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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/83

TRANS-AUSTRALIA SEISMIC SURVEY (TASS) 1972, OPERATIONAL REPORT

by

D.M. Finlayson and B.J. Drummond

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SUMMARY

In 1972, two 80 tonne explosions, at Kunanalling in Western Australia and Mt Fitton in South Australia, and a 10 tonne marine shot in Bass Strait were detonated by the Bureau of Mineral Resources. Seismic energy from the blasts was recorded at distances up to 2500 km.

The survey had two aims a) to supplement data derived from previous crustal investigations and provide an interpretation of velocity profiles to depths of the order of 150 km and b) to provide an opportunity to field test the Bureau's recently developed remote recording seismographs.

Several universities co-operated with BMR and operated field stations to record the blasts. Institutions operating permanent observatory networks provided seismograms after the survey. Fifty six recordings were made; this figure may be higher when records from field stations of the Australian National University come to hand.

This record sets out the methods used to prepare and fire the shots. The techniques used to fire the Bass Strait shot are of particular interest because it was the first shot of its kind in Australia.

Lists of recording locations and shot statistics have been prepared; a table of arrival data is also presented. No attempt has been made in this record to interpret any of the data.

INTRODUCTION

During 1970/71 two large explosions at the Ord Dam site in Western Australia were recorded over 2000 km shooting lines by BMR and a number of university seismic groups, and the results were used to interpret upper mantle structure down to depths of the order of 200 km (Denham et al., 1972; Simpson, 1973). These investigations were, at the time, the most extensive long range deep seismic soundings of their type in Australia, and when BMR received a gift of 360 tonnes of explosives from West Australian Petroleum Pty Ltd (WAPET) during 1971 a number of suggestions were made about how it could best be used in a few large explosions to give further recordings out to distances beyond 1000 km and add to our knowledge of upper mantle structure.

Also during 1971, the International Association of Seismology and Physics of the Earth's Interior (IASPEI) received proposals to use 10 tonne marine shots to generate teleseismic waves which could be recorded out to angular distances of 90° from the shot position (Jacob & Willmore, 1972). This sort of data is normally available only from earthquake sources, which have location and timing uncertainties, and from nuclear explosions, which are infrequent and have political aspects which seismologists prefer to avoid. If the 10 tonne shots give results, they could be a relatively cheap way of obtaining controlled deep mantle information. BMR undertook such a trial in conjunction with other large shots.

The Trans-Australia Seismic Survey (TASS) evolved from the various circumstances and ideas mentioned above, and the positions of the recording traverses were determined by the locations of the shots and their associated logistic problems. BMR and a number of universities were also developing unattended seismic tape recording systems for field use, and were better equipped to conduct such a survey than during the Ord Dam explosions of 1970/71.

This record describes the shot firing and recording operations connected with the Trans-Australia Seismic Survey (TASS) and lists the results of some of the recordings made. It is intended that interpretation of the results should be reported elsewhere.

1. SURVEY DESIGN

1.1 Search for Suitable Shot Locations

It was estimated that 80 tonnes of explosive would be required in a land shot to enable recordings to be made at distances in excess of 1000 km. To contain an explosion of this size it was estimated that 50 m of cover would be required and a search was initiated to determine whether or not old mine workings would be available. The Departments of Mines in South Australia and Western Australia were asked to assist with the search for sites in the Flinders Ranges and Kalgoorlie regions respectively. Mining districts near Tennant Creek and Charters Towers were also considered but were not studied.

Eventually both Departments drew up a short list of possible sites which were inspected by the mining inspectors from Kalgoorlie and Adelaide and D.M. Finlayson. Eventually, sites at Mt Fitton and Kunanalling were chosen (Pls 1 and 2).

One of the main considerations for a marine shot of 10 tonnes is the required depth of water of 230-250 m with low sea bottom gradients. The Australian continental shelf tends to dip steeply from the 200 m isobath and thus the number of potential locations is limited. Also, the logistics for firing such a shot require locations not too far from a good harbour with suitable vessels for charter.

Thus the potential locations were limited to the east coast of Australia between Brisbane and Hobart, the south coast between Bass Strait and Spencer Gulf, the west coast off Perth, and the northwest coast off Port Hedland.

Initial enquiries for a site off Kangaroo Island were made by Dr Sutton, University of Adelaide, who indicated that Professor Radok of the Horace Lamb Oceanographic Centre at Flinders University seemed to think that a location could be found in a submarine canyon south of Kangaroo Island. However, difficulties associated with finding a viable system for firing a shot off SA led to the rejection of this site.

When the project was suggested to the Royal Australian Navy, the area of firing was indicated as being off Jervis Bay since this would be convenient to Fleet Headquarters in Sydney. The detailed bathymetry in the area was not known at the time and it would have been necessary to conduct a local survey of the edge of the continental shelf to establish the best location. However, when the RAN turned down the project, this location was not considered further.

The move to negotiate with Esso Australia Pty Ltd for the use of one of their oil rig supply vessels in the Bass Strait led to investigation of sites on the eastern edge of the continental shelf. No detailed bathymetric charts were available for the area but examination of traverses by the BMR contract vessel M/V Lady Christine and RAN Hydrographic Office charts seemed to indicate that a suitable location could be found at the edge of the shelf about 65 km south of Orbost. The shot location in this area is shown in Plate 3.

A number of different methods were considered for deploying the shot, the most obvious being that employed by the Royal Navy in UK waters (see Appendix 1). However there were a number of objections to this method for Australian waters, the first being that it is necessary to have quite a large area of flat bottom at the correct depth to allow for the charge swinging on its anchor.

Another possible method considered was building the charge on a concrete raft, towing it out to sea and flooding the raft. This method was attractive but would have to rely on smooth sea conditions for the towing operation. Another method with a similar drawback was to put the charge in a barge with a bottom opening hopper.

Other methods considered include the construction of the charge over the side of a small ship from a number of small units, thus eliminating the necessity to handle a complete 13 ton load on a ship's derrick. The method finally adopted is described in chapter 5.

1.2 Recording Station Lines

After the shot locations had been finally determined it was decided that three main temporary recording lines should be established (Pl. 4).

The Nullarbor recording line

This line was designed to allow reverse shooting between the Kunanalling and Mt Fitton shots and to utilize seismic data previously obtained from the atom bomb tests at Maralinga (Bolt et al., 1958; Doyle & Everingham, 1964). BMR also had conducted a number of investigations to the west of Kalgoorlie, namely the Western Australia Geotraverse (Mathur, 1973) and investigations organized and conducted by Mundaring Observatory staff (Everingham, 1956, 1969, 1971). These studies provided control for modelling the crustal structure at the Kunanalling end of the line.

The Central Australian Line

This line was designed to make recordings between Mt Fitton and Alice Springs and reverse the line which recorded the 1971 Ord Dam explosion (Denham et al., 1972; Simpson, 1973). Recordings would also be made at the permanent seismic network of the University of Adelaide. BMR has conducted deep seismic reflection surveys in the Amadeus and Ngalia Basins (Brown, 1970) located on this line.

The New South Wales - Victoria Line

This line extended from Mt Fitton to the ANU Snowy Mts permanent seismic network stations. No deep refraction work had been done along it but ANU made recordings of the Caniken nuclear bomb test in the Aleutian Is (Alaska) along the line and obtained travel time residuals which indicated a change in upper mantle structure (Cleary, Simpson, & Muirhead, 1972). Deep seismic reflection work by BMR at Mildura and Broken Hill gave some indication of the crustal structure on this traverse (Branson et al., 1972). At the eastern end of the line a considerable amount of seismic refraction data is available from surveys off the NSW coast (Doyle et al., 1966); from explosions in southeast Australia and from the BUMP shots in Bass Strait (Kerr-Grant et al., 1969; Underwood, 1969; Johnson, 1970).

The Bass Strait shot was also expected to be well recorded at the Tasmanian permanent seismic recording network.

Two temporary stations were located northeast of the permanent Meekathara station in WA to attempt to gain a pseudo-reversal of the Ord Dam explosion data in that area.

2. EXPLOSIVES

During 1971 BMR received a gift of approximately 350 tons of Du Pont WW marine explosive from West Australian Petroleum Pty Ltd (WAPET), which was surplus to their needs; it was packed in 30 kg cans and stored in northwestern Australia. About 90 tons was unusable because of deterioration, but the remainder was transported to the Department of Supply magazine at Woodman Pt near Fremantle.

2.1 Explosive Trials

Various methods of firing the explosive were considered, including underwater firing. Two series of tests were conducted by BMR officers from Mundaring Observatory in cooperation with the Royal Australian Navy during October and November 1971 to determine the suitability of the explosive for use at depths down to 250 m. The trials indicated that it was not reliable at depths greater than 100 m. These findings were substantiated in May 1972 during further trials by BMR officers operating from a fishing vessel out of Bermagui on the NSW south coast. The metal containers for the explosive crushed readily even at depths of 100 m and if any leaks developed the explosive was rendered useless because it was soluble in water. A firing technique was developed which minimized the length of time that the shot was immersed.

These trials showed that the explosive could not be used for shots of the 10 tonne type proposed in chapter 1. After consultation with the Department of Supply it was decided to use RDX-TNT for the proposed 10 tonne marine shot to be fired at 200 m water depth (see chapter 5.3).

2.2 Safe Distances from Shots

Duvall & Fogelson (1967) in a US Department of Interior Bulletin give the following approximate figures for damage limits and recommended that ground velocity be used as the parameter for correlation with damage:

	7.6 in/s	(19.3 cm/s)	- major damage;
	5.4 in/s	(13.7 cm/s)	- minor damage;
greater than	2.0 in/s	(5.1 cm/sec)	- fair probability of producing some damage to structures.
less than	2.0 in/s	(5.1 cm/sec)	- low probability of causing damage.

There are a number of reports relating to the safe distances for blasting operations. The most recent authoritative work is the US Department of Interior, Bureau of Mines Bulletin 656 (Nicholls et al., 1971), Chapters 6 and 7 of which were directly relevant to the proposed BMR 80 tonne seismic shots.

Based on the recommendations of this report their Fig. 6.3 was extrapolated to the 180 000 lb level (approx 80 tonnes). Using an average scaled distance of 20 $ft/lb^{\frac{1}{2}}$ (9.0 $m/kg^{\frac{1}{2}}$) the safe distance works out at 9000 ft (1.7 miles or 2.7 km) assuming 2.0 in/sec (5.1 cm/sec) ground velocity as being the limiting velocity for structural damage. Using the very conservative scaled distance of 50 $ft/lb^{\frac{1}{2}}$ (22.5 $m/kg^{\frac{1}{2}}$) (from their Fig. 6.2) the safe distance works out at 20 000 ft (3.8 miles, 6 km).

Other investigations connected with the safe distances from blasting are quoted below.

Langefors et al. (1958) in Sweden related their investigations directly to mining and scaling from their results, the safe distance from an 80 tonne shot would be 2000 m (1.2 miles). Their safe distance represents the limit of falling stones in galleries and tunnels.

Morris (1950) of ICI recommends use of an equation: $8.2 = 110E^{\frac{1}{2}}/D$ (or $18.1 = 110E_k^{\frac{1}{2}}/D_m$) for computation of safe distances, which for an 180 000 lb shot gives 1.1 miles. (E = weight of explosives in lb, D = distance in feet, E_k = weight of explosive in kilograms, D_m = distance in metres).

Edwards and Northwood (1960) recommend using an equation

$$E^{2/3}/D = 0.1 \qquad (\text{or } E_k{}^{2/3}/D_m = 0.19)$$

equation for the safe distance and this includes a safety factor of 3. This gives approximately 6 miles for a 180 000 lb shot.

The Standards Association of Australia (1967) recommend a limit of 0.75 in/s and states that this 'recommendation gives a factor of safety for light damage of 6 when considering a building in good condition (or 8 thousandths of an inch at 15 Hz)'. Using their recommended formula:

$$A = \frac{K\,E^{\frac{1}{2}}}{D} \qquad \left(\text{or } A_{mm} = 11.5\,\frac{K\,E_k{}^{\frac{1}{2}}}{D_m}\right)$$

where A = amplitude in thousandths of an inch, A_{mm} = amplitude in millimetres, and K = constant factor depending on ground condition, a safe distance can be computed. Using $K = 200$, which seems realistic for the BMR shots, $D = 2.0$ miles (3.2 km). Using $K = 300$ for a conservative estimate, $D = 300$ for a conservative (3.2 km). Using $K = 300$ for a conservative estimate, $D = 3.0$ miles (4.8 km).

3. MT FITTON SHOT

3.1 Geology and Crustal Structure of the Mt Fitton Area

The Mount Fitton South Mine lies within that part of the Flinders Ranges known as the Mount Painter Metallogenic Province. The geology of the region is described by Coats & Blissett (1971). Ridgway (1948) gives a brief discussion of the Mount Fitton South Mine, but with little reference to the geology and structural control of the orebody.

The Precambrian crystalline basement is made up of lower Proterozoic metamorphosed sedimentary rocks intruded by several generations of Proterozoic granites. The sedimentary sequence is known as the Radium Creek Metamorphics. The succession totals over 20 000 feet of mainly arenaceous sediments and acid porphyries of possibly extrusive origin. The Radium Creek Metamorphics are intruded by two generations of granite - the 'Older Granite Suite' of Carpentarian age and the 'Younger Granite Suite' of Adelaidean age. The 'Older Granite Suite' and the Radium Creek Metamorphics are collectively known as the Mount Painter Complex.

The Mount Painter Complex is overlain by Adelaidean sedimentary cover rocks. At the Mount Fitton South Mine, the cover rocks are tillites of the Sturtian Fitton Formation. The orebody occurs in sheared and jointed coarse-grained rocks of the 'Older Granite Suite'.

The explosive was detonated in crystalline basement rocks.

Using data from earthquakes recorded at observations in the University of Adelaide's seismograph network, Stewart (1971b) has undertaken a study of the crust and upper mantle in the area of the Flinders and Mt Lofty Ranges. These investigations indicated that the crust in these areas is essentially uniform in composition and thickness. Depth to the Moho is approximately 38 km. Deviations from this ideal model exist where thick sedimentary piles occur in the Adelaide Geosyncline. Stewart (1971a) found no indication of a discontinuity equivalent to the Conrad Discontinuity found elsewhere. Below 25 km, a decrease in the energy release suggests a transition in the mode of energy release.

3.2 Shot Firing Operations - Report by J.N. Templer, Mining Inspector, SA Dept. of Mines

A proposal to detonate some 80 tons of DuPont WWEL explosive instantaneously in an old mine in South Australia initiated a search for a suitable area. Limitations indicated that there should be no structure within a 5-mile radius of the blast.

The old Mt Fitton South Copper Mine appeared a likely site (Pl. 5). This mine consisted of an adit some 330 feet long extending into an underhand stope. At 200 ft from the adit entrance, and extending to 260 feet from the entrance, open stoping had been done from the surface to the adit level and extended below. The underhand stope area appeared to have about 200 feet of solid rock cover above it. Calculations indicated that the underhand stope could contain the bulk of the explosive, with some explosive extending into the adit.

The open stoped area appeared the danger area in the scheme because of its proximity to the underhand stope.

Preparatory work included track formation from the main road about 4½ miles away to the mine site, including road formation through the wide Hamilton Creek and approaches at small creeks as well as clear areas near the adit entrance.

In the mine area, work included the timbering up of the stoping area in the adit, the clearing up of sand fill in the adit, the removal of material from the adit entrance, and plate laying in order to get explosives into position.

The open stope had to be blasted and filled from the surface to the adit level to provide resistance to the blast.

Area inspection revealed a well about 500 ft from the adit. It was expected that this would collapse with the blast, so the well was repaired before the shot was detonated. A tank nearby in poor state of repair was wired and strengthened before the blast.

Loading of Explosives

Because of the nature of the blast it was considered that complete detonation was essential. Partial detonation could cause difficulties and problems of access if refiring became necessary.

For this reason, because the explosive would extend for 60 to 70 ft along the stope and adit with some difficult stacking, it was decided to use one high-energy primer to approximately four canisters. Four separate initiating explosive lines of detonating fuse were used, with interconnections between lines about every 10 ft.

The canisters were loaded onto a truck and pushed along the adit to the start of the underhand stope. From here they were lowered to bottom of the stope and manhandled into position. Primers were placed as loading proceeded. Care was exercised to ensure that cans did not sever detonating-fuse lines.

Primers consisted of Anzomex M boosters (9 oz) as well as Hercules and DuPont boosters. Altogether primer relationship approximated 0.3% of the explosives charge.

The charging came to within 300 ft of the adit entrance and about 40 ft from the stope at adit horizon.

Stemming of the charge entailed the filling of some 5000 sand-bags and stacking in front of the charge.

Firing the Charge

The four detonating-fuse lines were brought together beyond the end of the sand-bags, connected together, and two instantaneous electric detonators attached. These detonators were fired from an area in Hamilton Creek using a 30-shot rack exploder.

Measurements etc.

Preblast surveys were made of Mt Fitton homestead, Mt Fitton talc mine, and other talc mines in the area. Cambridge vibrographs were set up on concrete blocks at an old woolshed area (about 3/4 mile from the blast) and at the Mt Fitton homestead (about 4½ miles from the blast). A Sprengnether Seismograph was set up at the Mt Fitton Talc Mine (about 8 miles from the blast).

Results

The blast was highly successful as complete detonation was obtained. The blast broke through the stope area and showered rocks over a considerable area. This is clearly visible in the photographs taken at the time of the blast and to be included in the full report (Templer, in prep.).

The stemming placed in the adit was successful as no material blasted from the adit.

