35	115.24	76	593.26
57	383.58	78	670.97	36	126.78	77	635.25
58	389.17	79	706.94	37	143.83	78	692.37
59	407.83	80	747.43	38	149.69	79	728.33
60	425.62	81	789.28	39	160.79	80	768.82
61	431.34	82	834.45	40	173.20	81	810.66
62	445.85			41	188.16	82	855.83

Distances are in kilometres.

TABLE 7. SHOT STATISTICS: TENNANT CREEK-TOWNSVILLE

No.	DATE 1979	SIZE (kg)	TIME h	m	s	LAT (S) Deg	Min	LONG (E) Deg	Min	ELEV. m	LOCATION
1	22/8	14 500	14	21	42.59 EST	20	33.45	147	48.80	200	Collinsville
2	23/8	3 500	12	02	18.74 EST	18	57.90	144	55.30	520	Greenvale
3	28/8	-	14	02	27.12 EST	19	22.02	146	49.82	55	Roseneath

NOTES

1. EST = Eastern Standard Time.

2. Charge size at Roseneath unknown. Previous shots averaged 1-1½ tonne.

The following shots were fired during the recording period but were not timed:

Location	Date	Time	Size (kg)	Approx. Lat. Deg	Min	Approx. Long. Deg	Min
Greenvale	16/8	4.0 pm	3200	18	57.9	144	55.3
Greenvale	18/8	4.0 pm	12100	18	57.9	144	55.3
Greenvale	24/8	12 noon	4400	18	57.9	144	55.3
Calcium	23/8	-	1400	19	40.6	146	47.8

Quarry/Mine Details

Quarry	Operator	Type
Greenvale	Queensland Nickel	Nickel (open-cut)
Roseneath	Farley and Lewers (Qld.)	Aggregate
Collinsville	Collinsville Coal	Coal
Calcium	North Australian Cement	Limestone

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TABLE 8

RECORDING STATIONS - TENNANT CREEK TO TOWNSVILLE

NO.	LATITUDE DEG	MIN	LONGITUDE DEG	MIN	ELEV. M	SET NO.	TAPE NO.	ON D	H	M	OFF D	H	M	NOTES
22	19	40.67	134	5.53	350	-	-	MANUAL			RECORDER			5,6,BMR1
6	19	36.98	134	10.26	400	015	3	09	14	11	10	09	50	1,BMR2
23	19	32.27	134	12.37	350	007	3	09	13	40	10	10	24	BMR3
24	19	26.08	134	13.53	340									2,ANU1
25	19	26.58	134	15.12	340	020	1	09	11	44	10	10	36	BMR4
26	19	26.58	134	23.52	340	008	4	09	11	18	10	-	-	7,BMR5
27	19	24.56	134	28.52	310	021	1	09	13	30	10	-	-	7,BMR6
28	19	21.60	134	33.68	260	009	3	09	10	04	10	11	58	BMR7
29	19	20.90	134	36.30	270									2,ANU2
30	19	20.80	134	39.24	260	014	3	09	09	38	10	12	26	BMR8
31	19	19.92	134	44.82	270	003	3	09	09	15	10	11	00	BMR9
32	19	19.55	134	50.60	260	016	1	09	09	33	10	11	25	BMR10
33	19	18.40	134	56.20	250	001	3	09	09	57	10	11	58	BMR11
34	19	17.82	135	01.88	260	011	4	09	10	25	10	12	27	BMR12
35	19	18.90	135	07.24	250									2,ANU3
36	19	22.78	135	15.48	235	017	1	09	10	50	10	13	04	BMR13
37	19	26.30	135	26.33	225	010	3	09	11	20	10	13	40	BMR14
38	19	29.18	135	30.24	225									2,ANU4
39	19	33.73	135	37.18	225	002	3	09	11	46	10	14	15	BMR15
40	19	39.30	135	44.59	227	004	4	09	12	12	10	14	45	BMR16
41	19	45.27	135	53.08	232									2,ANU5
42	19	48.60	135	57.77	232	012	4	09	12	40	10	15	33	BMR17
43	19	51.22	136	08.10	245	019	1	09	13	12	10	14	55	BMR18
44	19	51.52	136	13.42	240									2,ANU6
45	19	54.21	136	21.43	247	006	4	09	13	40	10	15	39	BMR19
46	19	57.25	136	28.59	244	013	4	09	14	09	10	16	01	BMR20
47	19	59.24	136	36.37	274	018	1	09	14	30	10	16	26	5,BMR21
48	20	02.26	136	39.75	305									2,ANU7
49	20	05.12	136	50.10	277	011	4	25	12	00	26	17	08	6,BMR22
						005	4	09	15	09	10	16	58	
50	20	04.21	136	59.20	225	010	3	25	13	30	26	16	22	BMR23
51	20	01.56	137	04.12	244									2,ANU8
52	20	00.51	137	12.13	244	001	3	25	14	53	26	15	46	BMR24
53	19	59.20	137	23.13	250	017	1	25	15	36	26	15	09	BMR25
54	20	00.90	137	31.60	250									2,ANU9
55	20	01.81	137	34.90	225	003	3	25	16	20	26	14	31	BMR26
56	20	00.20	137	46.82	225	016	1	25	17	14	26	13	55	BMR27
57	19	55.01	137	56.81	233	002	3	26	10	54	26	13	03	6,BMR28
58	19	55.35	138	00.00	235									2,ANU10
59	19	55.30	138	10.71	245	007	3	25	13	05	27	12	19	BMR29
60	19	56.40	138	20.86	267	021	1	25	09	27	27	11	47	BMR30
61	19	57.32	138	24.10	280									2,ANU11
62	19	59.65	138	32.30	340	008	4	25	10	12	27	11	18	BMR31

