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COCKROACH WATERHOLE AREA EXPERIMENTAL SEISMIC SURVEY,

NORTHERN TERRITORY 1964

by

C. CHENON

(Geophysicist, Institut Francais du Petrole,
Bureau des Etudes Geologiques, Paris)

The opinions and views expressed in this Record are those of the author and are not necessarily those of the Bureau of Mineral Resources.

The information contained in this report has been obtained by the Department of National Development as part of the policy of the Commonwealth Government to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus or statement without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

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SUMMARY

In November 1964, the Bureau of Mineral Resources made a brief experimental seismic survey near Cockroach Waterhole in the centre of the Tobermory 1:250,000 map area, Northern Territory. This survey was designed as part of a more extensive reconnaissance seismic survey to be made in 1964 and 1965 on areas of outcropping Lower Palaeozoic rocks in the southern part of the Georgina Basin. In this initial part of the survey a short trial profile was shot using a simple recording technique and noise tests and tests of various shot and geophone arrangements were carried out. It was established that, despite difficult drilling conditions and the prevalence of random, high frequency noise, a suitable seismic technique for reconnaissance in this area, which it was hoped was representative of a very extensive region, could be developed.

1. INTRODUCTION

Since 1956 the Bureau of Mineral Resources (BMR) has been making reconnaissance geological and geophysical investigations of the Georgina Basin in Queensland and the Northern Territory. As part of this programme, the BMR Seismic Party No. 1 carried out seismic surveys in the south-eastern part of the basin between the Toko Syncline and Canary in 1963 (Robertson, 1965) and 1964 (Jones, 1965). Prior to completion of the latter survey it was decided to follow it with a seismic reconnaissance survey to investigate the general configuration of the basin over the large area of outcropping Lower Palaeozoic sediments that occur in the southern part of the Georgina Basin in the region of the Northern Territory - Queensland border. This survey was originally scheduled to commence in September 1964 and to continue throughout 1965 with a break in the field season during the summer months from December to March. It was planned to commence the survey with a programme of experimental work designed to develop a suitable technique for reconnaissance seismic work on the Lower Palaeozoic formations, which cover a very extensive area.

Completion of the survey in the south-eastern Georgina Basin in 1964 was delayed until late in October, with the result that only about four weeks remained in the 1964 field season for work on the Lower Palaeozoic areas. This time was devoted to experimental work to develop a suitable shooting technique, on the understanding that the testing programme would, if necessary, be continued at the beginning of the 1965 field season. At the request of the BMR, the author, geophysicist from the Institut Francais du Petrole spent two weeks with the party in November to advise on the conduct of the experimental programme.

2. OBJECTIVES AND PROGRAMME

The survey had two main objectives -

1. To carry out experimental shooting on the Lower Palaeozoic carbonate rocks of the Georgina Basin to develop a useful technique for reconnaissance traversing in the basin.

   A large part of the Georgina Basin is overlain by limestones and dolomites of the Undilla and Ninmaroo groups (Mulder, 1961), which range in age from Middle Cambrian to Ordovician. These rocks cover many tens of thousands of square miles, including the greater part of the Tobermory, Glenormiston, Sandover River, and Urandangi 1:250,000 map areas. Moreover, it was known from a limited amount of previous seismic work on these formations that they present considerable difficulties in obtaining useful seismic results (Robertson, 1963 and Jones, 1965). Suitable shooting techniques, once determined, would therefore have widespread application.

   The location selected for the experimental work was near the stratigraphic test well BMR 12 (Cockroach) drilled by the BMR in 1964 near Cockroach Waterhole in the centre of the Tobermory 1:250,000 map area. This well (Nichols & Bell, 1965) first penetrated 460 feet of Upper Cambrian - Lower Ordovician Ninmaroo Formation, then passed into the Upper Cambrian Arrinthrunga Formation consisting largely of limestones and dolomites, and finally into Middle Cambrian Marqua Beds at 2721 feet. The well bottomed in Marqua Beds at 4000 feet.

An outline of the experimental programme drawn up before commencement of the survey, and intended as a flexible guide for the party leader, is presented in Appendix C.

2. To carry out reconnaissance reflection and refraction traversing in the vicinity of Cockroach Waterhole, the structures near Marqua, the north-west Toko Syncline, and possibly the Tarlton Range.

This programme of reconnaissance work was regarded as tentative, pending completion of the BMR aeromagnetic and stratigraphic drilling programmes being carried out in the Georgina Basin. Owing to the late commencement of the seismic survey described in this record, it was not possible to pursue this objective in 1964.

Appendix A provides information on the staff and equipment employed in the survey. Appendix B provides operational data on timetable, surveying, drilling, recording, etc.

3. DRILLING OPERATIONS

Drilling difficulties

In the area where the tests were made, a very hard formation appeared very close to the surface. Drilling of this formation was difficult and consequently slow. The 'jack hammer' method was tried to decrease the drilling time. The results were not conclusive. Because of variations in the hardness of this layer, rotary drilling with air remained the most rapid and economical method.

The depth at which this first hard layer is reached varies. In certain places it crops out and in others it is reached after 30 or 40 feet of very soft ground, generally sand. It is also cavernous. Up until now the cavities encountered have not troubled the drilling particularly. However, it would seem necessary to mention it in case larger cavities exist in places.