No damage was done at the Mt Fitton Homestead and none at the talc mines. Results obtained from the vibrographs indicated a surface wave of 0.050 inches vibration at the Woolshed and a wave of 0.003" amplitude at the Mt Fitton homestead. Frequency of vibration was very low (about 5 cycles per second).

The water tank collapsed (from ground movement) but the well was saved by prior work and water was still being pumped after the blast.

3.3 Local Safety Precautions

The 'safe distance' information sent to the SA Dept. of Mines was that contained in Chapter 2.2. The managing director of the talc mines 15 km away from the shot point was concerned about the stability of some of the open cut faces and withdrew his workers from the cuts during the shot. No effect was evident at the talc mines.

The SA Dept. of Mines personnel took the precaution of visiting all homesteads and camps within about 50 km of the shot to let them know of its detonation and also to prevent any 'stray' people coming close to the shot from some unexpected direction. Spectators were asked to view the shot from the vicinity of the field crew camp 4 km from the shot.

3.4 Comments on Shot Operations

The search for shot sites in the Flinders Ranges area was conducted by the SA Dept. of Mines and began in May 1972; the Mt Fitton South mine was eventually chosen in June. The Dept. of Mines field crew was sent to the area in August and was operating there until the shot was fired on Oct 25. One reason for asking the SA Dept. of Mines to do the work was the obvious availability of experts in underground mining. It was expected that the cost would be calculated on field costs only. The final cost to the Bureau was $25,000.

The old water tank near the shot location was destroyed by the blast despite efforts to save it by strengthening with timber and wire and emptying it of water before the shot. The owner was subsequently paid $1400 compensation for damage to fence and tank.

3.5 Shot Point Recording

The shot instant was determined by recording VNG radio time signals, a Mercer chronometer signal, and the signal from a geophone placed near the shot, on a multichannel paper recorder. The shot was also recorded on a PI seismic tape recording system about 1 km from the shot.

An attempt was made to record accelerations at 300 m and 600 m from the shot, but the two accelerographs malfunctioned and no records were obtained.

Shot locations and times are listed in Table 1 along with those for the other shots.

4. KUNANALLING SHOT

4.1 Geology and Crustal Structure of the Kunanalling Area

The Kunanalling district lies within the area covered by the Kalgoorlie 1:250 000 Sheet area. Kriewaldt (1969) has written explanatory notes on the sheet.

The beginning of the rock assemblage in the area has been dated at 2800 m.y. Extensive metamorphism, intrusion, and mineralization occurred during the next 400 m.y. A north to west-of-north regional trend now exists and obscures the original north to east-of-north palaeogeographical trend which occurred at the time of formation of the rocks. Kunanalling itself lies on the eastern limb of an anticline passing northwards from Coolgardie. Local dips are steep.

The rocks are composed of a metamorphosed shale, greywacke, and granite sequence alternating with a sequence of altered mafic and ultramafic extrusive igneous rocks. The mine at Kunanalling is located in sheared altered Archaean greenstone.

Estimates of crustal thickness and structure have been made by Mathur (1973) using data from the BMR Geotraverse. Mathur interprets the crust at Coolgardie, approximately 30 km south of Kunanalling, to be 34 km thick and composed of two layers. The thickness of the weathered zone and unaltered sedimentary sequence is negligible. The two layers were interpreted as 19.5 km and 13.5 km thick, and have measured seismic P velocities of 6.13 and 6.74 km/sec respectively. A third layer of 7.41 km/s velocity, although not observed at Coolgardie, is interpreted by Mathur as 1.5 km thick at Coolgardie and thickening to the west. The mantle has an apparent seismic P velocity of 8.25 km/sec.

4.2 Report by J. Zuvich, Mining Inspector, WA Dept. of Mines

Introduction

In March 1972 the West Australian Mines Department was approached by the Department of National Development, Bureau of Mineral Resources, Geology and Geophysics, for assistance in a project, initiated by that department, designed to study the crust of the Australian continent at depth.

Since the project included the detonation of a large charge in a mine in the Kalgoorlie region, the Kalgoorlie Branch of the Mines Department was asked to locate a suitable site and supervise the loading and detonation of the charge.

Site Selection

Eighty tonnes of explosives were used, occupying approximately 3220 cu ft of space. Specifications for the required site were as follows:

(a) At least 20 miles distant from Kalgoorlie

(b) A shaft approx. 150 ft deep, preferably in solid unweathered rock

(c) Away from current mining activity

(d) Reasonably accessible

(e) Dry

(f) Ideally, the shaft to have a dogleg or short drive (30-50 ft long) at the base to prevent a blow-out.

Owing to the current mining activity around Kalgoorlie, the most suitable area in which to find a site was considered to be the northwest of the town. After extensive investigations, sites at Ora Banda, Kintore, and Kunanalling were selected for further investigation. The bottoms of all these shafts were inaccessible and the former two required reconditioning before a descent could be made.

D.M. Finlayson of the Bureau of Mineral Resources was advised of the position and requested that the Mines Department organize an inspection of the underground workings to coincide with his visit to Kalgoorlie. F. Kennedy and C. Erceg were commissioned to recondition the shafts, a job which they satisfactorily completed at a cost of $498.66. The prospective sites at Ora Banda and Kintore were found to be unsatisfactory, but the mine at Kunanalling could be made suitable with a minimal amount of work.

This site was at the north end of the Premier mine at Kunanalling. Location and access to the mine area are shown in Plate 2. Access to the underground workings was via a vertical shaft, which bottomed at 130 ft below the surface (Pl. 6). At this level, extensive development work had been done which connected with the main lode open cut some 600 ft SE of the shaft. A parallel lode, some 60 ft into the hanging wall of the drive, had been developed and stoped in some places. The most suitable location for the charge was considered to be in the NW drive off the shaft. This drive extended about 90 ft NW of the shaft, and had two crosscuts off it. The volume requirements in this drive fell short of that required by some 1000 cu ft, and it was necessary to clean out the drive and crosscuts to obtain the required 3220 cu. ft.

This site fulfilled the specifications, except that the country rock was a sheared, oxidized greenstone. The shearing was parallel to the drives and dipped at approximately 45^{o} to the northeast. There were no workings above or below the selected drive, or to the NW and SW except for a small drive and stope off the shaft about 90 ft down.

A check was made with geologists from Western Mining Corporation as to the possibility of this mine ever becoming a viable gold mining operation. They stated that, to the best of their knowledge, this was unlikely.

Loading, Priming, and Stemming

Tenders were called by the Department of Supply for the preparation of the site, loading, priming, stemming, and firing of the shot. F. Kennedy and C. Erceg were the only, and successful, tenderers for a total price of $6470.

Access to the 130 ft level was gained through the vertical shaft using a compressed air hoist and special kibble running on rope skids. The kibble had a rectangular shape designed to hold four containers of explosives.

The shaft was in reasonable condition, so that the first job was to clean out the drive and crosscuts. This was done by hand shovels and the spoil wheelbarrowed some 300 ft to a bin below the level on the hanging wall vein. The operation was completed in advance of the scheduled time for loading to begin.

The time for the blast had now been set down for 12.05 pm on 25 October 1972.

A trial shipment of 12 tonnes of explosive was landed at the site on 6 October to determine the underground loading rate. It was found that the crew was capable of loading twelve tonnes per day.

Loading was resumed on 11 October and continued until completion on 16 October. The utilization of the specially constructed kibble greatly facilitated the loading operation.

The cans were stacked horizontally and as tightly as possible in the drive. Four separate lines of cordtex were run through the stack as loading proceeded. A plug of An60 gelignite was periodically attached to each cordtex line to act as a primer. About 70 lb of gelignite was thus used.

The charge occupied the full volume of the crosscuts and the drive to within 5 ft of the shaft. This section of the drive was packed with broken dirt - loose and in bags - so that in effect there wss 5 ft of stemming to the charge.

Detonation was finally effected by No. 12 electric detonators attached in series to each cordtex line and fired with a Beethoven exploder at a distance of about 1500 yards from the site.

Safety Precautions

Once explosives arrived at the site, security was maintained by one of the contractors' men camping near the site.

Evidence supplied by the Bureau on the possible damage to property etc. by the blast indicated that there was a low probability of any damage beyond a 1½ mile radius from the shot (see Chapter 2.1).

Nevertheless, the local mining companies were informed of the circumstances of the shot and advised to ensure that undergorond workmen were in a safe place at the time of the blast. All personnel at Scotia and Nepean were brought to the surface before the explosion, but no after-effects or damage were reported from any of the mines.

Several prospectors working within 10 miles of the site were similarly informed, but here again no effect was reported. Installations within a mile of the blast consisted of a pastoralist's concrete water tank, the Kunanalling government dam, a prospector's shack, and the old Kunanalling hotel ruin. These were not damaged except for a collapsed arch over a doorway at the hotel. A steel pole telephone line about 200 ft from the shaft was also unaffected but the PMG Department had dropped the wires before the blast.

At the time of the blast the local police co-operated in setting up road blocks on the main road past Kunanalling, and Mines Department personnel were stationed along all bush tracks leading to the site.

The local paper and radio stations also co-operated in advertising the blast and requested sightseers to keep at a safe distance.

After the blast notices were displayed at the site warning people against entering the crater.

Results of Explosion

The charge was initiated on schedule at 12.05 pm on 25 October 1972.

Ground vibration at 500 yards was quite noticeable but not severe. At one mile from the blast it was just perceptible. No tremor was felt by people at Coolgardie, 20 miles away, or at Kalgoorlie, 25 miles away. A Sprengnether seismograph instrument at Coolgardie gave the following readings:

1. Frequency - 2 cycles/second

2. Resultant Amplitude - 0.0005 inch.

These figures are well within the Standards Association code.

At the Geophysical Observatory at Mundaring, WA, the tremor recorded a three magnitude on the Richter scale.

Officers from the Mundaring Observatory determined the shot time by recording the signal from a geophone near the shot, VNG radio time signals and a chronometer signal on a multichannel recorder.

The effect at the site of the explosion was spectacular. Observers nearest to the scene saw the ground above the charge lift in a mushroom shape, and then split along its centre to release a cloud of dust and gases which formed a characteristic mushroom-shaped cloud. The dust ascended to several hundred feet and was visible from Kalgoorlie.

Surprisingly, there was very little dust emission from the openings to the south of the blast site although they were connected along the 130 ft level. Surprisingly also, no stones were thrown outside the immediate crater and dump perimeters.

Figure 4 shows the approximate relative positions of the crater and dumps with respect to the 130 ft level.

The resultant crater measured about 200 x 170 ft and was 20 ft below the original surface at the southern end. Uplift in the order of 6 ft was apparent around the rim of the crater for a distance of 10-20 ft. For about 30 ft beyond this area, cracks up to 1 inch wide developed.

Two crescentic dumps of broken oxidized ground were thrown up on the NE and SW sides of the crater. The former attained a vertical height of 34 ft above the surface, and the latter 28 ft. The larger dump lay at right angles to the schistosity planes of the country rock. Stoping on the hangingwall seam may have been partly responsible for the formation of a larger dump in this position.

The following figures give a rough estimate of the amount of ground broken by the blast.

		Volume (cu yds)	Tons
North East Dump		21 500	27 000
South West Dump		6 500	8 000
Crater		9 000	
Total rock broken		31 000 (solid)	55 000
or		47 000 (broken)	55 000
Quantity of explosive used	=	80 tons	
	=	179 000 lbs	
Explosive used/ton broken	=	3.3 lb	

These calculations are based on a factor of 22 cu ft of broken dirt to the ton and assuming that the ground was broken in an inverted conical shape below the crater for a depth of 140 ft.

Conclusion

The placement and detonation of the charge was performed on schedule in a satisfactory manner - owing primarily to the competence of the contractors involved.

The blast was spectacular to observe, as is the resultant crater and dumps.

No damage resulted from the blast.

The efficiency of the blast in producing the required seismic vibration could have been higher with deeper burial or more competent country rock. However, the above figures show it as a very low-frequency rock-breaking operating, which indicates that a great deal of energy was transformed into shock waves.

5. BASS STRAIT SHOT

5.1 Background to Shot Design

During the 1971 IUGG meetings in Moscow, P.L. Willmore of the Institute of Geological Sciences, Edinburgh, presented results of recordings of a 10 tonne seismic shot in the North Sea to the International Association of Seismology and Physics of the Earth's Interior (IASPEI) and proposed that this would provide a relatively cheap method of study of the earth's mantle. It was proposed that a working Group of IASPEI be set up to examine the possibilities of this type of study, and a copy of Willmore's report to be second meeting of the Working Group at Oslo, 22-25 November 1971, is given in Appendix 1.

A seismic energy source with a frequency spectrum centred about 1 Hz is thought to be optimum for the transmission of the energy as teleseismic waves and it is considered that a shot size of 10 tonnes could be logistically possible at reasonable cost.

J.C. Dooley of BMR was nominated as the Australian representative in the Working Group and it was indicated that BMR would attempt to fire an experimental 10 tonne shot during 1972 in conjunction with other shots to be fired for the Trans Australia Seismic Survey.

Cole (1948), Arons & Yennie (1948), and O'Brien (1960, 1967) have given the theory regarding the generation of seismic energy from underwater explosions. The explosion should be at such a depth that the first bubble caused by the explosion forms and collapses in a time corresponding to the desired period of the transmitted teleseismic wave, i.e. 1.0 seconds.

O'Brien (1967) gives the expression for the radius of the first bubble as

$$R = 12.5\ (W/(d + 33))^{1/3} \qquad \ldots\ (1)$$

where R = radius in ft

W = mass of TNT in lb

d = depth of water in ft

The half-period of the first bubble pulse is given as

$$T = 4.4W^{1/3}(d + 33)^{-5/6} \qquad \ldots\ (2)$$

where T = half-period in seconds.

For a 10 ton explosion this gives, for T = 0.5 s,

d = 227 m

and R = 12 m

Bearing in mind the 24% increase in power of RDX-TNT over TNT, and using a depth of 225 m, the final estimates for the period of the bubble pulse and the radius of the bubble are 1 s and 13 m respectively.

It is important to keep the gas bubble undisturbed by the sea bottom and thus the explosion must be generated at least 12 m off the bottom. It was decided to design the shot so that it would explode at 225 m depth in 250 m of water. The water depth was to be determined by an echo sounder on board the shooting vessel.

When it was known that a suitable vessel for firing the shot would probable be available in the Bass Strait area, a search was made for detailed bathymetric information. Unfortunately this information usually is limited to depths less than 200 m and thus it was difficult to pick out possible shooting locations. Generally speaking, the continental shelf begins to slope away steeply at depths greater than 200 m and it was difficult to find a flat sea bottom. In eastern Bass Strait there was some detail along widely spaced traverses of the BMR offshore marine survey (M/V Lady Christine). Other sources of information included the RAN Hydrographic Office.

On the basis of all information available it was decided to look for sites in eastern Bass Strait, where the 200 m isobath extends into the offshore Gippsland Basin (Pl. 3). After discussions with the Victorian Department of Fisheries and Wildlife and the Lakes Entrance Fishing Co-operative, the search area was selected as eastward along the continental shelf from a point 23 miles ENE of the Halibut A oil drilling platform.

It was suggested that the site be surveyed from a fishing vessel shortly before the shot firing date, but this was not done because Coulson and Bos (Esso) (See Chapter 5.3) advised that the shooting vessel would be able to carry out a search pattern and determine a site relatively easily. Subsequent events showed that it would have been more prudent to pre-survey the area and mark a site to which the shooting vessel could sail directly.

5.2 Geology and Crustal Structure of the Bass Strait Area

The Bass Strait region contains three major sedimentary basins: The Gippsland Basin, Bass Basin, and Otway Basin. The Bass Strait shot was detonated in the Gippsland Basin.

The geology of the thick sedimentary sequence in the Gippsland Basin has become well known in recent years through extensive offshore oil exploration. The structure of the lower crust and upper mantle is not, however, so well known.

A discussion of the sedimentary geology can be found in Boutakoff (1954/55). This account was written prior to the extensive oil search. Richards & Hopkins (1969) discuss the geology of the offshore sediments from information derived from oil exploration.

Thousands of metres of sediments have been deposited in the Gippsland Basin. Sedimentation began in the Ordovician on what is presumed to be Cambrian or Precambrian metamorphic basement, and continued until the Miocene. Breaks occurred during the Middle Devonian Tabberabberan Orogeny, marking the end of the marine deposition, and in the Mesozoic when glaciers removed much of the Permo-Carboniferous and Triassic lacustrine sediments. The Upper Cretaceous to Miocene sediments are marine and contain the oil source and reservoir rocks.

Boutakoff (op. cit.) studied the structure of the Gippsland area by comparing the gravity of the region (Dooley, 1952; Dooley & Mulder, 1953) with the geology. He states that the whole structural pattern of Victoria is governed by a system of northwest and northeast conjugate orogenic trends. The periods of orogeny mark the end of the Tasman Geosyncline sedimentation in the Ordovician and Lower Devonian (Richards & Hopkins, op. cit.). The northwest trend is predominant. In the south, the major axes swing to the northeast and in the sunklands and islands of Bass Strait appear to return to the northwest. This 'concertina' property is believed to represent major zones of weakness in the earth's crust, which are likely foci for epeirogenic downwarping and faulting.

Mesozoic and Cainozoic epeirogenic movements occurred along east-northeast and east-southeast conjugate axes; the former is largely predominant. En echelon faulting caused by these movements started the formation of the Gippsland Basin.