TABLE 8 (contd.)

NO.	LATITUDE DEG MIN	LONGITUDE DEG MIN	ELEV. M	SET NO.	TAPE NO.	ON D H M	OFF D H M	NOTES
63	20 03.38	138 43.90	305	009	3	25 10 45	27 10 46	BMR32
64	20 05.66	138 48.80	288	020	1	25 11 14	27 10 24	BMR33
65	20 09.12	138 51.57	287	015	3	25 11 41	27 10 39	BMR34
66	20 11.34	138 53.97	305					2, ANU12
67	20 13.51	138 55.68	302	014	3	25 15 01	27 09 43	BMR35
68	20 15.42	139 00.80	315	005	4	25 09 28	26 14 36	BMR36
69	20 19.30	139 05.33	337	013	4	25 09 45	26 14 57	BMR37
70	20 21.74	139 10.66	360	012	4	25 10 10	26 15 26	BMR38
71	20 22.23	139 13.92	370					2, ANU13
72	20 22.53	139 17.57	377	018	1	25 12 28	26 15 53	BMR39
73	20 26.83	139 24.00	400	006	4	25 12 47	26 16 17	BMR40
74	20 31.50	139 26.73	390	019	1	25 13 05	26 16 36	BMR41
75	20 37.73	139 28.80	360	004	4	25 13 26	26 17 04	BMR42
76	20 41.60	139 39.90	318					2, ANU14
77	20 50.00	140 02.87	300					2, ANU15
78	20 43.32	140 37.43	210					2, ANU16
79	20 38.28	140 59.07	135					2, ANU17
80	20 38.03	141 22.58	120					2, ANU18
81	20 39.33	141 46.67	130					2, ANU19
82	20 39.93	142 12.76	145					2, ANU20
83	20 42.60	142 32.80	230	002	4,5	15 16 07	30 10 11	
84	20 44.45	142 54.02	230	010	4,5	15 15 15	30 10 58	
85	20 44.36	143 05.21	230	017	2	15 14 45	30 11 35	
86	20 49.00	143 26.15	230	011	5,6	15 13 37	30 12 39	
87	20 52.38	143 45.00	250	016	2	15 11 51	30 13 21	
88	20 51.57	143 58.27	270	001	4,5	15 10 22	30 14 03	
89	20 53.12	144 16.58	350	003	4,5	16 11 27	30 14 55	
90	20 53.20	144 34.65	420	008	5,6	15 09 17	30 12 45	
91	20 49.77	144 47.85	420	009	4,5	15 10 05	30 11 55	
92	20 46.88	145 01.27	475	014	4,5	15 11 04	30 11 21	
93	20 41.17	145 14.13	500	021	2	15 12 29	30 10 40	
94	20 32.17	145 24.85	420	007	4,5	15 13 30	30 10 05	
95	20 22.79	145 40.18	335	015	4,5	15 14 41	- - -	4
96	20 14.13	145 54.27	330	020	2	15 15 48	30 08 02	
97	20 05.40	146 14.95	380	012	5,6	15 10 26	30 09 39	3
98	20 00.08	146 28.00	260	004	5,6	15 11 34	30 11 34	
99	19 55.20	146 40.02	290	019	2	15 12 59	30 12 31	
100	19 49.43	146 51.62	80	006	5,6	15 14 30	30 13 45	
101	19 56.36	147 02.60	75	013	5,6	16 08 54	31 10 24	
102	19 53.38	147 13.80	25	005	5,6	16 11 39	31 12 25	
103	19 52.15	147 32.76	50	018	2	16 13 41	30 16 35	
104	20 24.02	145 41.48	333	015	4,5	20 15 41	30 09 10	4
105	19 57.66	134 20.86	366					WRAB1

TABLE 8 (contd.)