Results attained and possibilities

After almost four weeks of drilling in this area, a certain number of results permit judgement of the drilling rates that it can be hoped to obtain. A day by day progress chart is included for each of the two Mayhew rigs working for the party (see Plate 2). The irregularities in output will be observed, varying between two extreme limits for a deep hole: one 105-ft hole per day per rig is the minimum, three 105-ft holes is the maximum. Without doubt this variation does not arise solely from the difference in the hardness at the spot to be drilled, but also from the depth at which this hard bed is reached.

Drilling of the hard layer is too much to hope for in the case of the Carey rig. This could not be used unless the arrangement chosen included holes extending not more than one or two feet into the hard bed. In this case, drilling times would remain within reasonable limits.

Economics

A priori, it appears undesirable to launch a survey of several months duration for reconnaissance of the basin with a shot-point arrangement using several deep holes (of the order of 100 feet) per shot-point. In fact, under the present conditions, an average output with two drills of more than one shot-point every two days could not be expected, for example, with 10 deep holes. Such really poor production could not be contemplated.

On the other hand, drilling of 20 holes to a depth of about 30 feet appears to require about four hours per drill. In these conditions, the output obtained, if such an arrangement were adopted, would be about four shot-points per day. Moreover, with such an arrangement it is possible to make use of the Carey rig. Additional production, although small, could doubtless reach three to five shot-points per week.

From the purely economic point of view, this output of about 20 to 25 shot-points, or 7 to 8 miles of traverse per week, while not good, would be acceptable.

4. RESULTS OF TESTS

Measurements of surface parameters

The first week's work was devoted to the study of surface parameters in the area where the tests were to be made. Two types of measurements were made:

(a) Uphole shots, with a maximum depth of 180 feet.
(b) Weathering shots, with shots very close to the surface.

These measurements at shot-points 250,255, and 260, at the extremities and in the centre of the experimental traverse, provided an initial indication of the different weathering layers and the velocity of the sub-weathering layer.

The values obtained showed that the thickness of the weathered layer varies from one place to another in non-negligible proportions and consequently only very general results can be stated.

The horizontal velocity in the first hard layer ranged from 15,000 ft/s to 17,000 ft/s. The vertical velocity in the first hard layer varied from about 11,000 ft/s to 12,000 ft/s. The vertical velocity in the weathered zone was 2000 to 3000 ft/s.

Trial profile

The programme (Appendix C) envisaged the carrying out at the beginning of the survey of a profile of about ten shot-points. The characteristics of this profile and the aim pursued are summaried below -

(1) Single hole, with depth and charge defined by the preceding tests. Depth 105 feet, charge 60 lbs, top of the charge at 90 feet.

(2) 16 geophones per trace in line along the traverse, spacing between geophones 10 feet.

(3) 12 traces on either side of the shot-point, distance between traces 150 feet. It will be observed that the distance between traces corresponds to the length of a trace. There is thus no overlapping.

(4) Very wide filter on the monitor : K18 - K160.

(5) Filter chosen for playback after tests : K30 - K92

The aim pursued is to give an idea of the quality of the results, using a simple technique, and the variation inquality from shot-point to shot-point.

The results obtained can be listed as follows -

(a) The first observation is the importance of the high frequencies that are seen all along the records and on almost all of the records. The periods observed may reach 4 milliseconds. The few low freqüencies that appear are modulated by the high frequency.

(b) The playbacks with narrower pass-bands only effect an improvement with high frequency filters. The playbacks with low frequency filters have practically no energy remaining. It is therefore established that the spectrum of the records obtained is very high frequency.

(c) The optimum playback filtering seems to be of the order of K36 - K92.

(d) The reflected signals that can be distinguished are weak and not very continuous. They comprise : a reflection at 0.35 second, the best distinguishable on three or four records, with frequency of about 80 to 100 c/s. Another phase alignment at about 0.5 second seems to exist on one of the records. Finally, a third energy arrival appears at about 1.3 seconds with very strong filtering on playback (MM36 - MM66 - with very steep slope).

(e) The surface velocities calculated from the first-break plots are high and variable fromshot-point to shot-point. The mean velocity of the first high velocity layer is about 16,000 ft/s.

(f) The thickness of the weathering appears very variable and limits the accuracy expected for the velocities of the first high velocity layer.

(g) A poorly defined discontinuity exists between shot-points 258 and 259. It produces a pronounced misalignment on the first breaks of the two records. The record from shot-point 259 has a very different make-up from the others. Perhaps a fault is involved.

(h) Uphole values are variable, from 15 to 30 milliseconds, a fact that supports the idea of important variation in the thickness of the weathering. However, the surface is smooth and the elevation variations small.

The conclusions that can be reached after the completion of this traverse are important : reflections exist in the area and can be followed; the detailed layout which it will be necessary to use will be appreciably heavier than that in the trial profile.

Noise tests

Choice of location. In theory, the programme envisaged that the location of the noise test would be chosen after careful consideration. The traverse from shot-point 250 to shot-point 260 was to provide all the

the necessary indications on the weathered zone, surface velocity, possibility of faulting, etc. This supposed that there would be time for deliberation between the end of the traverse and the beginning of the noise shot. Unfortunately the crew was a long way behind schedule (see Appendix D). Thus it was necessary to choose the location of the shot-point for the noise test even before the traverse was completed.