The zones of weakness proposed by Boutakoff have, as yet, to be located by deep crustal seismic refraction studies. They were not seen to exist from the BUMP data (Underwood, 1969). However, these data are somewhat incomplete. Velocity analysis yielded a depth to the Mohorovicic Discontinuity of 37 km under the Snowy Mountains and 25 km under shots in the west of Bass Strait. To obtain these figures, a one-layer crust was assumed to the Moho, which has a velocity of 7.84 km. There is some evidence for an intermediate layer in the crust.

It is estimated that the sedimentary thickness at the shot site is 2 to 3 km.

5.3 Shot Design and Firing - Report by W.H. Coulson, Explosives Consultant, Melbourne

Introduction

In August 1972, W.H. Coulson was engaged by BMR to design, construct, and detonate an explosive charge to be fired in about 250 m of water in Bass Strait approximately 65 km south of Orbost in Victoria.

The size of the explosive charge (nominal 10 tonnes) and the positioning in the sea (225 m in a depth of 250 m) were in accordance with the recommendations of the meeting in Oslo in November 1971 of the Working Party on 10-tonne Explosions, and it was hoped that world-wide observation of the resulting signals would result.

The shot was initially planned for October 1972, but delays from various causes, chiefly negotiations regarding the charter of the vessel, led to the postponement of the shot until late in December 1972.

When Coulson joined the project there was some doubt about the suitability of the proposed ship, the Smit-Lloyd 33 (an oil rig maintenance vessel under semi-permanent charter to Esso Australia for work on the Bass Strait oil and gas field), and the first action was to inspect the ship and discuss with the ship's captain and with K.Bos, manager of the Barry Beach Marine Terminal, what loads the ship's equipment could handle and how a 10-ton charge with the necessary ancillary gear could be put into the sea. The results of the inspection and discussion were satisfactory and BMR was informed on 18/9/72 that the Smit-Lloyd 33 was a suitable ship. Consequently the charge, and the method of supporting the charge at the required position relative to the sea bottom, were designed around the capabilities of the Smit-Lloyd 33 and were tailored to suit this particular ship's equipment.

Essentially this included an explosive charge made up of 325 individual small packages which could be stacked into a steel mesh cage supported 25 m above the sea bottom by a number of buoys near the surface, and anchored to the sea bottom by a concrete mooring. The heaviest single item was the concrete and steel mooring, which had an 'in air' weight of about 15 tonne (Pl. 7).

The main explosive charge was prepared at the Munitions Filling Factory, St Marys, NSW, and stored in the Department of Supply Magazine Area at Derrimut, Victoria, until required. The priming charge was prepared at the Explosives Factory, Maribyrnong, Victoria, and stored at Derrimut.

At first it was hoped that the explosives would be loaded aboard ship at the Barry Beach Marine Terminal of Esso Australia, but the company declined to give permission for this, and it was then proposed to use the Commonwealth-owned explosives loading facility at Point Wilson in Port Phillip. However, as this would add at least two days to the charter time for the ship, it was finally decided to load the explosives over the Port Welshpool jetty in Southern Victoria.

This was made possible by the co-operation of the various Victorian State Authorities acting through the Port Officer in Victoria (A.J. Wagglen).

The non-explosive components were loaded on the Smit-Lloyd 33 at Barry Beach on Monday morning, 18 December 1972, and the ship then moved the short distance to Port Welshpool, where the explosives were taken aboard and the vessel sailed for the firing site at about 1900 hrs on 18 December 1972. Due to an unexpected refusal by the crew (on instructions from their union) the cans of explosive had to be manhandled aboard and into the cage by the scientific personnel, the State Explosives Inspector, and the drivers of the lorries.

Arriving off Lakes Entrance at about 0700 hrs on the 19th, the ship changed Captains and then proceeded to search for an area with a suitable depth (137 fathoms) of water. This was not located until after midday and was far from ideal because the bottom was sloping sharply towards the southeast; however, as the weather forecasts indicated a return of unsettled weather on Wednesday it was decided to proceed with off-loading despite the not-too-good bottom contours. The explosive charge was put overboard, the firing line rigged, and the charge fired at 1850 hrs on Tuesday, 19 December at $38^{\circ}17'33''$S Lat. $148^{\circ}48'35''$E Long., which is approximately 60 km south-southeast of Orbost.

Explosives Used

The main charge consisted of 22 750 lb of a 'lean Torpex' and contained -

10 700 lb of TNT	(47.03%)
10 100 lb of RDX	(44.40%)
1 600 lb of Aluminium	(7.03%)
350 lb of Beeswax	(1.54%)

This mixture was prepared by puddling 21 lb of Torpex 4A biscuit with 49 lb of molten 55/45 + 1 RDX/TNT/BWX, making a total of 70 lb of mixed explosive which was cast into a 4 gallon tinplate can. 325 cans were filled; each can was

9½ inches square by 13 3/4 inches high with a 7-inch diameter lever lid in one end. After being filled with 70 lb of cast high explosive, each can was sealed with bitumen. These cans were filled at Munitions Filling Factory, St Marys, NSW and transported to the Magazine Area at Derrimut on pallets holding 1 ton each.

One can was prepared at Explosives Factory, Maribyrnong, as a priming charge; it contained 4 strands of ICI 100 grains PETN per foot 'Cordtex', onto each of which was threaded 5 perforated Tetryl pellets each weighing 1¼ oz, The Cordtex with Tetryl pellets was suspended in the can and the can filled with poured 55/45 RDX/TNT and finally, after cooling, sealed with bitumen. The priming charge consisted of 70 lb RDX/TNT, 25 oz of Tetryl Pellets and 400 grains of PETN in Cordtex.

The four strands of cordtex were each 1000 feet long and were bound together every 3 feet with waterproof adhesive tape to a multistrand flexible copper cable which was secured to lugs on the primer can and so arranged that any tension strains were taken by the copper cable and not by the cordtex.

To facilitate handling, both during transport to the ship and whilst lowering the charge into the sea, the whole of the cordtex/copper cable/priming can assembly was wound on to a wooden cable drum. This proved to be very effective in preserving the cordtex from damage.

The priming can was not put into the charge until immediately before submersion at the firing site, and the detonator was not attached to the booster until it had been decided to fire.

The sea surface end of the cordtex was secured to a small raft, consisting of four small empty drums supporting a wooden platform. One strand of cordtex passed through one hole of a two hole ICI 5 oz Anzomex D Pentolite booster, and the other three strands of cordtex were taped to the outside of the booster. An ICI Seismic Detonator was securely taped into the remaining hole in the booster, and connected by 1½ miles of twin (7/011) Poly/Nylon telephone cable to the firing box aboard ship. The cable had been supplied as three reels of 880 yards each, and all joints were soldered and potted with epoxy resin in PVC tubing, except for the final connection at the raft, where the wires were twisted together, sleeved in PVC, and securely bound in waterproof vinyl tape. The inboard end of the firing cable leads were twisted together, securely insulated with PVC tape, and bound to a fitting aboard ship until ready for connection to the firing box. Only Coulson handled the inboard end, and connection was not made to the firing box until the ship had reached its safe position (+1 mile).

Connection was made to the output terminals at -1 minute, and the generator cranked to 1800 volts before firing at time zero. The total resistance of the firing cable (3 miles) was 320 ohms.

Power of the Explosive Used

The explosive used in the Bass Strait Seismic shot was chosen for two reasons.

1. It was already Commonwealth property and it was readily available at a low cost.

2. It is unaffected by wetting with water, and consequently crushing of the container and the intrusion of sea water, due to the hydrostatic pressure of 320 psi at the firing point, would be unimportant.

This property of the TNT-based cast explosives makes them ideal for underwater work and avoids the need to encase the explosive in watertight pressure-resistant containers, which for depths of the order of 225 m are difficult and expensive to produce. The tin-plate cans used for the Bass Strait Shot were cheap, off the shelf, commercial items (biscuit tins).

The mixture of TNT, RDX, Al, and BWX used is more powerful than an equivalent weight of TNT and for comparison with charges of other explosives fired overseas it is desirable to express the power of the Bass Strait shot in terms of a common standard, now almost universally accepted as TNT = 100.

Power is a difficult property to measure, and present day thinking is towards the use, for comparison purposes, of a calculated value based on the number of gas molecules produced per gram, and the temperature of detonation.

Using the generally accepted values, for TNT, RDX, and Aluminium, and assessing the calorific value of Beeswax as - 2500 (which is reasonable) and allowing for 1.6% of BWX, the calculated power for the mixture used is 123.5, based on TNT = 100.

Consequently the 22750 lb of 'lean torpex' had a power equivalent of 28080 lb of TNT.

Positioning of the Charge in the Sea

The position specified for the charge at the moment of firing was at 225 m in a depth of 250 m and this required some system of supporting the charge at 25 m above the sea bottom.

After discussions with the ship's Captain, and with K. Bos, the manager of the Barry Beach Marine Terminal of Esso Australia, a system was designed which would achieve the desired position for the explosive and which could be readily handled by the ship's gear.

This design envisaged a weight or mooring on the sea bottom, a steel cage to hold the explosive charge, four buoys to provide positive buoyancy to the charge, and a marker buoy to float on the surface to indicate the position of the charge beneath. These were all to be attached to one another by steel cables of the correct length and of sufficient strength to permit the lifting and recovery of the components if bad weather (or some other circumstance) made this necessary.

This required the construction of a 10 t (in water) concrete mooring and a steel cage to hold the explosives, the provision of suitable lengths of cable spliced to eyes, a number of shackles, a 100 t swivel, 4 cylindrical foam filled steel buoys, and a double cone marker buoy for the surface.

The cable and the buoys were supplied by Esso Australia at no cost, and the casting of the concrete mooring, the fabrication of the steel work, and the rigging was done by E.E. and H.M. Jones of Yarram, Victoria.

The ship used in the operation was the Smit-Lloyd 33, owned by Smit-Lloyd Australia Ltd and under charter to Esso Australia. The charter was transferred to the Commonwealth for the period of the operation. The ship, which is of about 1600 tons displacement, 196 ft long and 38 ft beam, is ideally suited to this type of work, having several winches of adequate power, an extensive working area, and a large 'A' frame over the stern extending outboard. The 3200 HP Engines give a cruising speed of 12½ knots, and with twin screw variable pitch propellers together with 300 HP side thrusters forward of the bridge, the ship is extremely manoeuvrable. All the information required for the control of the ship and the operation of its gear is displayed on the bridge. A wide range of telecommunication (Radio and Radar) equipment is carried and position location by 'Shoran', together with sonic depth recording gives immediate information of position, distance and depth.

The plan of operations for putting the various items overboard was:

1. The concrete mooring was held on the sterm roller, while it was attached to the steel cage holding the explosive charge, by four wire ropes secured to eyes at each corner of the concrete block

2. The mooring was eased overboard and allowed to hang from a cable while the steel cage was lifted and drawn into position on the stern roller

3. The cage was lowered overboard but held with its top level with the deck.

4. The wooden square block was withdrawn and the Priming Charge inserted and secured in position

5. The mooring and cage were lowered on the main cable, which was attached to the top of the cage by means of a 100 t swivel until only a few metres of cable remained on deck.

6. The four buoys to provide positive buoyancy were shackled to the top end of the main cable by short lengths of wire rope and the main cable allowed to run overboard, the load being taken on a supplementary cable attached to the shackle holding the buoys.

7. The double cone marker buoy was also attached to this shackle, and when the supplementary cable was paid out until the mooring was on the bottom all the items were in a vertical line at the correct distances apart.

8. Finally the supplementary cable was let go overboard.

9. During lowering of the charge the wooden drum with the cordtex wound on it was turned by hand to pay out the cordtex, the top end of the cordtex attached to the Pentolite Primer being finally secured to the small float, which was then cast overboard.

No problems arose in putting overboard the mooring, cage, and buoys, and the 1.8 km of firing line, frequently buoyed with plastic air bags, was paid out easily and safely because of the ship's extremely effective speed and aspect control.

Firing the Charge

Because of the time spent in searching for a relatively flat bottom at the required depth of 137 fathoms (250 m) on 19 December 1972 the lowering overboard of the mooring, cage, and buoys was not begun until 1400 hrs on 19 December 1972 and completed by 1830 hours, which was too late in the day to use some of the recording stations which went out of action at 1815 hrs. In these circumstances it was planned to lie off during the night and connect up and fire the next day, but soon after arriving at this decision the marker buoy was suddenly pulled under, leaving only the float with the cordtex attached linking the charge to the surface. The reason for the submersion of the marker buoy is not known, but it was most probably due to the mooring's slipping down the slope of the sea bottom, which as shown by the depth indicator was steeply inclined. As there was no confidence that this movement would not occur again it was decided to connect up and fire that evening although it was realized that some of the recording stations would miss the signal.

The seismic detonator was taped into position in the Pentolite booster and the firing cable paid out, with plastic air bag floats attached every 100 feet or so. Eventually 1.8 km of cable was run out, the firing box and timing instrumentation connected up, and the charge fired at 1950 hrs on Tuesday 19 December 1972. Detonation appeared to be complete, and a severe shock was felt in the ship, which was approximately 1½ km from the charge. Some electric lights were broken and some electric relays tripped, but there was no indication of damage to the ship's hull or machinery.

Time to Fire

The shot box impulse to the detonator was about 1800 volts and the resistance of the firing cable was 320 ohms; so current to the detonator was approximately 5.6 amps. The delay inherent in the detonator at this current is about 1.1 milliseconds.

The major source of delay in firing the charge was in the time taken for the 100 grain cordtex to propagate detonation along a 1000-foot length at a mean pressure of 160 psi. ICI Australia (who made the cordtex) advise that the mean velocity of detonation for the cordtex used was 6520 m/s at atmospheric pressure, and they think it unlikely that this value would increase significantly due to the hydrostatic pressure, so that 1000 feet of the Cordtex would take about 46.8 ms to propagate detonation from one end to the other.

This, plus say 1 ms for the detonator delay, suggests that the total delay from the completion of the firing circuit to the detonation of the charge, would have been close to 48 ms.

Comments

Although the charge assembly and the putting into position of the charge in the sea went very well, and the charge appeared to detonate completely, a great deal of trouble was met in locating a position giving the right depth of water. In the short time available the best that could be done was over a spot with a steeply sloping bottom. It is probable that this was primarily responsible for the submersion of the marker buoy and the forced decision to fire later in the day than planned.

It would be a great advantage in any further operations of this nature if the location could be surveyed and a spot with desirable bottom contours chosen before the explosive charge is put overboard. This may mean that the explosive carrying vessel has to stay longer on location or that the survey should be done by another craft some time ahead.

5.4 Shot Firing Operational Log

All times are Australian Eastern Summer Time

Dec 17 Sunday		Coulson at Barry Beach pm
Dec 18 Monday	7.00	'Smit-Lloyd 33' on charter
	9.15	BMR Party arrives Barry Beach, ocean swell 12-15 ft and falling
	12.00	Rigging of cables and cages 90% complete
	12.15	Bilges pumped at bilge wharf
	13.00	Explosives reported at Port Welshpool accompanied by Victoria Department of Mines Inspector
	13.30	Back at loading wharf
	14.30	Loading remaining buoys, stands, etc, complete
	14.43	Sail from Barry Beach for Port Welshpool accompanied by Ken Bos, Esso Manager, Barry Beach
	13.50	Arrive Port Welshpool
	14.00	Weather improving, swell 5-6 ft
	18.00	Explosives loaded and packed, ship inspected by Department of Shipping and Transport
	18.10	Sailed from Port Welshpool
	18.40	Anchored in Corner Inlet to lash down
	19.00	Weather still improving
	21.15	Up anchor and sailed from Corner Inlet
Dec 19 Tuesday	05.20	Dropped anchor off Lakes Entrance
	06.10	Picked up Captain Steve Mathews, Captain Ray Shutt disembarked

	06.15	Up anchor and sail for shot site
	09.45	'Talked through' whole operation with ships officers, Coulson, SHORAN operator, BMR party
	10.15	On approximate station
	10.30	Fathometer fault
	12.50	Fathometer working intermittently
	13.50	Spot located and marked with buoy attached to sinker
	14.00	Commenced deployment operations
	14.30	Rendezvous with 'Ballina Star', see Section 5.8 - Fishing Inspection (depths confirmed)
	15.30	Charge and sinker swinging on stern
	17.45	Sinker on bottom and all buoys and cordtex deployed. Decision made to wait until 07.00 next morning before firing
	17.50	Surface main marker buoy sinks slowly due to unknown causes
	17.55	Decision made to fire shot as soon as possible because of danger of losing shot altogether
	18.35	Detonator attached to cordtex and firing line streamed for 1.1 miles from shot
	18.45	Five minute warning and all systems checked
	18.49	One minute warning, shot box connected and charged up
	18.50	<u>Shot fired</u>
	19.30	Firing line pulled in and back at shot site. No buoys or cable recovered. Cordtex raft recovered. Less than 5 dead fish spotted on surface from vessel, dinghy, and 'Ballina Star'. Polystyrene foam bits scattered on surface presumably from large buoy interiors.
	20.30	Sailed from site for Barry Beach.
Dec 20 Wednesday	07.30	Alongside at Barry Beach (Smit-Lloyd 33 off Charter 08.00)
	11.00	All BMR gear off ship, BMR party and Coulson depart Barry Beach.

5.5 Comments on Shipborne Operations

When the shooting vessel came on charter to BMR it was under the command of Captain Ray Shutt who organized the preparations at Barry Beach, took the vessel round to Port Welshpool, loaded the explosives, and then took it to Lakes Entrance. Because of the normal staffing arrangements for the vessel, Captain Shutt finished his tour of duty on Monday 18 December and the relieving Captain, Steve Mathews, was brought out to the the vessel from Lakes Entrance by the fishing boat 'Passadena Star'; it took Captain Shutt ashore on completion of the changeover.