NO.	LATITUDE DEG. MIN	LONGITUDE DEG. MIN	ELEV. M	SET NO.	TAPE NO.	ON D H M	OFF D H M	NOTES
106	19 56.65	134 21.15	366					WRAB2
107	19 55.47	134 21.41	366					WRAB3
108	19 54.30	134 21.63	366					WRAB4
109	19 52.76	134 22.05	366					WRAB5
110	19 51.39	134 22.11	366					WRAB6
111	19 50.54	134 22.85	366					WRAB7
112	19 48.92	134 22.93	366					WRAB8
113	19 47.57	134 23.12	366					WRAB9
114	19 46.12	134 23.65	366					WRAB10
115	19 56.65	134 20.42	366					WRAR1
116	19 56.93	134 21.93	366					WRAR2
117	19 57.00	134 23.30	366					WRAR3
118	19 57.11	134 24.48	366					WRAR4
119	19 57.57	134 25.66	366					WRAR5
120	19 57.32	134 27.35	366					WRAR6
121	19 57.40	134 28.64	366					WRAR7
122	19 57.43	134 30.11	366					WRAR8
123	19 57.55	134 30.98	366					WRAR9
124	19 57.66	134 32.52	366					WRAR10

NOTES

1. Station 6 of Nobles Nob to Warrego line is common with second station of Tennant Creek to Townsville line.

2. ANU1, ANU2, etc. were portable recording stations of Australian National University. Operating period was continuous during period of BMR recording.

3. Station 97 located at the Charters Towers seismological observatory.

4. Station 95 was shifted slightly to avoid interference from cattle. The new site was designated site 104.

5. Site 22 was at the Skipper mine site and was occupied only by a manual recorder to shot-time the Skipper shot and to record a Warrego shot.

6. Manual records of the following shots were obtained at these sites:

   (a) Warrego 17/7 at site 22.
   (b) Skipper 9/8 at site 49.
   (c) Mount Isa 26/7 at site 57.
   (d) Nobles Nob 19/7 at site 21.

7. Recorder switched off accidently.

8. BMR1, etc. are the original numbers as used in the field notes for all BMR stations (BMR1 = site 1).

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TABLE 8 (Contd.)

9. WRA = Warramunga seismic array.
   B1 = Station 1 on the Blue (north-south) line.
   R1 = Station 1 on the Red (east-west) line.

10. On/off times are in Days, Hours, Minutes.
    BMR sites 49-75 were occupied in July (Mount Isa shot).
    BMR sites 22-49 were occupied in August (Skipper shot).
    BMR sites 83-104 were occupied in August (Earthquake recording).
    Times for sites 49-75 and 83-104 are Eastern Standard Time.
    Times for sites 22-49 are Central (N.T.) time.
    BMR recorders were programmed to record only between 0700 and 1800 each day, except for sites 83-104 which operated continuously.
    ANU stations operated continuously; ANU times are Universal Time.

TABLE 9 - Shot-to-station distances : Tennant Creek-Townsville BMR stations only

	Collinsville	Roseneath	Greenvale	Calcium
Station	Distance	Distance	Distance	Distance
83	549.14	472.16	314.97	458.68
84	512.37	438.33	288.91	423.88
85	492.95	420.03	274.80	405.15
86	456.96	389.59	257.34	373.13
87	424.69	362.68	244.26	344.72
88	401.63	341.59	232.14	322.91
89	370.20	315.54	223.07	295.32
90	339.01	289.46	215.77	267.73
91	315.63	267.22	206.82	244.77
92	291.99	245.61	201.34	222.21
93	269.06	221.74	193.35	197.78
94	250.20	196.79	181.43	173.08
95	224.52	165.37	175.16	141.29
96	202.41	136.58	174.39	112.02
97	171.35	100.58	186.87	73.36
98	153.56	79.91	198.67	49.87
99	139.02	63.57	211.58	30.17
100	128.52	50.67	224.74	17.61
101	105.62	67.18	247.52	38.90
102	95.82	71.45	263.14	51.17
103	81.16	93.41	293.23	81.37
104	222.06	165.27	178.21	140.68

Distances are in kilometres.

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TABLE 10

Tape recorder parallax corrections in seconds referred to the radio channel. Corrections for PI systems (16-21) determined in 1979; corrections for Akai systems (1-15) determined in 1973 (Connelly & Collins, 1973). Note: These corrections must be added to the times read from the appropriate channel.

Recorder	Radio	Clock	Low Gain	High Gain
1	Reference	0.00	+0.01	+0.01
2	"	0.00	0.00	0.00
3	"			
4	"	0.00	0.00	0.00
5	"	0.00	+0.01	+0.01
6	"			
7	"	+0.01	-0.02	-0.02
8	"	0.00	+0.01	+0.01
9	"	0.00	+0.01	+0.01
10	"	+0.01	0.00	0.00
11	"			
12	"	0.00	0.00	+0.01
13	"	0.00	+0.01	0.00
14	"	+0.01	-0.01	0.00
15	"	+0.01	+0.03	+0.02
16	"	-0.06	0.00	-0.06
17	"	-0.27	0.00	-0.29
18	"	-0.07	0.00	-0.06
19	"	-0.09	0.00	-0.07
20	"	-0.07	0.00	-0.06
21	"	-0.06	-0.02	-0.05

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