In fact, drilling was slow. In order to have one or two holes available to start the noise shot, the drilling had to be decided at least a day in advance. Drilling for the noise shots commenced on Monday 9th at shot-point 256 the same day that the traverse was shot from shot-point 251 to 254 and from shot-point 256 to 258. The noise shots were commenced on Tuesday 10th before the traverse was finished (shot-point 259). The position was thus chosen arbitrarily on the profile.

Drilling posed a thorny problem. The party leader had envisaged 10 holes to 105 feet for the noise shots. Such a programme seemed clearly prohibitive, given the slow drilling progress. It was decided to use two new holes - one hole to 105 feet and one to 30 feet. The hole used for the traverse would be recovered by redrilling to 105 feet. To avoid any waiting by the recorder truck, a drill remained at the shot-point to redrill the same holes rapidly in case they become blocked.

The solution employed was not ideal. The same hole deteriorates in proportion to the number of times it is re-used, but there was no other choice short of accepting three to four days of drilling with the two rigs for the noise shots. In the end, each deep hole was shot more than twelve times.

Shooting of noise shots. The trial profile surveyed revealed strong high frequencies on the records obtained. High frequencies had therefore to be expected also on the noise tests recorded without filtering, etc. High frequencies are generally random. Therefore, the interval between traces had to be small. It was chosen as 20 feet.

By mistake, one geophone per trace was used at the beginning of the noise tests although the programme envisaged groups of eight bunched closely together. Subsequently eight were used. It was therefore possible to have an interesting comparison between the results of eight geophones and one geophone per trace. It was found that there was no noticeable difference.

A diagram showing the layout of the spreads is shown in Plate 4. This includes the position of the transverse spreads.

The noise test was recorded in the classical manner : it was shot in a single hole with constant charge (10 lbs), gain constant with time, gain chosen as a function of distance, no filtering, and no AGC.

The noise test was shot at two different depths, 105 feet and 60 feet, to determine whether the depth is important for the organised noise. One shot (Spread 4) was fired at 30 feet, a little below the beginning of the first hard layer encountered by the drill, to prove that the high frequencies really do originate from the hard formation and are not related to the depth of shot.

The gain adopted for the monitor record was carefully chosen and required several tests on different spreads.

The time required to carry out the noise test was three days, which, considering the number of shots (about 30), can be considered satisfactory.

Analysis and results. The noise test records obtained are unusual and very different from what is generally encountered (Plate 3). They begin in time along the record with very high frequency, then rapidly lose their energy (0.5 second). A few organised low frequencies appear on the spreads most distant from the shot-point. These are modulated by the high frequencies, which make the picking very difficult and not very reliable. Under these conditions, the rational, classical type of analysis of this noise test was impossible and was not therefore attempted.

Nevertheless, a certain number of facts emerge from a careful study of the records. They will now be reviewed.

We have seen that the organised noise is not pickable. In order to attempt to gain an idea of the velocities and periods of this organised noise, while not trying to calculate its energy, the complete noise test was replayed with AGC, starting with the original tapes with constant gain. It was thought that this would bring out the pickable low frequency alignments. Even in this way no significant alignment emerged. Some do exist but at a very low energy level. The order of magnitude of this energy level can be estimated. In fact, when the energy level is considerable in the first 100 or 200 milliseconds of the record, some organised noise can be seen at about one second. On the same record, for the traces furthest from the shot-point, the energy level (with constant gain) of the first arrivals is weaker and at about 1 second, low frequency alignments can no longer be picked, and only equipment noise is present. It is concluded from this that the limit of the dynamic range of the equipment is reached. Consequently the energy of the organised low frequencies is about at least 25 dB below the energy of the high frequencies at the beginning of the film.

Organised transverse noise does not exist either - or at least is not visible.

No reflection signal appears, even on the records replayed with AGC.

The first-breaks were picked in detail. From them, the velocity of the first arrival emerges as : V_1 = 17,000 ft/s and V_2 = 18,400 ft/s.

A large irregularity is evident on the first-breaks for shot-points 258 and 259. Other irregularities make it possible to state that the thickness of the weathering is very variable.

The high frequencies appearing near the beginning of the records were studied carefully. The following facts emerged :

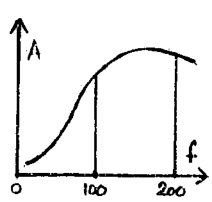
(a) The attenuation with distance from the shot-point is marked. It is of the order of 40 dB between the nearest recording points (100 feet) and the most distant (more than 4000 feet). For the same apparent level of energy on the records, the gains varied from position 3 to position 7 with a step of 10 dB for each position.

(b) The high frequencies seem incoherent for the distance between traces used (20 feet). In fact, it is difficult to be able to 'pick' continuous alignments except at the first-break level. A single alignment appears and its velocity is about 8000 ft/s.

(c) The correlation between similar traces recorded from different shots appears weak in the zone of high frequencies. No direct tests were done, but comparison is possible between two traces shot in the same conditions with different gains.

The results (b) and (c) lead to a consideration of the high frequency noise as random for the distance between traces chosen.