In addition to the ten members of the ship's crew, there were on board three BMR staff (D.M. Finlayson (party leader), P.E. Mann and C. Rochford, the BMR explosives consultant (W.H. Coulson), the Department of Services and Property marine navigator (T. Rooney), and SHORAN operator (R. Cooper). The deck handling operations were under the direction of the ship's 1st officer, Jost Besier, and were conducted with commendable efficiency considering the fact that a full rehearsal had not been conducted and thus a few tricky problems had to be solved. The deployment operation took approximately 3 3/4 hours.

Weather played a very important part in the whole project. During the week preceding the shot, a large high-pressure system approached Bass Strait from the Great Australian Bight and winds backed from southwest to southeast with decreasing intensity. Wave heights in the Strait decreased from 16-20 ft in the two days before the shot to 2-4 ft on the day of the shot. The large 'high' was centred over the Strait on the day of the shot and the two days after and produced very calm conditions, with only light winds: ideal weather for the project. All those on board the shooting vessel agreed after the operation was completed that to attempt to deploy such a charge in anything but ideal conditions would invite disaster.

Radio communication between the 'Smit-Lloyd 33' and BMR Canberra was not as good as it might have been because, perhaps, of the hesitancy of the captain and BMR to use the good offices of the Esso staff at Barry Beach Marine Terminal. Because Esso, Sale, had expressed a wish to stay out of the project as far as possible, the captain attempted to use the Department of Shipping and Transport communication network with the resultant lag in keeping BMR Canberra informed of progress. In the event, Esso Barry Beach were quite pleased to help us in our predicament using their excellent communications network, but it was not until late on 19 December that this channel was used and even then not to its full extent. This aspect of the exercise will require improvement in future projects of this type.

The fault which developed in the Kelvin-Hughes fathometer was very annoying but it is difficult to foresee such equipment faults without expensive full sea trials. The instrument had been working perfectly in the range 0-100 fathoms, which is the normal operating range for the Bass Strait. However when it was switched to the deeper range required for the BMR exercise only very weak signals were received, not good enough to establish bottom topography. When the instrument was examined, a sliding phosphor-bronze electrical contact broke and it took some time to fabricate a new one. After this repair it was difficult to say conclusively that the contact was the major fault because the signal, although slightly improved, was still not very satisfactory. It was in this condition that the instrument was used to choose the shot site. Fortunately the fishing inspection boat 'Ballina Star' was able to confirm bathymetry when it rendezvoused with the 'Smit-Lloyd 33'. The fathometer fault delayed the exercise for about 3 hours.

The settling of the charge on the sea bed was a very disappointing feature of the firing operation. This could have been due to the sinker sliding down the slope as suggested by Coulson (Chapter 5.3), or to loss of buoyancy in the main buoys. These buoys were submerged 18 m below the surface and the fact that they were old may have meant that rust had set in and allowed water to enter. This may have been sufficient to reduce the buoyancy, and the slow rate at which the charge sank led the Party Leader (D.M. Finlayson) to favour this hypothesis. In future exercises of this nature it would be preferable to use a massive surface buoy as used off Scotland. Apart from seeing any buoyancy faults developing, it would also be recovered for further use.

As suggested by Coulson in his report, a sea-bottom survey should be made before any future exercise of this nature so that the larger shot-firing ship is not held up by routine depth-sounding.

5.6 Navigation

The shot position was determined using facilities available to the oil exploration industry in Bass Strait, provided by Offshore Navigation Pty Ltd. The system used is SHORAN distance measuring equipment and requires two base stations onshore. These were located at Mt Taylor and Mt Raymond; the Australian Metric Grid (AMG) co-ordinates for the stations were as follows:

Mt Taylor	N = 5,826,484 m	latitude	37°42'28"S
	E = 549,290 m	longitude	147°33'41"E
Mt Raymond	N = 5,824,783 m	latitude	37°42'49"S
	E = 640,919 m	longitude	148°36'02"E

The SHORAN ranges from the shooting ship observed at the time of the charge settling on the sea bottom were:

Mt Taylor = 79.178 miles (127.397 km)

Mt Raymond = 41.549 miles (66.852 km)

The ranges were to the SHORAN antenna on the shooting ship. The stern of the ship from which the charge was lowered was 120 ft (36.6 m) bearing 050 magnetic from the antenna.

The subsequent computation of the shot position by the Survey Branch, Department of Services and Property, gave the following co-ordinates:

latitude $38^{\circ}17'33''$S

longitude $148^{\circ}48'35''$E.

The Survey Branch surveyor on board the shooting ship observed the navigation method and made the necessary computations in Canberra to determine the latitude and longitude.

The depth of sea bottom was determined using a Kelvin-Hughes fathometer which developed a fault during the operation but was eventually repaired. The depth to bottom was subsequently confirmed by the fathometer on board the fishing vessel 'Ballina Star'. The fathometer profile on the edge of the continental shelf where the shot was located is shown on Plate 8. At the shot location the bottom depth was measured as 252 m with all corrections, and thus the shot was initially placed at 227 m. However the depth of the charge at detonation after it had settled on the bottom was probably 252 m.

5.7 Shipborne Recording

A sketch of the deployment of shot and ship before firing is shown in Plate 7. The shot was fired using a 2000V SIE high voltage blaster as described in chapter 5.3. Timing control was achieved by recording the shot impulse from the blaster on a 6-channel direct-reading galvonometer recorder (Visigraph recorder) along with VNG radio time signals received via a Labtronics receiver and the time code from a BMR NCE-1 digital clock. A single hydrophone over the ships side was also connected to the Visigraph recorder via a BMR TAM-4 seismic amplifier. The recording paper speed was 2 cm/s.

A 12-channel Vector marine hydrophone streamer was deployed from the ship pointing towards the shot marker buoy. This was used to determine water wave and sea-bottom velocities. However, there would be considerable distortion of the latter due to the gradient of the sea bottom. The 12 MP-8E hydrophones were 7.6 m apart and their output was recorded on a SIE RS-4 13 channel direct writing oscillograph, one channel being used for VNG radio time signals.

The corrected time for the shot and the local velocities are:

Corrected shot time	07.50 00.77 s UT 19 December 1972
Apparent water velocity	1.47 km/s
Apparent sea bottom velocity	3.22 km/s

5.8 Fishing Inspection

The detonation of explosives in water will kill any fish in the immediate vicinity of the charge, especially in confined waters. However, the effects of damage to commercial fishing by seismic shots at sea are not well known. Keams & Boyd (1965) have given an account of damage to fish in the waters off British Columbia, Canada, but no other well documented inspections have come to the notice of the authors of this Record.

The Victorian Department of Fisheries and Wildlife and the Commonwealth Departments of Primary Industry and Shipping and Transport were informed of BMR's intentions regarding the shot. Subsequently, fears of widespread damage to commercial fishing were expressed by the Lakes Entrance Fishing Co-Operative, and during the planning stages of the project, D.M. Finlayson went to Lakes Entrance to discuss the matter with the Co-operative management. The extent of their fishing grounds was defined and an agreement reached on the general location of the shot. It was also agreed that some form of fisheries inspection was desirable, and an arrangement was subsequently made that the Department of Fisheries and Wildlife inspector at Bairnsdale should attempt to define extent of damage to fishing using the facilities on board a Lakes Entrance trawler hired by BMR.

The inspector was asked to provide the following information:

1. Establish the extent of commercial fish in the shot area designated by the shooting vessel. In the shooting area just at the edge of the continental shelf, flathead is the main commercial fish and is caught by trawling. The 250 m of water required for the shot was estimated to be about the depth limit of trawlers.

2. Estimate the number of dead fish on the surface after the shot by inspection and the extent of bottom dead fish out to 2 miles from the shot by trawling.

Report by K.J. Street, Dept. of Fisheries and Wildlife Inspector, Bairnsdale

The detonation of the explosive device took place at 6.50 pm on the 19 December last and O'Riley and I were on board the 'Ballina Star' to carry out observations before and after the blast. We had one trawl shot in the area just before the explosion and this yielded two boxes of flathead and one box of mixed fish.

The skipper of the 'Ballina Star', Dennis Shepherd, was of the opinion that fish were generally scarce in the area at that time.

We were back on the detonation site twenty minutes after the explosion and patrolled the area for an hour and twenty minutes searching for signs of dead fish. During that time we found a dead Hake, one Morwong, and one dead Penguin. Despite an intensive search of the area these were the only casualties that were found.

Comment - D.M. Finlayson

Discussions with fishing industry interests before the shot provided useful information about the nature of the sea bottom at the shot site. It is important that the consultations take place in an exercise of this nature and every consideration was given to possible criticisms. The fishing inspection did not include any underwater trawls after the shot, hence no indication of the extent of damage to bottom fish was obtained.

6. SEISMIC RECORDING OPERATIONS AND RESULTS

6.1 Equipment Types

As well as the observatory networks run by BMR, the Australian National University, and the Universities of Adelaide, Tasmania, and Queensland, 34 sets of portable seismic recording equipment were set up to record the shots. The following list describes the type and number of portable sets operated, and the operating authority.

Organization	Equipment	Number of Sets
BMR	Vertical Willmore seismometer MK II, PI frequency modulated tape recorder, automatically switched on for ¼ hour every hour, for 12 hours each day	6
	Vertical Willmore seismometer MK II, Akai frequency modulated tape recorder, automatically switched on for ¼ hour every hour, for 12 hours each day	7
	4.5 Hz and 20 Hz geophones (4 in line with shots, spacing 6 metres), Seismic Amplifiers SIE PT-700, Oscillograph SIE TRO-6, Magnetic Recorder (FM) SIE PMR-20	1
	Willmore Recorder, manually operated	1
ANU	Vertical Willmore seismometer MK II, Sony direct record slow speed tape recorder, 24 hour operation (Muirhead and Simpson, 1972)	10
Univ. of Qld	80 Ton Shots: 2 Hz Geophone, SIE PRO 11 recorder, manually operated	1
	Bass Strait Shot: (a) 2 Hz Geophone, SIE PRO 11 recorder, manually operated	1
	(b) 2 Hz Geophone, Brush paper recorder, manually operated	1
	(Note: (a) and (b) operated at the one site)	
Univ. of Adelaide	Paper recorders, manually operated 2 Hz Hall-Sears geophones	2
	ANU Type tape recording system	1
Univ. of Melb.	Willmore Seismometer, MKII, frequency modulated tape recorders, manually operated	3

6.2 Positioning of Shots and Stations

Accuracy of 0.1 km in the positioning of shots and stations was required.

The two land shots were positioned by scaling the latitudes and longitudes of their positions off local topographic maps. The Bass Strait shot, as mentioned in Chapter 5, was positioned by SHORAN.

The co-ordinates of most of the sites of portable stations were determined from the positions marked on 1:250 000 topographic maps. Four of the sites on the Nullarbor Plain, Ooldea (OA), Cook (CK), Deakin (DN), and Forrest (FT), were adjacent to Division of National Mapping trigonometric points or bench marks.

Observatory co-ordinates were obtained from bulletins issued by the various operating authorities.

6.3 Record Analysis

After the survey, all other participating institutions except ANU sent BMR copies of their records. Because of the time involved ANU undertook to replay their tapes at their own convenience and to publish the results elsewhere.

The borrowed records, with the records from the BMR stations, were analysed independently by three geophysicists. Each seismic arrival was given a quality of good, fair, or poor. Arrival quality is based on amplitude and frequency of the arrival and any phase difference it might have with the background signal, be it noise or an earlier phase being overriden by the new arrival. Despite these criteria used for determining arrival quality, the value given to the quality remains to some extent subjective, but is still useful in determining how much weight should be given to a point in fitting it to a set of data. For example, in cftting a time-distance curve to a set of points, weights of five, three, and one corresponding to good, fair, or poor were given to the arrivals in the current project.

The estimated accuracy in the timing of the onset of arrivals was defined as 1,2,3, or 4. These values represent the following limits:

$$1 < 0.1$$

$$0.1 \leq 2 < 0.5$$

$$0.5 \leq 3 < 1.0$$

$$1.0 \leq 4$$

Arrivals on observatory records could generally be timed with an accuracy of 3, and perhaps 2, using minute marks on the seismic traces. Because the BMR field stations use high quality tape recording equipment, the recorded seismic and timing signals may be manipulated during playback to allow much more accurate timing of events. The seismic traces, both high and low gain, are recorded in the field with VNG one-second time signals and a coded time signal from a BMR low power digital clock. The tapes from the survey were replayed at BMR at four times their recorded speed and the traces were output on a Brush 6-channel pen recorder. The pen recorder has several speeds which allow the 'stretching' of the time scale and consequent increase in the timing sensitivity. Parallax errors due to nonalignment of recording heads have been measured and are allowed for. Consequently, most arrival times can be determined with an accuracy of 1 or 2.

Included in the accuracies are the uncertainty in picking the beginning of an arrival, the error in the timing system of the equipment, and any parallax in the recording and play-back systems.

Shot-to-station distances and azimuths were determined with program ROBBINS2, and the arrival data were punched onto computer cards to be run with program REFDAT. Program REFDAT lists the data in the forms shown in Tables 1, 2, and 3. Programs ROBBINS2 and REFDAT are described by Cull (1973).

6.4 Success of Recording

Thirty-four sets of portable seismic equipment were operated and thirty-five observatories were expected to record the blasts. Not all, however, were successful. The stations which recorded at least one arrival are listed in Table 2 with their latitudes and longitudes. In this table, and in Table 3 where arrival data are listed, temporary stations may be distinguished from observatories by the use of two-letter abbreviations of their names, as distinct from the internationally recognized three-letter symbols of the observatories.

Neglecting all the ANU stations except CAN, for which arrival times are available, a total of 118 recordings were expected from the three shots at stations within Australia. 56 (47.5%) were successful. However, some failures were due not to malfunction of the equipment but to the signal being indistinguishable from noise because of low signal to noise ratio. The Mt Fitton shot was recorded at a maximum distance of 2092 km at MEK. Of the stations in Table 2 which were operating for this shot, only MUN was at a greater distance (2237 km).

Fifteen stations (14 observatories and one field station) were at distances greater than 1786 km, the longest distance over which the Kunanalling shot was recorded (Kunanalling to WRA), and four observatories were at distances greater than 2466 km, the greatest distance over which the Bass Strait shot was recorded (Bass Strait to WRA). If the 20 stations at distances greater than the greatest 'recorded' distances are neglected, 98 arrivals might be expected in Australia. On this basis, a success rate of 56% was achieved. However, the above criterion for determining which stations are expected to be successful is subjective.

Of the 20 stations rejected above, 19 are observatories. This is because the field stations, being mobile, were placed in favourable locations.

The survey was important to BMR because it provided the first field test of the BMR portable seismic stations. Five PI recorders were run for both the land shots and a sixth for the Mt Fitton blast only. Eight recordings were successful from a possible eleven (73%). A higher success rate might have been possible if the quality of the recording on the tape had been higher. The poor quality of recording was eventually traced to the type of tape used. Consequently, a different brand has been tested and found to be more suitable for this type of recording. Seven Akai recorders were run for both the land shots. Six recordings were successful out of a possible fourteen (43%). The low success rate of the Akai recorders is mainly due to the lack of reliable play-back facilities for checking test tapes made during the routine pre-field tests of the equipment. The quality of records of successful recordings may be higher when the tapes are replayed on precision play-back equipment yet to be provided; however, no more seismic events are expected to be recovered.

After the land shots, the field equipment was returned to BMR and any mechanical problems were rectified. Six PI recorders and six Akai recorders were set up in the field to record the Bass Strait Shot. However, because they were programmed to record for only the first fifteen minutes of each hour, they were not operating at the time of the Bass Strait Shot (see Table 1). Consequently they were not considered in the calculations of the percentages of success above.

6.5 Interpretation

The results listed in this record are interpreted by Finlayson Cull, & Drummond (in prep.). That paper also lists estimates of the magnitude of the shots as seismic energy sources.

7. ACKNOWLEDGMENTS

In a survey of this complexity there are innumerable people who have been extremely helpful and BMR wishes to thank all those who assisted. Special mention must be made of the following:

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The management of Esso Australia Pty Ltd, Sale, Vic., and Mr Ken Bos, manager of the Esso Marine Terminal, Barry Beach, Vic.;

Mr Steve Mathews, Mr Jost Besier, and crew of the shooting ship 'Smit-Lloyd 33';

Mr Bill Coulson, explosives consultant, Melbourne;

Western Mining Corp., Kalgoorlie;

Department of Supply Explosives Factory, St Marys, NSW, and Maribyrnong, Vic.;

The Australian National University, Riverview College, Sydney, the Universities of Melbourne, Adelaide, Queensland, Tasmania, and New England, some of whom put out temporary stations and assisted in the field or otherwise contributed data from permanent recording stations.

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APPENDIX 1

REPORTS TO IASPEI WORKING GROUP: P.L. WILLMORE

WORKING GROUP ON 10-TON EXPLOSIONS

DISCUSSIONS IN OSLO, NOV. 22-25, 1971

Convenor: P.L. Willmore

The Working Group on 10-ton Explosions was established by the IASPEI at the General Assembly of the IUGG in August 1971, in order to follow up the possibility of making teleseismic observations on comparatively small underwater explosions. In view of the fact that several members of the Working Group were expected to attend the NORSAR symposium, the IASPEI recommended that a second meeting of the Working Group should be convened at that time. The organisers of the symposium generously allocated time in the open sessions for the presentation of a report on the pilot experiment (Jacob and Willmore, 1971). The Working Group session which followed was attended by 7 of the official members of the Working Group or their nominated alternates, and by a number of other interested participants.