(d) The high frequencies are clearly related to the hard layer encountered near the surface. The comparison shots at different depths for the noise test, and particularly on geophone spread No. 4, with shots at 105 feet, 60 feet, and 30 feet - all shot with the charge located in the hard layer - generate high frequencies. However, it seems that the high frequencies increase in importance with depth. It was considered impossible for the high frequencies to be generated in the soft, sandy layer above the first high velocity layer and this was later confirmed when shooting at a depth of 8 feet.



(e) It seems that the spectrum of the waves emitted by the explosion in the hard layer could be represented by the curve opposite. Spectral analysis of the noise test traces would be necessary if it was required to obtain more information on the spectrum. In actual fact, only a very vague idea can be obtained by statistical study of the order of magnitude of the periods: these vary from 4 to 10 milliseconds.

Conclusions. There seem to be thus two methods for resolving the problem of the shot-point pattern :

(a) To shoot in the hard layer providing the high frequencies and lay out enough geophones and holes, spread out over a large surface, to cancel this random high frequency.

(b) To shoot above the high frequency layer and organise the geophones and holes in a conventional manner to decrease the importance of the organised noise, which in this case would doubtless be considerable.

The first solution seems to be the best since the effect of shooting above the hard layer is to introduce a high-cut filter that would seriously attenuate the already weak reflection signals of high frequency. The degree of improvement required to obtain a satisfactory record would then be impossible to achieve with any practical combination of holes and geophones.

Tests of shot and geophone arrangements

The times devoted to these tests and their respective dates will be found in Appendix D. In Appendix E, information will be found defining the arrangements used and the conclusions that can be drawn from the direct comparisons of the monitor records and playbacks. Here, only the most general results and the considerations that justify them will be discussed.

Conduct of the tests. The time available for tests of shot and geophone arrangement was about two weeks, or a maximum of ten days field work. The logical order that would have been possible to follow was found to be fettered with two major problems :

(a) Drilling. It has been seen that the drilling was difficult. It was the end of the field season, with equipment and personnel that had just spent 9 months in the field, and it was humanly impossible to ask the optimum production from them. It was also the beginning of the hot season and work in these conditions was far from easy.

(b) Seismic well logging. The party was working near the BMR 12 (Cockroach) drill site and had to remain ready to carry out seismic logging the day required by the operator. It happened that the latter had numerous technical troubles and that the date of the logging was changed several times.

The planned programme therefore had to be modified quickly in order not to lose a day's field work for the recording truck, while at the same time making the most of the incomplete progress of the drilling. These facts taken together may make the order of the tests appear rather illogical.

The whole of the tests of shot and geophone arrangements can be divided into two principal groups :

(1) Tests of multiplication, where the goal is simply to attempt to decrease the high frequencies, which seem to be random, by a large multiplication of holes and geophones distributed over a large surface,

(2) Classical tests (provided for in the programme), where holes and geophones are in line. The goal here is to determine the improvement as a function of the evolution of the spacial filter. A few complementary remarks on the choice of the parameters of distances between units seem useful and interesting.

Tests of multiplication. As the high frequency noise recorded on the noise test seems incoherent for the spacing between traces chosen, i.e. 20 feet, an arrangement of numerous geophones and numerous holes with a minimum spacing between units of 20 feet is going to 'see' this noise as effectively random. The value of theoretical improvement in the signal-to-noise ratio that could be expected could be calculated from the formula

$$\text{Improvement} = \sqrt{nm} ,$$

where n is the number of geophones and m the number of holes.

For example, if it is required to compare a single hole and 16 geophones (although the spacing between geophones would be about 10 feet) with 20 holes and 32 geophones, there would be an improvement for the random noise of about :

$$\sqrt{m.n/16} = \sqrt{20 \times 2} = \sqrt{40} = 6.3,$$

or about 16 dB. It must therefore be expected that the arrangement (see test sheet 1, Appendix E) used would give significant results in improvement. It might not be sufficient, but the appearance of the record would make the improvement stand out.

However, in the organisation of the shot-points, no particular reasoning should be sought for the distribution of the four lines of holes. A place was kept free in the centre, without holes, only for reasons of convenience. In fact, the pattern was drilled by a rig on 'stand-by' during the shooting of the noise test. It was necessary to keep sufficient space in the centre to allow the shooter free movement. The interest resides in the shape of the shot pattern. A square pattern was used (160 feet x 160 feet) covering a large surface, yet whose dimensions remained of the order of the distance between traces. However, it would be more logical in new tests to use 25 holes, with an extra line of 5 holes along the traverse.

Classical tests (planned in the programme). Here, two parameters varied - on one hand the value of the cut-off wave number Kc, i.e. the length of the geophone group, and on the other hand the number of units (geophones or holes) - in such a way as to improve the spatial filter.

Two values of Kc were used, one corresponding to the distance between traces so that it was easy to calculate the spatial filtering corresponding to simple mixing of 2:1 or 3:1, and the other with a value of Kc halved, or an arrangement with the length of geophone group equal to twice the distance between traces and an overlapping of 50%.

The distance between units was fixed by the number of units chosen :

$$Kc = 1/2ne,$$

where n is the number of units and e the distance between units.

Spatial filtering was used in the same way for the holes as for the geophones, with a very similar Kc.

Results

The results can be very simply summarised:

(1) The experiments in multiplication gave the expected results. The high frequencies were cancelled or at least strongly diminished and the reflections appeared. However, the records were still not very good and could doubtless still be improved.

(2) The experiments in varying the characteristics of the spatial filter did not result in any important improvement but considerably increased the task of drilling to the point of making it prohibitive. It is thus confirmed that the organised noise is of little importance.

(3) High frequency filters must be used both on the monitor record and on playback, the optimum values appearing to be 20 or 24 to 120c/s for the monitor and 36 to 92c/s for the playback.

Thus the frequency band recorded on the monitor record is quite important.

(4) Increasing depth of drilling does not produce much improvement. It is therefore not necessary to shoot deeply (105 feet). On the other hand a too shallow depth should not be chosen (see test sheet 2, Appendix E). The optimum depth thus seems to be of the order of 30 feet. In any case it is necessary to put the charge in the hard layer at a depth sufficient to ensure that it is in solid, unweathered, high velocity material.

Comparison of field record and coefficient of reflection

The coefficient of reflection was calculated from the sonic log of BMR 12 (Cockroach) well located several miles from the experimental traverse. A description of the curves obtained is given by Chenon (in prep.) Here the record obtained in the field after the tests is compared with the coefficient of reflection constructed with a sampling interval of 5 milliseconds one-way time, corresponding to a low-pass filter of 100c/s (see Plate 5).

The agreement of the two curves, coefficient of reflection and seismic trace, is satisfactory. Individual events may be compared as follows.

The reflection at 0.35 second stands out well on the field record and appears as the best reflection obtained. Its frequency is about 80 to 100 c/s and its amplitude is diminished considerably with a low-pass filtering of less than 90 c/s. It is thus strongly confirmed that the high frequencies recorded on the test records correspond to the form of the spectrum emitted by the shot and not to the frequency related to the coefficient of reflection. In fact, this reflection is still quite marked on the coefficient of reflection calculated with the sampling interval of 10 milliseconds one-way time (low-pass filter 50 c/s). This reflection corresponds, according to the geological information available, to the top of the Marqua Beds. The traverse shot at the beginning of the tests shows that this reflecting horizon is continuous and it must be hoped that it can be followed over a long distance.

Oscillations between 0.20 and 0.27 second appear on the field record in the form of two separate reflections. They are not very good, but are pickable as poor events.

On the field record, a good reflection at about 0.5 second appears, which begins just at the end of the coefficient of reflection calculated. It does not seem from the coefficient of reflection that there could be a multiple of this importance. This reflection would therefore be real. If it is so, a strong discontinuity in velocity must appear just below the bottom of well BMR 12 (Cockroach) in the following 200 or 300 feet. It must therefore be regretted that the drill was stopped at 4000 feet and that it was not able to continue the few extra feet necessary for this control.

This premature stopping is all the more regrettable since the field geologist expected basement before 4000 feet and it was quite possible that the basement was several hundreds of feet below the bottom of the well. Knowledge of the position of the basement would be very important for the remainder of the survey to be carried out in 1965. In fact, if the basement corresponds to the reflection at 0.5 second, the quality of the records obtained at the end of the experiments is established as very satisfactory and very few tests will still need to be done before embarking on production work. On the other hand, if the basement is appreciably deeper, it will still be necessary to improve the records obtained - hence perhaps two weeks of additional tests.

5. CONCLUSIONS

Tests in the area of Cockroabh Waterhole lasted four weeks. They allowed the unusual character of the region to be defined, i.e., little organised noise of low frequency and much incoherent, high frequency noise. They emphasised the problems of shothole drilling.

Drilling was very slow once the first thick layer of high velocity material was reached. Single holes of about 105 feet deep gave inadequate results, whereas the drilling of patterns of say 10 holes to this depth would be prohibitively slow. On the other hand, shot patterns of 20 holes to a depth of about 30 feet gave satisfactory results and a weekly production of about 20 to 25 shot-points could be achieved in this manner. If such a production is not considered adequate, the drilling output of the party could be increased either by increasing the party's drilling personnel and working one of the Mayhew rigs for three shifts of eight hours per day or by hiring an additional rig and crew. The first solution would be the most economical.

Measurement of surface parameters at several locations indicated that the thickness of the weathered layer varies considerably over intervals of about a mile, despite small elevation changes. A trial profile about three miles in length using a simple technique indicated that weak reflections are obtainable. The spectrum of the records is one of high frequency, including the reflected signals, so that high-pass filter bands are necessary both in recording and playback. A series of noise tests indicated that the predominant noise when shooting in the first high velocity layer was of high frequency and that it appeared random for geophone spacings of about 20 feet. Coherent noise of low frequency was of relatively very low amplitude except when shooting with the charge above the high velocity layer. Noise tests and tests of various shot and geophone arrangements indicated that the best solution for improving reflection quality was to use large areal patterns of holes and geophones (e.g. 25 holes and 32 geophones) designed to reduce random noise. The optimum shooting depth seems to be about 30 feet or a few feet below the top of the first high velocity layer.