The Working Group drew the following conclusions from the results of the pilot experiment:

a) 10-ton shots, fired under the prescribed conditions, could yield clear P-wave onsets on closely-filtered, high-performance seismographs at distances at least as great as 90^{o}. Long-range records were obtainable in favourable locations by conventional equipment (e.g. Brisbane D = 144.7^{o}) but onsets were generally close to the noise threshold. The result was to be expected from the apparent body wave magnitude ($m_b = 4.38 \pm 0.40$).

b) The firing conditions appropriate to the 10-ton shot (200 metres below the surface in 210 metres of water) were evidently very close to optimum, and should be adhered to in any future experiments. Charges large enough to produce significantly higher signal levels would be highly unwieldy in open-sea conditions. Charges in the range of 2-5 tons would be useful for regional pilot studies, but could not be expected to yield world-wide observations.

c) The logistics of a world-wide operation would depend largely on the length of time for which temporary field stations could be maintained in uninterrupted operation. Equipment operating continuously would minimise the problems. Equipment with an uninterrupted running time of as little as 1 hour could be used, but this would require shots to be fired within pre-arranged periods of the order of half an hour. As the British pilot operation had required about 6 hours of shot preparation and recovery, and as ships might be reluctant to stand by for long periods when the charges had been positioned, it would seem that unrehearsed crews might have considerable difficulties in holding to the schedules imposed by short-run recording equipment.

d) In spite of the inherent difficulties of the project, the Working Group recognised the great potential value of observations from a set of standardised and controlled seismic sources distributed around the seismically active regions of the world. Considerable further benefit would be derived from the fact that, if temporary installations could be sustained in operation for a few months, covering a series of explosions, an unprecedented opportunity would arise for studying the detectability, source mechanism and travel-time patterns of natural events, using the explosions as calibrating points.

e) The members of the Working Group were aware of several field operations during the period June-September 1972, in which suitable recording stations were being deployed. It was thought that two or three potential shooting organisations might provide explosions during this period, but others would require longer notice to set up funds, or to organise pilot studies, which might lead to further experiments in 1973 or 1974.

f) The International Seismological Centre should be approached with a view to applying its normal group and location programmes to the preliminary readings obtained from the proposed operations. The entire suite of records (many of them probably on non-interchangeable magnetic tapes) could provide material for numerous parallel research studies, and it was hoped that recording organisations would accept the responsibility of generating appropriate playouts on request.

In view of the above conclusions, the Convenor was authorised to approach organisations with possible shot-firing and recording capabilities within the above-mentioned time intervals, and agreed to cirdclate a report on the results of this correspondence by the end of February 1972.

Reference

Jacob, A.W.B. and Willmore, P.L. 1971, "Teleseismic P Waves from a 10-ton Explosion", available from IGS Global Seismology Unit, 6 South Oswald Road, Edinburgh, EH9 2HX, Scotland.

APPENDIX TO 'TELESEISMIC P WAVES FROM A 10 TON EXPLOSION'

1) Equipment

The ship was used was the RNAS 'BARFOOT' (Plate 10), a salvage vessel equipped with good lifting gear and a crew accustomed to working with explosives. The explosives officer was Mr C.C. Moore, who was assisted by two other members of the staff of NCRE. Dr Jacob carried out the timing using the signal from a geophone on the ship's hull and time signals from radio stations MSF, HBG, and a recording of BBC radio 2 as a back-up.

The charge was made up of

44 x 500 lb charges each in 100 lb metal containers

2 x 300 lb depth charges

1 x 50 lb charge

The total weight of explosive was 22650 lbs (about 10,300 Kg). The charges were all of TNT and were packed in a welded steel box measuring about 3.35 metres long by 2.1 metres wide by 1.4 metres high. The explosives were put in two layers with 24 x 500 lb charges in the bottom layer and the rest in the top layer. The shot was detonated by the two 300 lb depth charges which were fired electrically. The 50 lb charge was separately wired and fused to allow a second attempt without raising the charge if the first attempt to fire failed (most likely reason would have been a broken firing cable).

Weight of explosives	10 tons
Weight of metal (box and cannisters)	3.7 tons
	13.7 tons

2) Firing procedure

The 14 ton box was hoisted over the side and hung from an anchored Admiralty First Class buoy. Hoisting and lowering the box proved to be a slow process and it was fortunate that the sea was calm by the time it was attempted. It would have been very difficult to control the box while it was slung from the derrick if the ship had been rolling. When the charge had been hung from the buoy the ship was allowed to drift away and firing cable with fishing floats on it was paid out until the ship was a safe distance from the charge (see Fig. 2). The range was measured using the ship's radar and checked by the amount of firing cable paid out.

Two firing cables were led to the firing cable buoy (10 metres off the lifting buoy) but only one was brought to the ship. The other was merely attached to the firing cable buoy. The charge was fired electrically to retain control over the instant of firing in case other shipping arrived unexpectedly.

The whole process from anchoring to recovery of the buoy and other gear took about 6 hours, but as this was a first and only attempt it would be possible to cut this time considerably with more practice. However, a calm sea is essential and the operation would have to be refined if it is to be possible in rougher conditions.

3) <u>Questions for the Working Group</u>

a) How useful would it be to fire exact repetitions of our 10-ton shot in different locations? Should we test larger shots, multiple shots, or any other variants of the basic experiment? Would a restricted preliminary programme (a few shots into selected targets) be useful?

b) Can we improve technique, i.e., by using lighter or cheaper containers, superior handling methods, etc.?

c) What are the favoured dates and locations for (i) further trial shots, (ii) the main experiment?

d) What organisations should be approached in respect of (i) shooting, (ii) recording? How should these contacts be made?

e) How much, and what type of central control will be needed for the world-wide experiments?

f) What arrangements should be made for data collection and preliminary reduction?

PROGRESS REPORT 10/3/72 - 10-TON EXPLOSIONS FOR TELESEISMIC OBSERVATIONS

To Working Group
and interested parties

1 Technique

Since the discussions which took place in Oslo on 22-25 November 1971 some discussions on the physical technique of firing have continued. The conclusions are as follows:-

1.1 Containment of Charge.

It seems likely that the steel tank in which the charge is packed could be made considerably lighter than that which was used in the 1971 experiment. A manufacturer of the transportable skips used for waste disposal has been asked to submit a proposal for a container suitable for the proposed British charge and the results of this study will be available to other interested participants.

1.2 Depth of shooting for explosives other than TNT.

A communication has been received from A.L. Hales, which credits Aarons and Yennie with the original formulation of the optimum-depth conditions, and encloses depth-frequency charts for TNT and for Nitramon WWEL. This communication is being copied to prospective shooting organisations.

1.3 Firing Schedule.

There is still some uncertainty about the length of time which will be required to complete the operation of lowering the charge and detonating it, and in some areas it may be necessary to allow latitude in the moment of detonation to ensure that the neighbourhood of the charge is clear. Nevertheless, it is thought probable that a charge could be detonated within a specified 40-munute interval, and that any hitch in the programme could be accommodated by specifying reserve periods at intervals of 2 or 3 hours after the planned occasion. It is therefore suggested that shooting organisations should arrange to detonate between 5 minutes past and 45 minutes past an exact hour, aiming at the beginning of the scheduled period. By these means distant field parties whose equipment is capable of running for periods of about one hour will have a good change of successful recording.

1.4 Advice to Field Parties

All field parties expecting to observe the explosion with short-run equipment are requested to register their names and contact addressed by returning a copy of the enclosed form to IGS Edinburgh. This will enable us to inform them of advance schedules by air letter and to conform eventual detonation of charges by telegram. The inclusion of a cable address would be particularly useful if recording is to be intermittent.

2. Safety Requirements

Discussions have taken place about the possible hazards of the experiment under the following subject headings:-

2.1 Triggering of earthquakes

It is known that underground events can give rise to aftershock sequences in the vicinity of the source and the question has been raised as to whether our explosion could generate any hazard in this direction. Evidence, however, suggests that aftershock triggering requires changes in the long term stress pattern in the ground, which is why major earthquakes produce substantial aftershock sequences. Nuclear explosions which generate cavities produce minor adjustments after the shot, but very large underground explosions (e.g. Cannikin and Longshot) have been fired in tectonically sensitive areas without any serious effects. Our own explosions will be several orders of magnitude smaller than these events and will not generate any permanent deformation of the ground. It is therefore considered that the aftershock hazard can be discounted.

2.2 Damage to Fish

The depth required for detonation will, in most cases, remove the charge from areas of commercial fishery and in any case the lethal radius of the shock wave will be somewhat limited. If one considers the probable lethal radius as being proportional to the radius of the charge, one sees that the effect of our explosion is likely to be limited to something of the order of 5 times the radius of a single 135 kg depth charge.

In the light of this situation, British fishery authorities have made no objection to 10-ton shots in the proposed firing sites in British waters, but have suggested that, as an additional precaution, small preliminary shots (about 1 kg) might be fired in the vicinity of the main charge to scare away marine animals which might otherwise be injured.

2.3 Tsunamis or Turbidity Currents

There is no danger of any direct generation of a dangerous water wave by a 10-ton shot, but it is possible that, in exceptional circumstances, a turbidity current might be initiated and that this might have undesirable secondary effects. The factors militating towards the generation of such currents are the presence of substantial thicknesses of unconsolidated sediment with a long slope to deep water (in excess of 2 or 3 degrees in gradient) below an unstable deposit. A particularly undesirable condition is that in which the charge and the unstable deposits of sediment are at the head of a canyon which can contain an initial mud flow, and thereby increase the intensity of the subsequent scouring effect. The unstable deposits are particularly likely to occur near the mouths of major rivers, and the effects of a minor tsunami can be exaggerated if the waves can enter an estuary near the source.

In addition to the possibility of tsunamis one should consider the possibility of breaking submarine cables and should, therefore, avoid shooting up-shelf from a cable line, particularly if the cable has shown any earlier history of damage by turbidity currents. Ecological damage can also result from underwater disturbance. It is not expected that shooting authorities will have much difficulty in avoiding these dangerous combinations of circumstances, and the sites favoured for shots in British waters are in closed basins. Those interested in obtaining background information on turbidity currents may wish to consult the article by Munk (The Sea, 1963 Vol 1) or the articles by Morgenstern, by Andresen and Bjerrum and by Dill in Marine Geotechnique, 1967, ed. A.F. Richards, University of Illinois Press.

3. Proposals for 1972

It is now probable that the UK will be able to fire a shot in the Western Islands of Scotland about the middle of June, the preferred location being in the vicinity of 57 degrees 30 minutes North, 5 degrees 55 minutes West.

In July, the Australian authorities are proposing a shot off Kangaroo Island, South Australia (presumably about 37 degrees South, 137 degrees East).

Suggestions for trial shots have also been made to the Navies of Canada, Japan, the United States, Peru, Chile and Argentina but there is as yet no confirmation of plans for shooting in these areas.

Several organisations have given notice of intention to deploy recording parties.

TABLE 1

~~251072~~ TRANS-AUSTRALIA SEISMIC SURVEY ,1972. SHOT POSITIONING AND TIMING.

PARTICIPATING ORGANISATIONS - BMR,ANU,UNI.OF ADELAIDE,UNI.OF QLD,UNI.OF TAS,
RIVERVIEW OBS

THREE LARGE SHOTS FIRED. 1 MT,FITTON(NORTH FLINDERS RANGES),80 TONS
DETONATED 25/10/72 , 01HR 05M 00.04S UT
LAT. 30DEG 00.4MIN LONG. 139DEG 33.8MIN

2 KUNANALLING(NEAR KALGOORLIE),80 TONS
DETONATED 25/10/72 , 04HR 05M 01.23S UT
LAT. 30DEG 40.5MIN LONG. 121DEG 04.0MIN

3 BASS STRAIT (40 MILES SOUTH OF ORBOST),10 TONS
DETONATED 19/12/72 , 07HR 50M 00.77S UT
LAT. 38DEG 17.6MIN LONG. 148DEG 48.6MIN

COMPLEMENTARY DATA AVAILABLE FROM 1970,71 ORD RIVER BLASTS AND 1956 ATOMIC TEST
DATA FROM MARALINGA .

TABLE 2

RECORDING STATION LOCATIONS

		LOCATION	ABREVIATION	LATITUDE DEG MINS	LONGITUDE DEG MINS	ELEVATION METRES	INSTITUTION	SHOT DEPTH METRES
S	1	MT.FITTON	S FIT	30 00.4	139 33.8	-0.0		=0.0
S	2	KUNANALLING	S KUN	30 40.5	121 04.0	-0.0		=0.0
S	3	BASS STRAIT	S BAS	38 17.6	148 48.6	252.0		227.0
R	1	PARTACOONA	PNA	32 00.4	138 09.9	-0.0	UA	=0.0
R	2	ISLAND LAGOON	ILN	31 23.6	136 52.2	-0.0	UA	=0.0
R	3	WALLET	WTT	33 25.8	136 55.3	-0.0	UA	=0.0
R	4	KINGOONYA	KA	30 57.7	135 20.1	-0.0	UA	=0.0
R	5	SEVENHILL	SNL	33 53.2	138 38.4	-0.0	UA	=0.0
R	6	MT.BRADY	BY	29 14.8	134 59.0	-0.0	BMR	=0.0
R	7	OODNADATTA	OOD	27 33.7	135 27.0	-0.0	UA	=0.0
R	8	TARCOOLA	TR	30 37.2	134 30.3	-0.0	UA	=0.0
R	9	UMBERETANA	UMB	30 14.4	139 07.7	-0.0	UA	=0.0
R	10	CLEVE	CLV	33 41.5	136 29.7	-0.0	UA	=0.0
R	11	ADELAIDE	ADE	34 58.0	138 42.5	-0.0	UA	=0.0
R	12	MT.WILLOUGHBY	WY	28 03.2	134 09.2	-0.0	BMR	=0.0
R	13	GRANITE DOWNS	GD	26 58.1	133 23.9	-0.0	BMR	=0.0
R	14	COLDEA	DA	30 29.0	131 52.0	-0.0	BMR	=0.0
R	15	BELLFIELD	BFD	37 10.6	142 32.7	-0.0	BMR	=0.0
~~R~~	~~16~~	~~MILL RIDGE~~	~~MR~~	~~24 51.3~~	~~133 09.5~~	~~-0.0~~	~~BMR~~	~~=0.0~~
R	17	COOK	CK	30 41.4	130 25.5	-0.0	BMR	=0.0
R	18	ALICE SPRINGS	ASP	23 41.0	133 53.8	-0.0	BMR	=0.0
R	19	TOOLANGI	TOO	37 34.3	145 29.4	-0.0	BMR	=0.0
R	20	DEAKIN	DN	30 46.3	128 57.2	-0.0	BMR	=0.0
R	21	TALBINGO	TAO	35 36.7	148 17.3	-0.0	ANU	=0.0
~~R~~	~~22~~	~~KHANCOBAN~~	~~KHA~~	~~36 12.8~~	~~148 07.7~~	~~-0.0~~	~~ANU~~	~~=0.0~~
R	23	CABRAMURRA	CAB	35 55.6	148 26.0	-0.0	ANU	=0.0
R	24	CANBERRA	CAN	35 19.2	148 59.9	-0.0	ANU	=0.0
R	25	JENOLAN	JEN	33 49.5	150 01.3	-0.0	ANU	=0.0
R	26	INVERALOCHY	INV	34 57.0	149 40.0	-0.0	ANU	=0.0
R	27	WAMBROOK	WAM	36 11.3	148 53.0	-0.0	ANU	=0.0
~~R~~	~~28~~	~~MEROMBI~~	~~MER~~	~~33 57.0~~	~~150 34.8~~	~~-0.0~~	~~ANU~~	~~=0.0~~
R	29	FORREST	FT	30 53.0	127 46.6	-0.0	BMR	=0.0
R	30	RIVERVIEW	RIV	33 49.8	151 09.5	-0.0	COL	=0.0
R	31	WARRAMUNGA	WRA	19 56.7	134 20.5	-0.0	ANU	=0.0
R	32	CHARTERS TOWERS	CTA	20 05.3	146 15.3	-0.0	QU	=0.0
R	33	BRISBANE	BRS	27 23.5	152 46.5	-0.0	QU	=0.0
~~R~~	~~34~~	~~BALLINNA~~	~~BA~~	~~31 01.4~~	~~125 19.7~~	~~-0.0~~	~~BMR~~	~~=0.0~~
R	35	ZANTHUS	ZS	31 01.8	123 33.1	-0.0	BMR	=0.0
R	36	KALGOORLIE	KLG	30 47.0	121 27.5	-0.0	BMR	=0.0
R	37	KUNUNURRA	KNA	15 45.0	128 46.0	-0.0	BMR	=0.0
R	38	MANTON DAM	MTN	12 50.8	130 07.8	-0.0	BMR	=0.0
R	39	MUNDARING	MUN	31 58.7	116 12.5	-0.0	BMR	=0.0
~~R~~	~~40~~	~~MEEKATHARRA~~	~~MEK~~	~~26 36.8~~	~~118 32.7~~	~~-0.0~~	~~BMR~~	~~=0.0~~
R	41	OFFICER BASIN	OF	27 05.7	124 44.6	-0.0	BMR	=0.0
R	42	KOWEN FORREST	KN	35 17.3	149 17.6	780.0	BMR	=0.0
R	43	COOBER PEDY	CP	29 15.7	134 58.4	-0.0	UA	=0.0
R	44	SANDSTONE	SS	28 01.2	119 18.0	-0.0	BMR	=0.0
R	45	MT.CAVENAGH	CV	25 54.6	133 07.9	-0.0	BMR	=0.0
~~R~~	~~46~~	~~HOBART~~	~~TAU~~	~~42 54.6~~	~~147 19.2~~	~~-0.0~~	~~TU~~	~~=0.0~~
R	47	MOORLANDS	MOO	42 26.5	147 11.4	-0.0	TU	=0.0
~~R~~	~~48~~	~~TARRALEAH~~	~~TRR~~	~~42 18.2~~	~~146 27.0~~	~~-0.0~~	~~TU~~	~~=0.0~~
R	49	SAVANNAH	SAV	41 43.2	147 11.3	-0.0	TU	=0.0
~~R~~	~~50~~	~~SHEFFIELD~~	~~SFF~~	~~41 20.2~~	~~146 18.4~~	~~-0.0~~	~~TU~~	~~=0.0~~
R	51	SILVERTON	SN	31 49.3	141 11.6	-0.0	ANU	=0.0
~~R~~	~~52~~	~~MARS~~	~~MS~~	~~32 11.0~~	~~142 03.2~~	~~-0.0~~	~~ANU~~	~~=0.0~~
R	53	ASHMONT	AT	32 28.8	142 57.4	-0.0	ANU	=0.0
~~R~~	~~54~~	~~BEILPAJAH~~	~~BH~~	~~32 52.3~~	~~143 48.1~~	~~-0.0~~	~~ANU~~	~~=0.0~~
R	55	MOSSGIEL	ML	33 19.0	144 22.9	-0.0	ANU	=0.0
R	56	BOOLIGAL	BL	33 50.2	144 53.3	-0.0	ANU	=0.0
R	57	FERNDALE	FE	35 14.2	147 05.6	-0.0	ANU	=0.0
R	58	MEADOWS	MS	35 58.3	147 07.3	-0.0	ANU	=0.0
R	59	SCOTTS PEAK	SPK	43 02.3	146 16.5	-0.0	TU	=0.0
~~R~~	~~60~~	~~STRATH GORDON~~	~~SGO~~	~~42 50.0~~	~~146 12.4~~	~~-0.0~~	~~TU~~	~~=0.0~~

TABLE 3

PRELIMINARY RECORDED SEISMIC DATA

SHOT	RECORDER	LOCATION	ABREV	DISTANCE (KM)	AZIMUTH DEGS	TRAVEL TIME SECS	REMARKS	ACC(SECS)	TT MSL SECS	INST
1	1	PARTACOONA	PNA	258.8	210.7	39.56	GOOD	0.10	39.56	UA
						44.16	FAIR	0.10	44.16	
						70.66	FAIR	0.10	70.66	
						71.96	GOOD	0.10	71.96	
1	2	ISLAND LAGOON	ILN	300.3	238.5	44.96	GOOD	0.10	44.96	UA
						49.86	GOOD	0.50	49.86	
						81.76	GOOD	0.50	81.76	
1	3	HALLET	HTT	384.4	188.9	55.96	GOOD	0.10	55.96	UA
						64.46	GOOD	0.10	64.46	
						96.66	GOOD	0.10	96.66	
						109.46	GOOD	0.10	109.46	
1	4	KINGOONYA	KA	419.5	254.3	58.81	GOOD	0.10	58.81	UA
						66.62	GOOD	0.10	66.62	
						72.93	GOOD	0.10	72.93	
						115.54	FAIR	0.10	115.54	
						117.25	FAIR	0.10	117.25	
1	6	MT.BRADY	BY	451.4	279.6	62.30	GOOD	0.10	62.30	BMR
						62.89	GOOD	0.10	62.89	
1	8	TARCOOLA	TR	491.2	260.8	67.70	GOOD	0.10	67.70	UA
						68.00	GOOD	0.10	68.08	
						70.46	GOOD	0.10	70.46	
						76.60	FAIR	0.10	76.60	
						79.06	FAIR	0.50	79.06	
						120.46	GOOD	0.50	120.46	
1	9	UMBERETANA	UMB	49.3	238.2	8.16	GOOD	0.10	8.16	UA
1	10	CLEVE	CLV	501.2	214.6	68.16	GOOD	0.10	68.16	UA
						76.06	GOOD	0.50	76.06	
						85.56	FAIR	0.10	85.56	
						136.96	GOOD	0.50	136.96	
1	11	ADELAIDE	ADE	555.9	188.1	77.16	FAIR	0.10	77.16	UA
						135.46	GOOD	0.10	135.46	
						154.36	GOOD	0.10	154.36	
1	12	MT.WILLOUGHBY	WY	571.9	291.5	77.86	GOOD	0.01	77.86	BMR
						78.98	GOOD	0.01	78.98	
						99.68	FAIR	0.50	99.68	
						116.50	POOR	0.50	116.50	
						124.70	POOR	0.50	124.70	
						135.40	POOR	0.10	135.40	
						140.10	FAIR	0.10	140.10	
1	14	OOLDEA	OA	742.5	264.0	97.20	POOR	0.50	97.20	BMR
						97.79	GOOD	0.10	97.79	
						100.75	FAIR	0.10	100.75	
						102.17	GOOD	0.10	102.17	
						173.64	FAIR	1.00	173.64	
1	15	BELLFIELD	BFD	841.8	161.6	110.76	GOOD	0.10	110.76	BMR

SHOT	RECORDER	LOCATION	ABREV	DISTANCE (KM)	AZIMUTH DEGS	TRAVEL TIME SECS	REMARKS	ACC(SECS)	TT MSL SECS	INST
						196.66	GOOD	0.10	196.66	
						241.96	FAIR	0.10	241.96	
1	16	MILL RIDGE	MR	852.3	310.5	112.00	GOOD	0.10	112.00	BMR
						112.70	GOOD	0.10	112.70	
						115.00	FAIR	0.10	115.00	
						119.70	GOOD	0.10	119.70	
						127.20	FAIR	0.10	127.20	
						176.40	FAIR	0.10	176.40	
						195.60	GOOD	0.10	195.60	
1	17	COOK	CK	881.7	262.8	114.68	GOOD	0.10	114.68	BMR
						115.64	GOOD	0.10	115.64	
						203.00	FAIR	0.50	203.00	
1	18	ALICE SPRINGS	ASP	898.6	319.9	117.86	GOOD	0.10	117.86	BMR
						129.80	FAIR	0.10	129.80	
						143.00	POOR	0.10	143.00	
						149.16	FAIR	0.10	149.16	
						205.46	GOOD	0.10	205.46	
1	19	TOOLANGI	TOO	1002.9	148.4	129.96	FAIR	0.10	129.96	BMR
1	24	CANBERRA	CAN	1062.4	126.1	137.26	FAIR	0.10	137.26	ANU
						141.00	GOOD	0.10	141.00	
1	29	FORREST	FT	1135.7	262.1	145.46	GOOD	0.10	145.46	BMR
						147.53	FAIR	0.10	147.53	
						157.60	FAIR	0.10	157.60	
						184.76	FAIR	0.10	184.76	
						254.16	POOR	0.50	254.16	
1	31	WARRAMUNGA	WRA	1232.5	333.5	157.00	GOOD	0.50	157.00	ANU
1	32	CHARTERS TOWERS	CTA	1288.0	33.0	164.00	GOOD	0.10	164.00	QU
						288.46	FAIR	0.50	288.46	
1	34	RAWLINNA	RA	1370.8	261.7	172.86	FAIR	0.10	172.86	BMR
						177.00	FAIR	0.10	177.00	
						307.00	FAIR	0.50	307.00	
1	40	MEEKATHARRA	MEK	2092.3	275.2	255.66	FAIR	0.10	255.66	BMR
1	41	OFFICER BASIN	OP	1484.5	278.9	187.27	FAIR	0.10	187.27	BMR
						188.92	GOOD	0.10	188.92	
1	42	MOWEN FORREST	KN	1083.0	125.2	139.70	GOOD	0.10	139.51	BMR
						140.80	FAIR	0.10	140.61	
1	43	COOBER PEDY	CP	452.1	270.4	62.36	GOOD	0.10	62.36	UA
1	44	SANDSTONE	SS	1983.0	271.3	240.46	FAIR	0.10	240.46	BMR
1	45	MT.CAVENAGH	CV	778.6	308.6	103.10	GOOD	0.10	103.10	BMR
						111.40	FAIR	0.10	111.40	
						128.10	GOOD	0.10	128.10	
						173.60	FAIR	0.50	173.60	

TABLE 3 (continued)

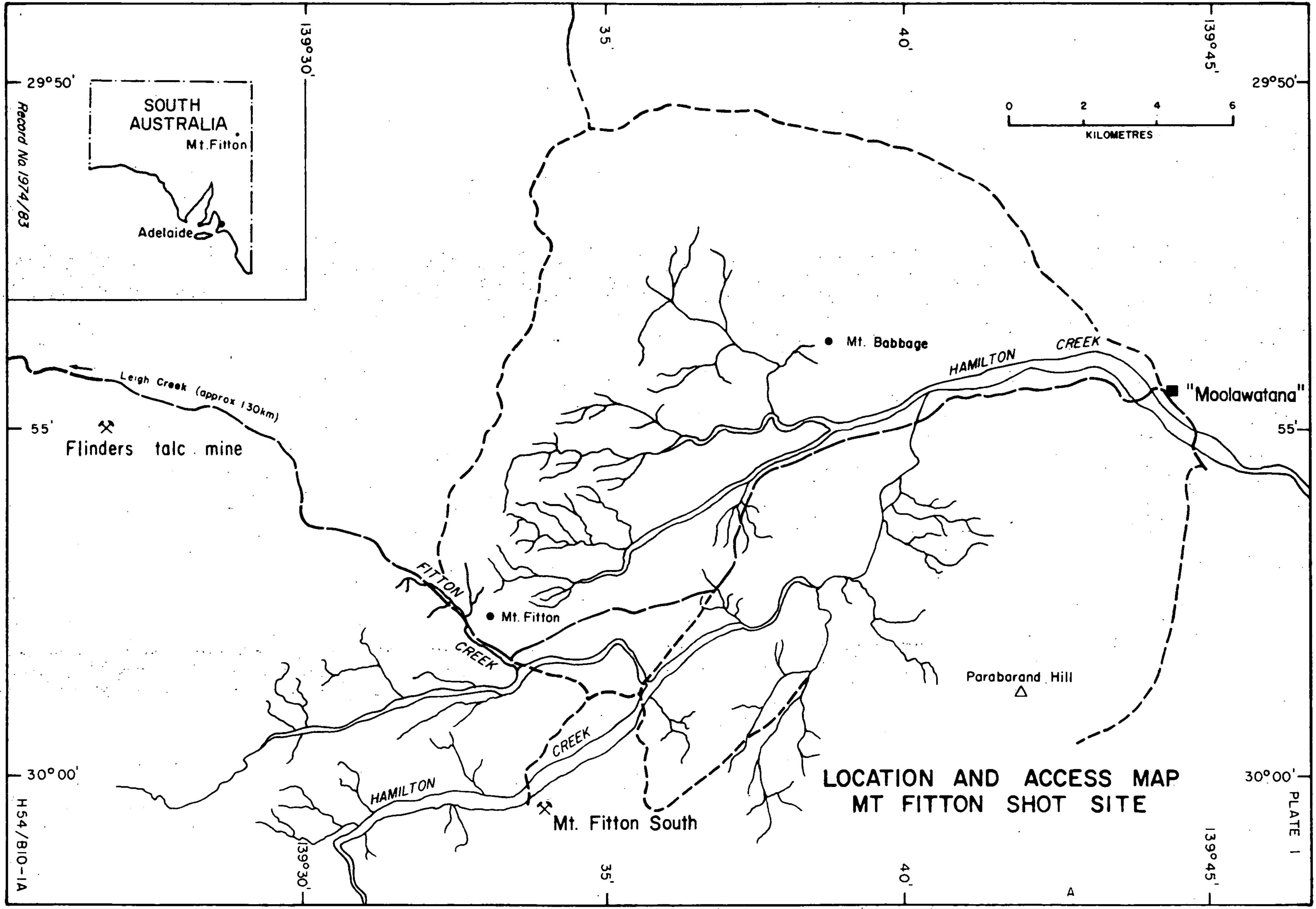
SHOT	RECORDER	LOCATION	ABREV	DISTANCE (KM)	AZIMUTH DEGS	TRAVEL TIME SECS	REMARKS ACC(SECS)	TT MSL SECS	INST
						179.10	GOOD 0.50	179.10	
2	2	ISLAND LAGOON	ILN	1509.6	97.1	189.47	POOR 0.10	189.47	UA
						192.97	FAIR 0.50	192.97	
2	8	TARCOOLA	TR	1287.4	93.2	163.42	FAIR 0.10	163.42	UA
						175.01	FAIR 0.10	175.01	
						289.80	POOR 0.50	289.80	
2	17	COOK	CK	896.4	92.5	116.05	FAIR 0.10	116.05	BMR
						116.67	GOOD 0.10	116.67	
						118.47	FAIR 0.10	118.47	
2	29	FORREST	FT	642.7	93.8	84.93	POOR 0.10	84.93	BMR
						86.01	FAIR 0.50	86.01	
						151.70	FAIR 1.00	151.70	
						180.80	FAIR 1.00	180.80	
2	31	WARRAMUNGA	WRA	1785.9	51.4	218.80	GOOD 0.50	218.80	ANU
2	34	RAWLINNA	RA	409.5	96.5	56.79	GOOD 0.01	56.79	BMR
						66.77	GOOD 0.01	66.77	
						71.51	POOR 0.10	71.51	
						79.42	FAIR 0.50	79.42	
						97.60	POOR 0.50	97.60	
						115.77	FAIR 0.50	115.77	
2	36	KALGOORLIE	KLB	39.4	107.9	6.37	GOOD 0.10	6.37	BMR
						10.97	GOOD 0.10	10.97	
						12.77	GOOD 0.10	12.77	
2	39	MUNDARING	MUN	484.4	251.4	64.57	FAIR 0.10	64.57	BMR
						80.97	POOR 0.10	80.97	
						112.77	GOOD 0.10	112.77	
						132.77	GOOD 0.10	132.77	
						135.27	GOOD 0.10	135.27	
						147.57	GOOD 0.10	147.57	
2	40	MEEKATHARRA	MEK	513.2	330.7	68.87	GOOD 0.10	68.87	BMR
						81.07	GOOD 0.10	81.07	
						121.77	FAIR 0.10	121.77	
						140.27	GOOD 0.10	140.27	
2	41	OFFICER BASIN	OF	534.8	43.0	72.21	FAIR 0.10	72.21	BMR
						72.97	GOOD 0.10	72.97	
2	44	SANDSTONE	SS	340.6	329.3	47.97	GOOD 0.10	47.97	BMR
						53.47	FAIR 0.10	53.47	
						67.77	FAIR 0.50	67.77	
						83.47	GOOD 0.10	83.47	
						94.37	GOOD 0.50	94.37	
3	1	PARTACOONA	PNA	1193.4	302.5	153.70	POOR 0.50	153.75	UA
						169.40	FAIR 0.10	169.45	
3	3	WALLET	WRT	1042.6	298.1	135.20	FAIR 0.10	135.25	UA
						289.70	FAIR 0.10	289.75	

TABLE 3 (continued)

SHOT	RECORDER	LOCATION	ABREV	DISTANCE (KM)	AZIMUTH DEGS	TRAVEL TIME SECS	REMARKS	ACC(SECS)	TT MSL SECS	INST
3	9	UMBERATANA	UMB	1260.7	312.2	162.60	FAIR	0.50	162.65	UA
						166.70	GOOD	0.10	166.75	
						185.60	GOOD	0.10	185.65	
						214.40	FAIR	0.10	214.45	
						230.20	FAIR	0.10	230.25	
						281.30	FAIR	0.10	281.35	
						293.00	FAIR	0.10	293.05	
3	11	ADELAIDE	ADE	975.3	289.1	134.30	POOR	0.10	134.35	UA
						149.80	POOR	0.50	149.85	
						199.40	FAIR	0.50	199.45	
						222.70	FAIR	0.10	222.75	
						262.60	FAIR	0.10	262.65	
3	15	BELLFIELD	BFD	565.9	280.7	77.00	GOOD	0.10	77.05	BMR
						79.00	FAIR	0.10	79.05	
						84.20	GOOD	0.10	84.25	
						93.20	GOOD	0.50	93.25	
						101.70	GOOD	0.10	101.75	
						111.20	GOOD	0.10	111.25	
						154.20	GOOD	0.10	154.25	
3	16	ALICE SPRINGS	ASP	2151.0	314.5	270.20	FAIR	0.50	270.25	BMR
						275.00	FAIR	0.10	275.05	
3	19	TOOLANGI	TOO	302.6	284.3	45.10	GOOD	0.10	45.15	BMR
						49.20	GOOD	0.10	49.25	
						54.20	GOOD	0.10	54.25	
						82.70	GOOD	0.10	82.75	
						89.40	GOOD	0.10	89.45	
						94.40	GOOD	0.50	94.45	
3	24	CANBERRA	CAN	330.4	3.0	49.10	GOOD	0.10	49.15	ANU
						55.20	GOOD	0.50	55.25	
						98.20	FAIR	0.50	98.25	
3	30	RIVERVIEW	RIV	538.5	28.3	88.70	POOR	0.10	88.75	CO
						92.80	FAIR	0.10	92.85	
						147.80	FAIR	0.10	147.85	
						152.20	GOOD	0.10	152.25	
						158.50	GOOD	0.10	158.55	
						165.10	FAIR	0.10	165.15	
						174.10	FAIR	0.10	174.15	
3	31	WARRAMUNGA	WRA	2466.5	321.5	296.70	GOOD	0.50	296.75	ANU
						300.70	GOOD	0.50	300.75	
3	46	HOBART	TAU	527.9	193.3	72.10	FAIR	0.10	72.15	TU
						74.50	FAIR	0.10	74.55	
						77.90	GOOD	0.10	77.95	
						143.40	FAIR	0.10	143.45	
						151.30	GOOD	0.10	151.35	
3	47	MOORLANDS	MOO	480.7	196.1	66.90	GOOD	0.10	66.95	TU
						67.20	GOOD	0.10	67.25	
						82.30	GOOD	0.50	82.35	