Comparison of the better field records with the coefficient of reflection derived from the sonic log of BMR 12 (Cockroach) well showed that the best reflection recorded, at a time of about 0.35 second, corresponded to a pronounced velocity change near the boundary at 2721 feet between the Arrinthrunga Formation and the Marqua Beds below.

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APPENDIX A

Staff and equipment

Staff

Party Leader	J.S. Davies
Geophysicist	P. Montecchi
Observer	G.S. Jennings
Clerk	R.J. Cherry
Shooter	R.D.E. Cherry
Drillers	B.G. Findlay R.O. Larter A. Zoska
Surveyors	T. McDiarmid
Mechanic	T.H. Clark
Wages hands	14

Equipment

Magnetic recorder	Electro-Tech DS7-7 and PP7 junction box
Seismic amplifiers	T.I. 7000B
Oscillograph	Electro-Tech ER66
Geophones	Hall-Sears HS-J (about 1100)
Cables	Vector 1/3 mile
Transceivers	Traeger TM2 (2) and Pye (3)
Drills	Mayhew 1000 (2) and Carey (1)
Printing machines	Este Standard A dyeline copying machine; Durst 609 enlarger.
Workshop	On Bedford 4 x 4 chassis C10669, with alternator, compressor, greasing unit, arc welder, grinding wheels, and hand tools.

Vehicles

Party leader's vehicle	International AB120, 1-ton utility	4 x 4	ZSU 097
Recording truck	International AB120, 1-ton utility	4 x 4	ZSU 092

Personnel carrier	Land Rover panel van	ZSM 076
Personnel carrier	Land Rover station wagon	ZSM 077
Cable vehicle	Land Rover LWB	ZSM 041
Cable vehicle	Land Rover LWB	ZSM 046
Flat Top	Bedford, 5-ton, 4 x 4	ZSU 007
Workshop truck	Bedford, 5-ton, 4 x 4	C10669
Shooting truck	Bedford, 5-ton, 4 x 4	ZSU 108
Water tanker	Bedford, 5-ton, 4 x 4	ZSU 013
Water tanker	Bedford, 5-ton, 4 x 4	ZSU 109
Water tanker	Bedford, 5-ton, 4 x 4	ZSU 094
Water tanker	Bedford, 5-ton, 4 x 4	ZSU 095
Carey rig	Bedford, 5-ton, 4 x 4	ZSU 110
Mayhew rig	International R190, 4 x 4	ZDA 064
Mayhew rig	International R190, 4 x 4	ZDA 094
Office caravan	Carapark, tandem axle	C02710
Explosives trailer	4 wheel trailer	C79721
Kitchen trailer	4 wheel trailer	ZTL 464
Workshop trailer	Baby Quinn	C15197
General purpose trailer	4 wheel trailer	ZTL 128
General purpose trailer	4 wheel trailer	ZTL 129
General purpose trailer	4 wheel trailer	ZTL 130

APPENDIX B

Table of operations

Sedimentary basin	:	South Georgina Basin
Area	:	Tarlton Downs - Tobermory
Camp site	:	Base camp 2 miles east of Cockroach Waterhole
Established camp	:	29th October 1964
Surveying commenced	:	2nd November 1964
Drilling commenced	:	2nd November 1964
Shooting commenced	:	3rd November 1964
Miles surveyed	:	3
Topographic survey control	:	Dept. of Interior bench marks
Total footage drilled	:	7934 ft
Total number of holes drilled	:	182
Explosives used	:	1.955 short tons
Datum level for corrections	:	500 ft above mean sea level
Weathering velocities	:	2000-3000 ft/s
Sub-weathering velocities (horizontal)	:	15,000-17,000 ft/s
Sub-weathering velocities (vertical)	:	11,000-12,000 ft/s
Source of velocity distribution	:	Integrated sonic log and well velocity survey at BMR 12 (Cockroach)

Reflection shooting data

Shot-point interval	:	1800 ft
Geophone groups	:	See Appendix E
Geophone group interval	:	150 ft
Holes shot	:	30
Miles traversed	:	3
Common shooting depths	:	105 ft, 30 ft
Usual recording filter	:	K18 K160
Usual playback filter	:	K36 K92
Common charge sizes	:	Single holes 60 lbs, 5 x 20 lbs, 10 x 10 lbs, 20 x 2½ lbs, 20 x 5 lbs

APPENDIX C

Outline of experimental programme

Location of traverse. The location for the initial testing of the reflection technique should be close to the BMR 12 (Cockroach) well (passing within a few hundred feet). The direction of the traverse should be along the strike of the geological formations, if this is possible to assess in advance. Three miles of ten shot-points will be required initially.

Deep hole tests. The usual technique of 'shooting up' a deep hole will be carried out at the centre and each end shot-point of the three-mile section. Because of very difficult drilling conditions, it may not be possible to obtain holes to 250-300 feet in a practical time; shallower holes will probably have to suffice, but they should be at least 100 feet deep. This shooting will provide information on:

(a) Drilling conditions

(b) Sub-weathering and weathering velocities and depth

(c) Best shooting depth

(d) Charge size required

(e) Best amplifier filter settings (wide-band) for record (several shots at best depth required)

(f) Initial AGC and suppression decay settings.

Weathering spreads. A shallow refraction (weathering) spread should be shot in conjunction with each of the three uphole tests for comparison and assistance in computing near-surface parameters.