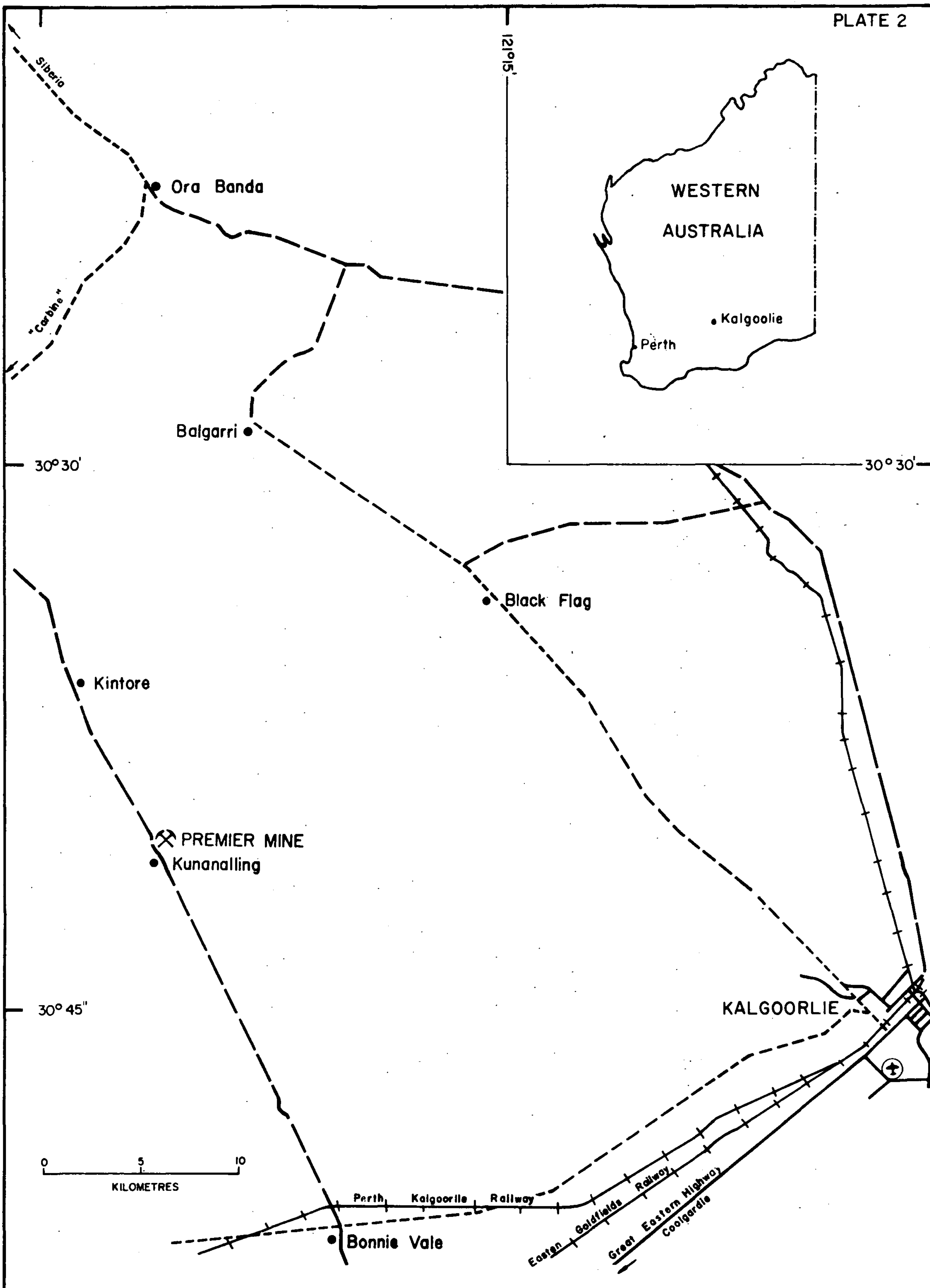
Table 3 (continued)

SHOT	RECORDER	LOCATION	ABBRV	DISTANCE (KM)	AZIMUTH DEGS	TRAVEL TIME SECS	REMARKS	ACC(SECS)	TT MSL SECS	INST
						111.20	FAIR	0.10	111.25	
						136.10	FAIR	0.10	136.15	
3	48	TARRALEAH	TRR	458.3	203.5	68.20	GOOD	0.50	68.25	TU
						75.40	FAIR	0.50	75.45	
						80.40	FAIR	0.50	80.45	
						87.60	GOOD	0.10	87.65	
						102.40	FAIR	0.10	102.45	
						139.20	FAIR	0.10	139.25	
3	49	SAVANNAH	SAV	404.9	199.5	57.10	GOOD	0.10	57.15	TU
						64.50	GOOD	0.10	64.55	
						72.40	GOOD	0.10	72.45	
						79.70	FAIR	0.50	79.75	
						125.30	FAIR	0.10	125.35	
3	50	SHEFFIELD	SFF	400.1	211.6	55.70	GOOD	0.10	55.75	TU
						62.40	GOOD	0.10	62.45	
						66.90	GOOD	0.50	66.95	
						78.40	GOOD	0.50	78.45	
3	59	SCOTTS PEAK	SPK	568.8	201.3	96.00	FAIR	0.10	96.05	TU
						124.90	FAIR	0.10	124.95	
						159.80	GOOD	0.10	159.85	
3	60	STRATH GORDON	SGN	551.7	202.7	75.40	GOOD	0.10	75.45	TU
						81.90	FAIR	0.50	81.95	
						95.80	GOOD	0.10	95.85	
						100.90	FAIR	0.10	100.95	
						123.70	GOOD	0.10	123.75	
						146.70	GOOD	0.10	146.75	