Preliminary reflection shoots. The three miles of line (ten shot-points) will be shot next, using single holes (depth and charge determined by the deep hole tests) and 16 geophones per trace at 10-ft intervals. This shooting will give an idea of the quality from shot-point to shot-point.

Noise test. The results of the previous work should be studied before choosing the location for a noise test. Surface conditions such as elevation, depth of weathering, and weathering and sub-weathering velocities should be reasonably uniform along the noise test location. Serious anomalous conditions (particularly if faulting is indicated) should be avoided even if it means moving off the line already shot. If reflected energy has been recorded on part of the traverse, and there are no anomalous conditions over this part, then it would be desirable for the noise test to be located there, so that there is some chance of recording reflected energy on the noise test. The noise test will extend out to at least 4000 feet, with a geophone interval of about 25 feet. Two transverse spreads will be shot at a distance of about 1500 feet. The eight geophones in a group will be bunched at the geophone pegs. No AGC will be used and charge size and hole depth will remain constant (even if extra holes have to be drilled) at those values determined by the deep hole tests. A wide-band filter should be used. In general, the noise test will be shot and analysed according to the principles set out in a BMR internal memorandum by C.S. Robertson.

Analysis of the noise test will provide the following information:

(a) Velocities and frequency band-widths of coherent noise events and reflected signal (if recorded).

(b) Relative amplitudes of random noise, coherent noise events, and reflection signals (if recorded).

(c) Time relationships between noise and reflections.

This information will be used as a guide in the design of multiple geophone and shot arrays in the subsequent tests.

Comparison tests of geophone and shot arrays. A series of comparison tests will be shot to give direct comparisons between various types of geophone and shot arrays. These tests can be developed through four stages:

(a) In-line patterns for down-the-line noise

(b) Areal patterns for random noise

(c) Areal patterns for transverse noise

(d) Tapered areal patterns for more selective rejection of noise.

The in-line testing will approximately follow the steps set out below:

(1) 1 hole - 8 geophones

(2) 1 hole - 16 geophones

(3) 1 hole - 24 geophones

(4) 5 holes - selected from (1), (2), and (3)

(5) 10 holes - selected from (1), (2), and (3)

(6) 20 holes - selected from (1), (2), and (3)

Twenty-four geophones and twenty holes will be considered the worthwhile limit of units for in-line cancellation. Some of the above tests will be repeated using different values of Kc. In comparing areal patterns, the same principle of at least doubling the effort between comparisons will be followed.

Production test. The three miles of traverse will be re-shot using what appears to be the otpimum technique from the comparison tests, assuming that there is some visible information on the records (even though it may be poor). In choosing the optimum technique, slow drilling progress may have to be taken into account. This shooting may also involve further comparisons on different sections of the traverse, and perhaps even a comparison of two techniques along the whole three miles.

Expanded spread. An 'expanded spread' type of shoot will be carried out, similar to a 'velocity shoot'. The optimum shooting technique arrived at by this stage will be used. Trace interval will be 50 feet and the spread will be taken out to at least 7800 feet. If the information obtained from the earlier work shows that the traverse is not along strike, then a short cross-traverse should be shot to determine the strike, and the expanded spread traverse placed along the strike. The expanded spread will provide the following information:

(a) If good to fair quality reflections are being recorded, then average vertical velocities may be calculated.

(b) If reflections are still in need of improvement any residual noise should show up and an assessment made of the possibility of filtering it further.

(c) The possibility of separating reflection signal and noise in time, by the use of offset shooting.

(d) The maximum shot-to-geophone distance which may be safely used if a multiple coverage technique is being considered.

Multiple coverage shooting. If satisfactory results have not been obtained using the techniques listed above, then the multiple coverage technique will be applied. Since multiple elimination is not likely to be an objective of this shooting, the normal split-spread geometry may be used, although consideration will be given to increasing the spread length to improve the rate of progress. A 12-fold coverage will be shot, for later processing as 4-, 6-, and 12-fold stack.

APPENDIX D

Recording Schedule

Date November, 1964	Shots fired			
2	Weathering shots	-	4 shots	
3	Weathering shots	-	4 shots	
	Depth tests	-	5 shots	- SP 250
4	Uphole shots	-	6 shots	- SP 250
5	Depth tests	-	3 shots	- SP 255
		-	3 shots	- SP 260
	Uphole shots	-	2 shots	- SP 255
		-	4 shots	- SP 260
9	Traverse-9 shots - SP 251 to 254 and 256 to 258			
10	Noise test	-	12 shots	
11	Noise test	-	13 shots	
12	Noise test	-	9 shots	
13	Pattern test	-	1 shot	- SP 256
	Play back filter tests			
16	Pattern test	-	6 shots	- SP 256
17	Pattern test	-	2 shots	- SP 256
		-	1 shot	- SP 255
18	Pattern test	-	4 shots	- SP 255
19	Traverse	-	1 shot	- SP 259
	Pattern test	-	1 shot	- SP 254
20	Conventional well velocity survey			
23	Tests	-	4 shots	- SP 255
24	Tests	-	2 shots	- SP 255
		-	1 shot	- SP 254
26	Tests	-	1 shot	- SP 253
		-	1 shot	- Near BMR 12 (Cockroach)

APPENDIX E

Test sheets

Test sheet 1

Aim :

Reduction of the incoherent high frequencies by multiplication of geophones and holes. Large area covered by the holes and geophones.