LOCATION AND ACCESS MAP
MT FITTON SHOT SITE

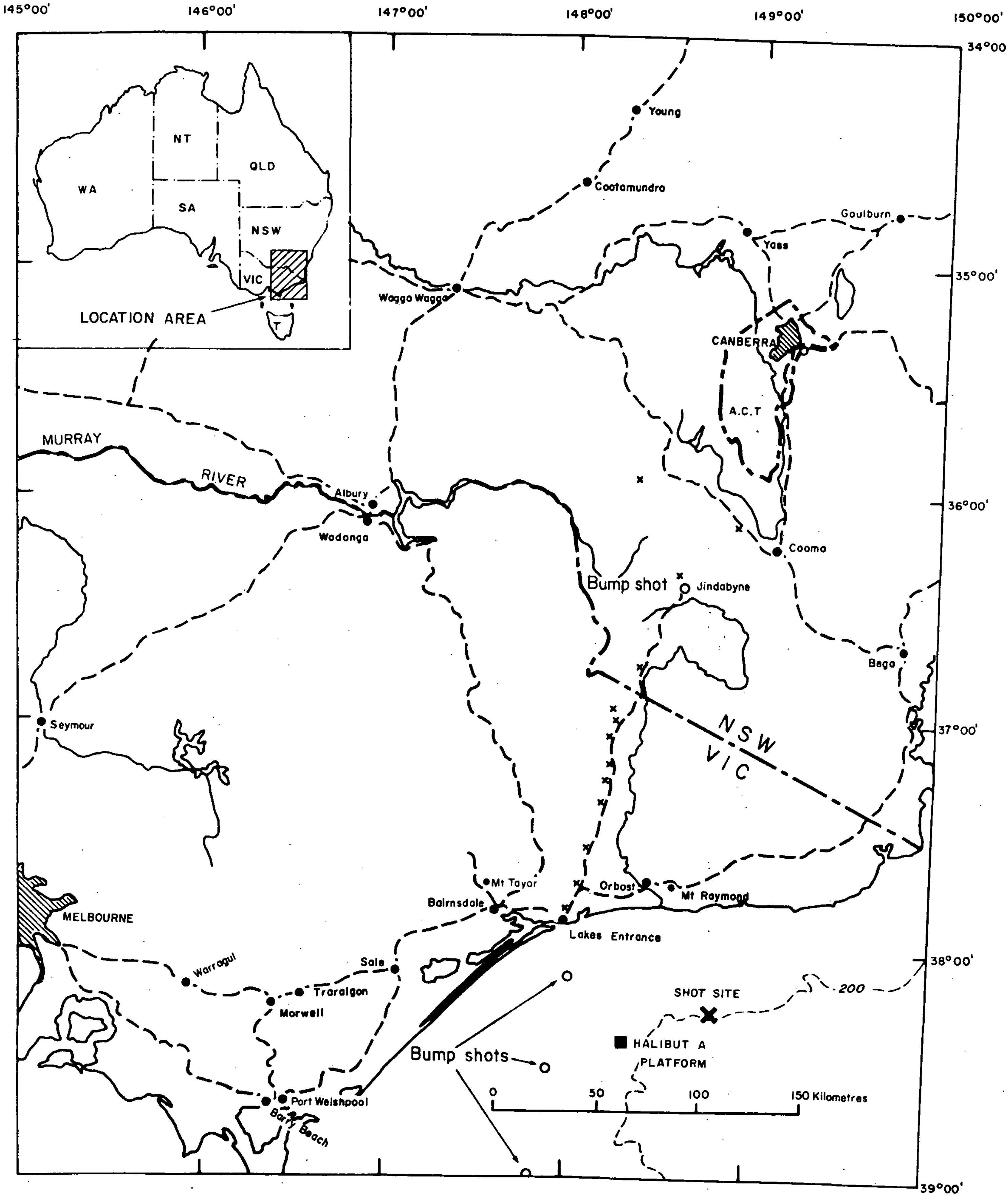
PLATE 2



LOCATION AND ACCESS MAP KUNANALLING SHOT SITE

Record No. 1974/83

H51/B10-2A

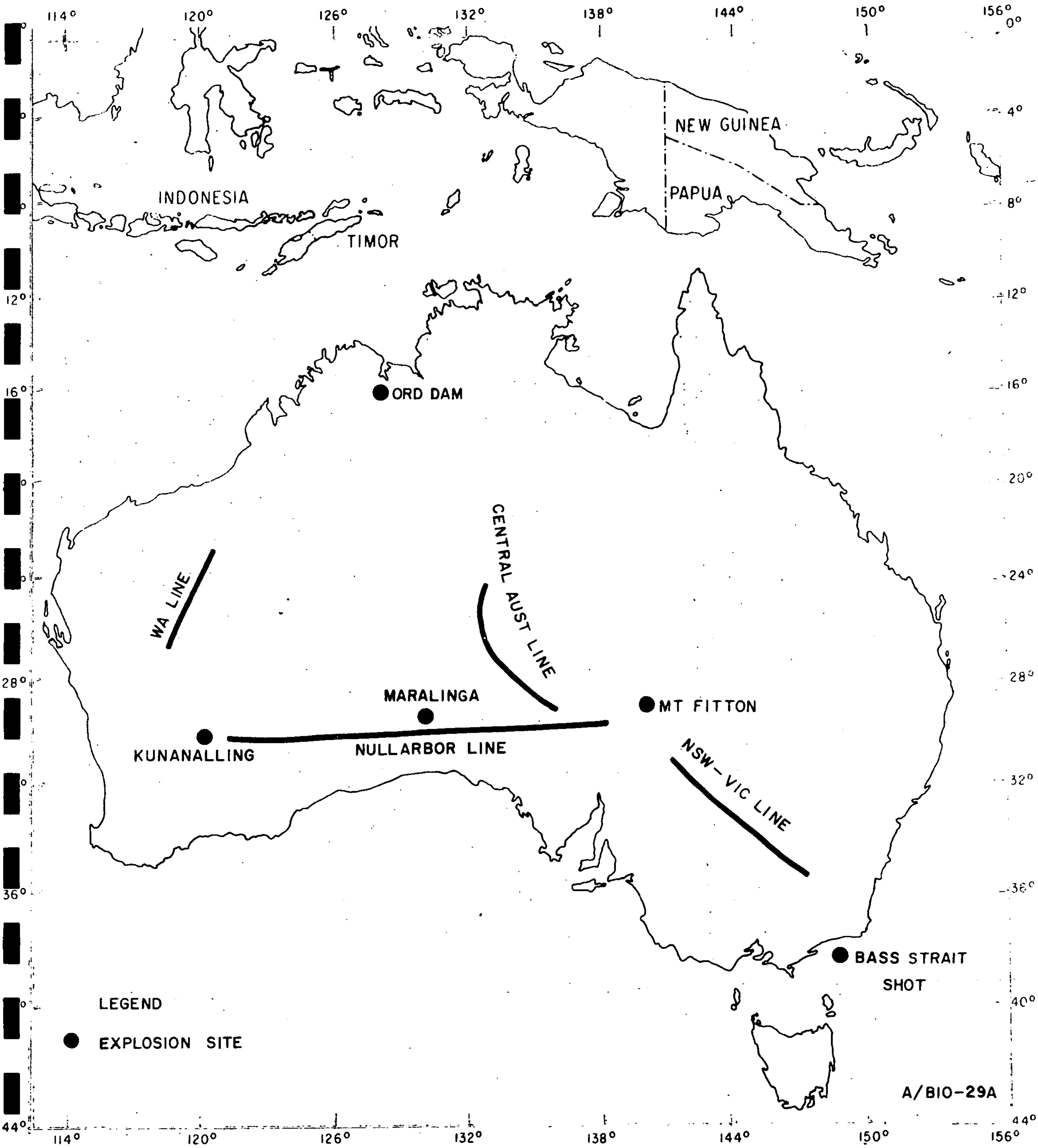


LOCATION MAP BASS STRAIT SHOT SITE

Record No. 1974/83

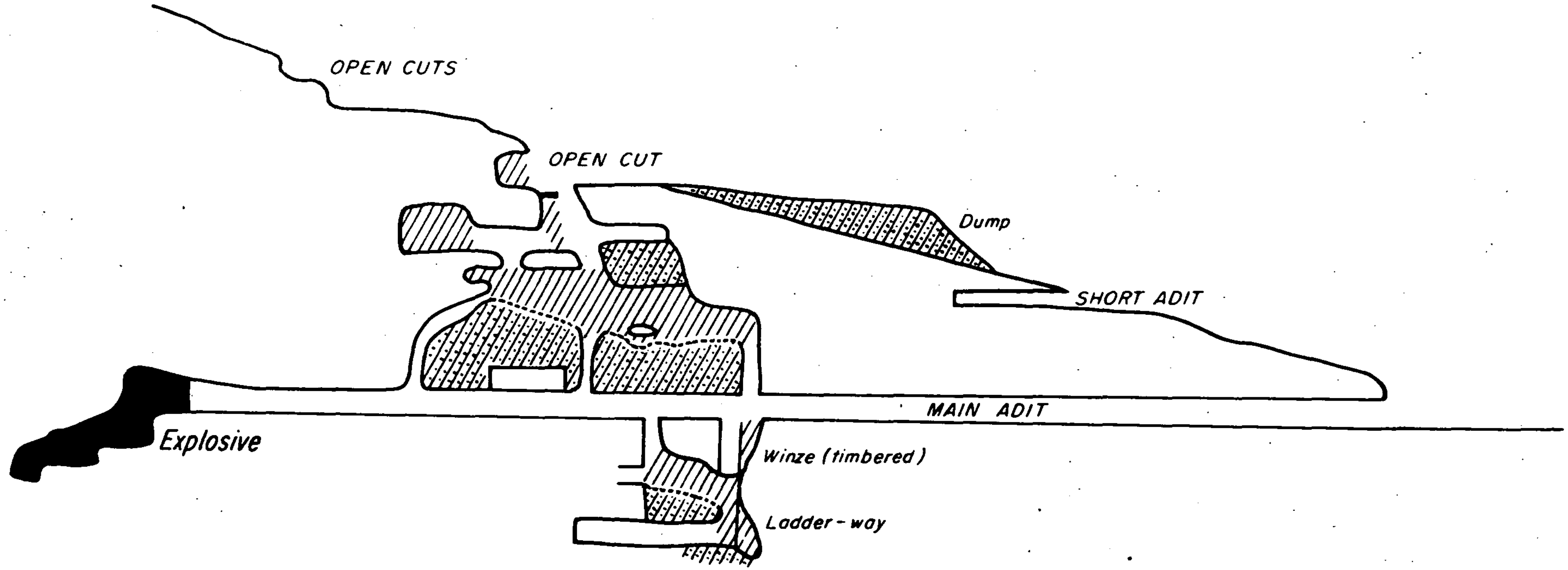
V/B10-1A

PLATE 4

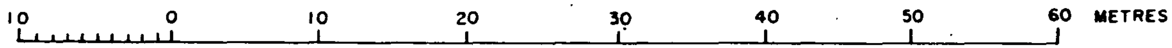


BASED ON A/BO-15

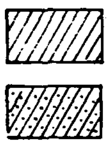
TRANS-AUSTRALIA SEISMIC SURVEY (TASS) TEMPORARY RECORDING LINES



HORIZONTAL AND VERTICAL SCALE



LEGEND



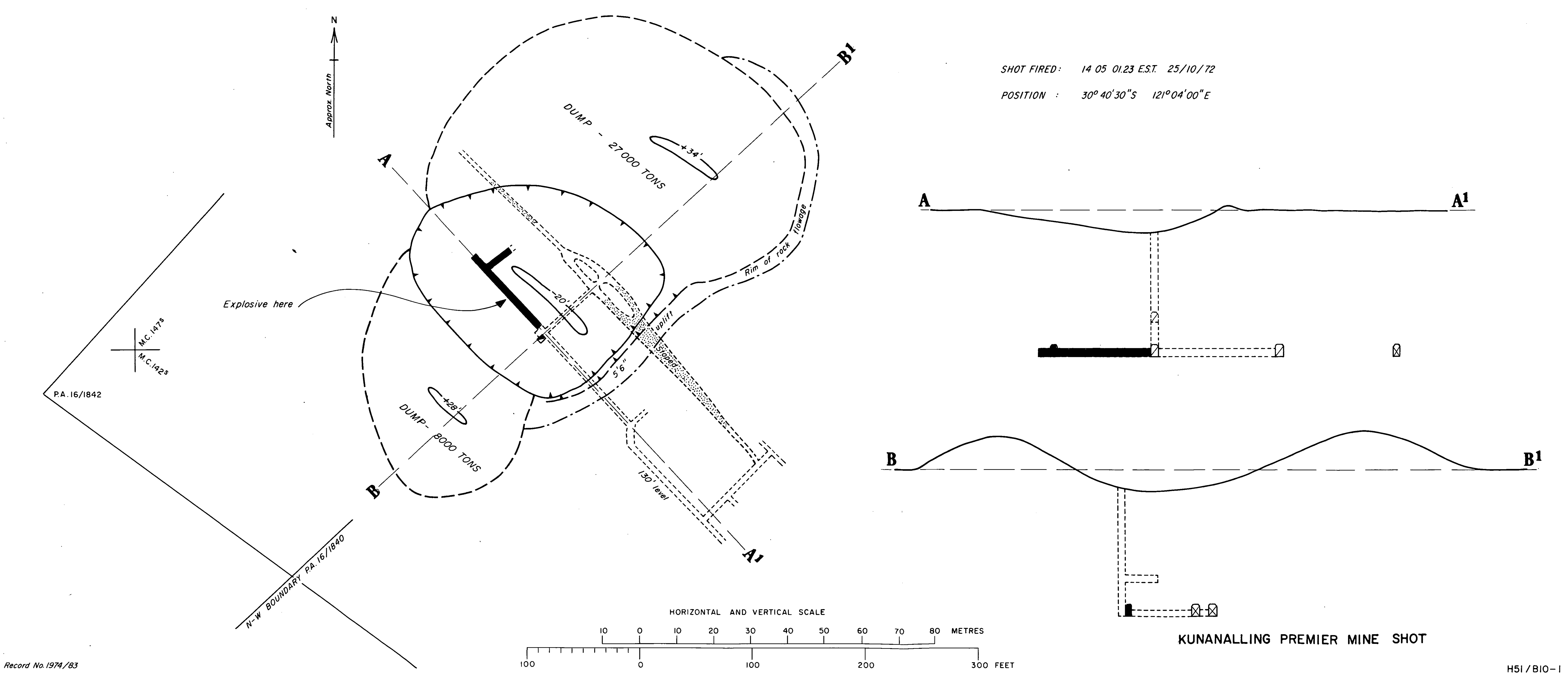
Open stope

Filled stope and dump

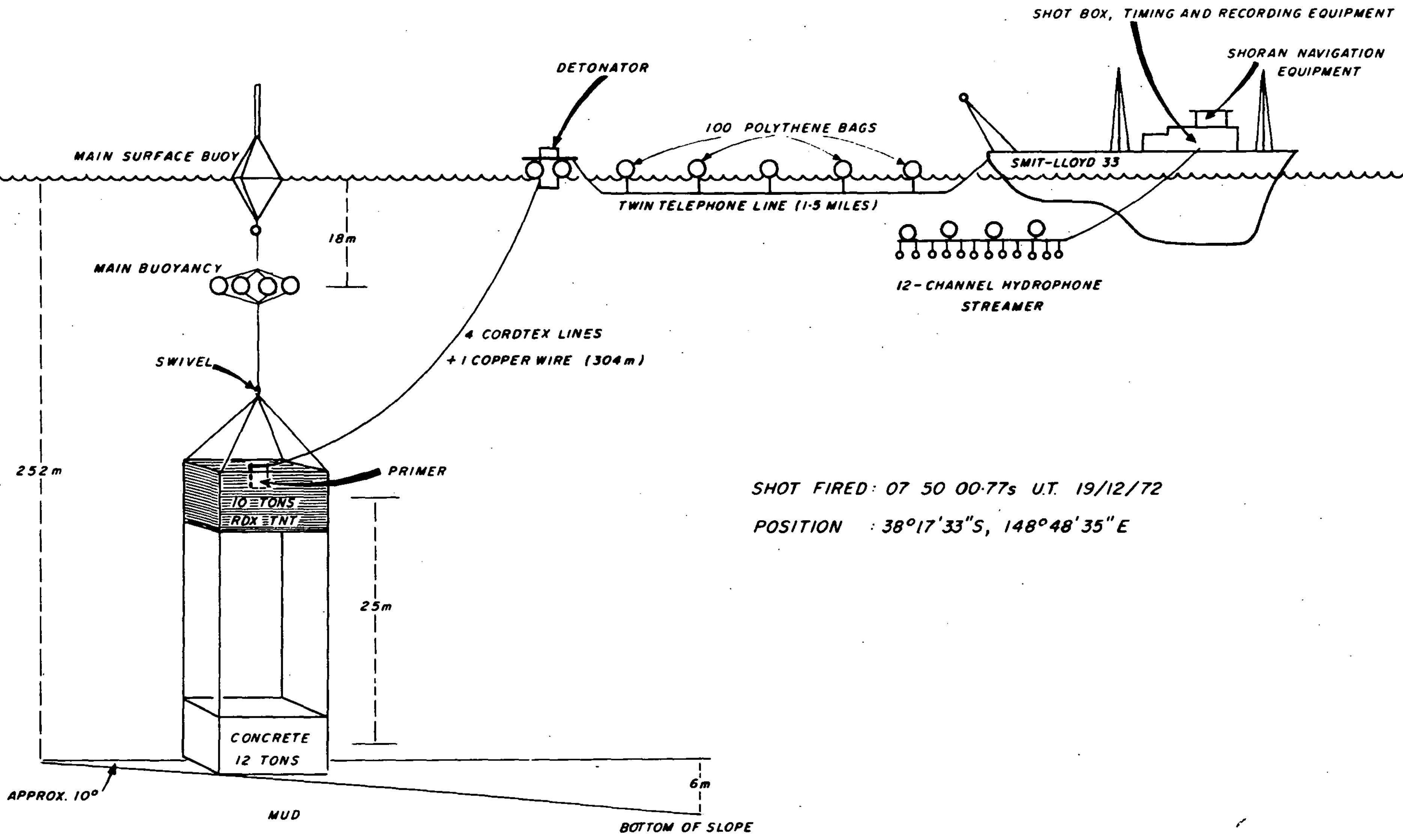
MT FITTON SOUTH SHOT

SHOT FIRED 11 05 00.04 E.S.T. 25/10/72

POSITION 30° 00' 24" S 139° 33' 48" E



KUNANALLING PREMIER MINE SHOT

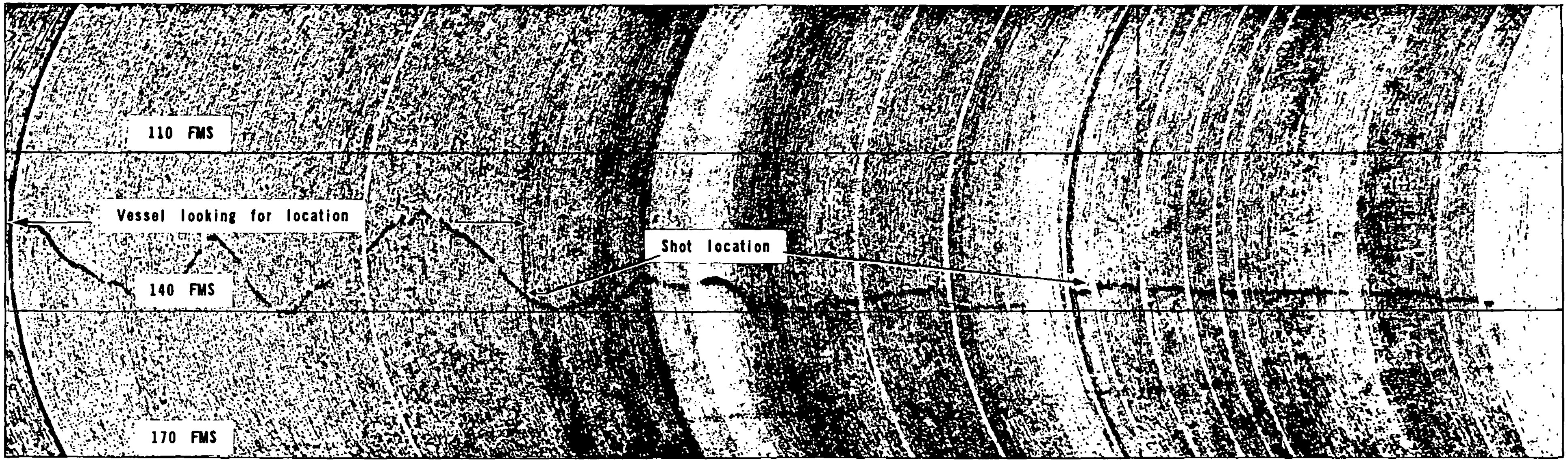


SHOT FIRED : 07 50 00·77s U.T. 19/12/72

POSITION : 38°17'33"S, 148°48'35"E

BASS STRAIGHT SHOT DEPLOYMENT

Record No. 1974/83

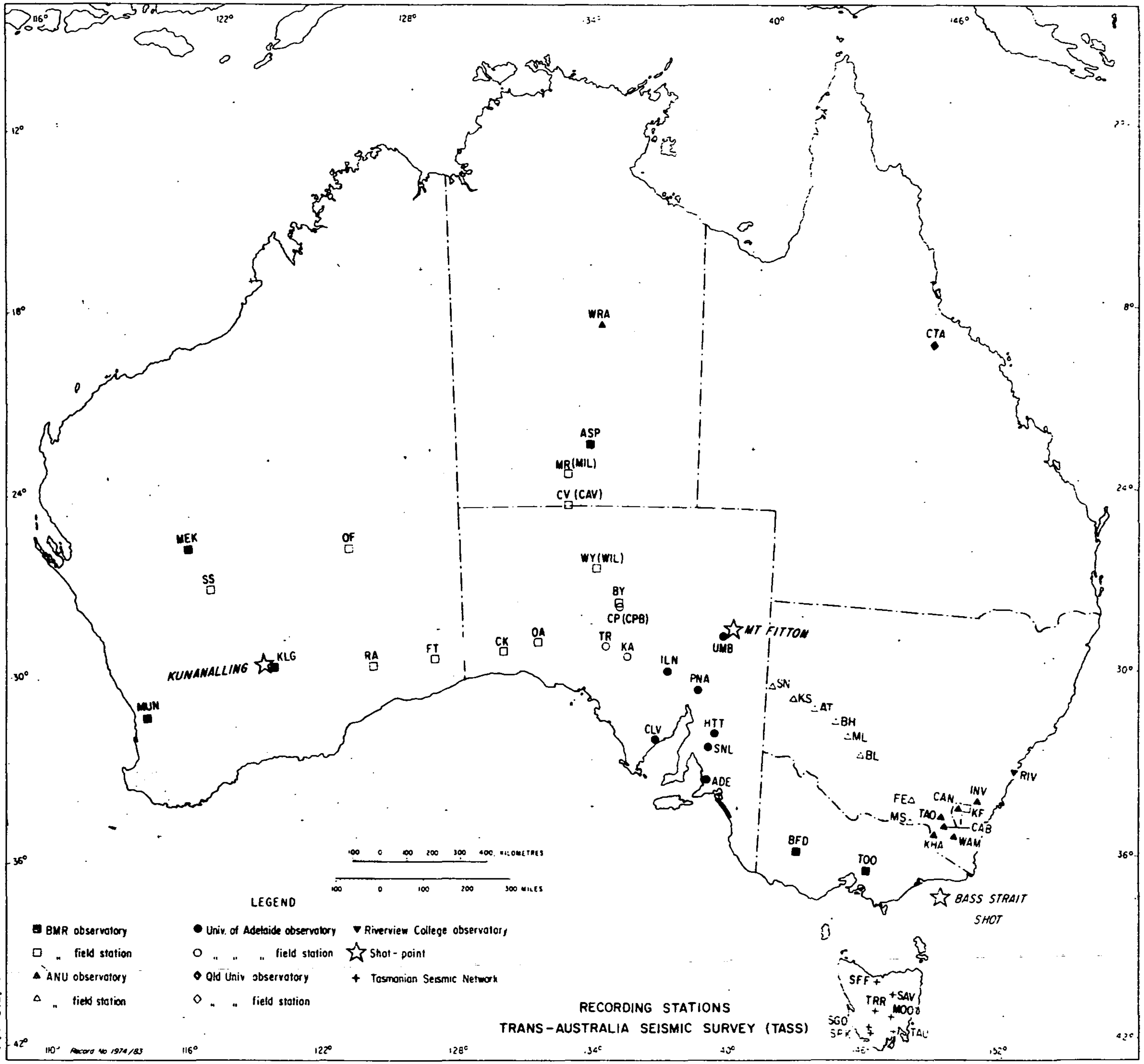


SMIT LLOYD 33 DECEMBER 1972 SHOT LOCATION 38°17'33"S 148°48'35"E

BATHYMETRY AT SHOT-SITE, BASS STRAIT

J55/B10-1A

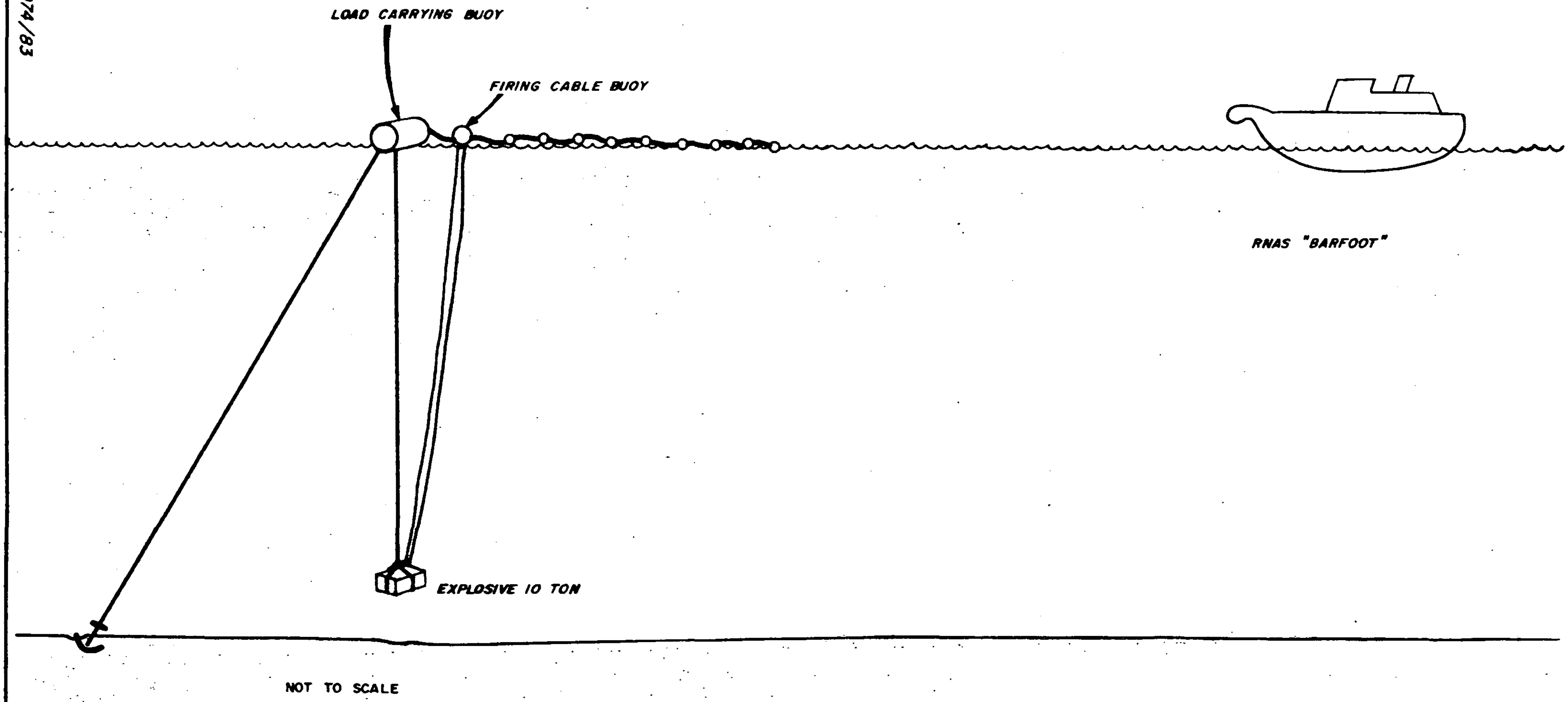
PLATE 8



A/BIO-14A

PLATE 9

(From NMF... 283) (BASED ON A/BO-58)



Record No. 1974/83

TEN TON EXPLOSION NORTH SEA

PLATE 10

A/B10-30A