Hole pattern	Geophone pattern
20-hole square + x + + + + y + + + + + ——Traverse——→ + + + + + + + + + + 4 lines of 5 holes as in diagram. x = y = 40 ft.	32 geophones + x + + + + + + + y + + + + + + + + ——Traverse——→ + + + + + + + + + + + + + + + + 4 lines of 8 geophones as in diagram. x = 20 ft, y = 30 ft.
Other details Depth : 30 ft Total charge : 50 lbs	Spread : 2 x 12 traces - shot at centre of spread. 150 ft between traces. Filter on original : K24 - K120 Filter on playback : K36 - K92

Conclusions:

(1) Record noticeably better. Very satisfactory quality.

(2) The high frequencies are not evident.

(3) Several phase alignments pickable, of which two are of fair quality.

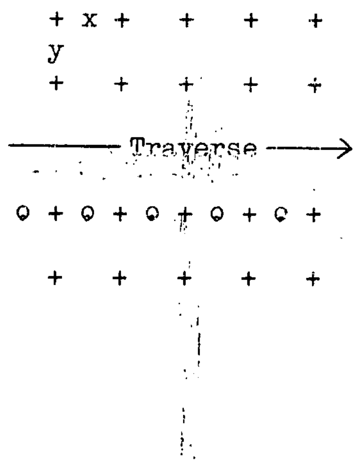
(4) The mixed record is better still. Mixing is quite possible since the traces have no overlapping on the ground.

Test sheet 1A

Aim : Different arrangements starting from those shown in test sheet 1 in order to evaluate better the degree of improvement.

Hole pattern

Holes to depth of 30ft
x = y = 40 ft.



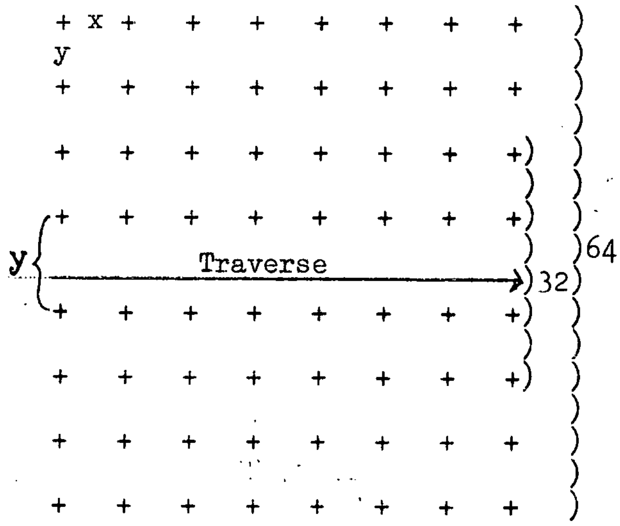
(A) 20 holes with $2\frac{1}{2}$ lbs per hole

(B) 10 holes (2 lines of 5) in the centre with 10 lbs per hole

(C) 10 holes 20 ft apart in line (o and +) 10 lbs per hole

Geophone pattern

32 or 64 geophones per trace
x = 20 ft, y = 30 ft.



(a) 32 geophones per trace as in diagram

(b) 64 geophones per trace as in diagram

Other details:

Spreads : 12 or 24 traces with the shot at the end. 2 x 12 traces with shot at the centre and 150 feet between traces.

Original filter : (i) K24-K120 (ii) K18-K160

Playback filter ; numerous different filters.

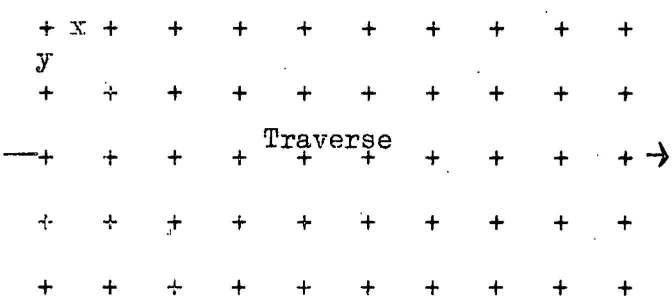
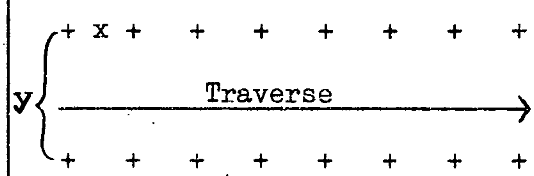
Conclusions:

(1) No improvement in relation to the arrangements as shown in test sheet 1 - rather poorer in general. But these tests are difficult to judge, for the 20 holes at 30 ft were used too often and the quality of the results could suffer in consequence (many misfires).

(2) The tests of playback filters tend to suggest that the best pass-band is about 36 to 92 c/s.

Test sheet 2

Aim : Reduction of incoherent high frequencies by multiplication of geophones and holes.
Reduction of drilling load by shallow holes.

Hole pattern	Geophone pattern
50 holes in a square pattern  5 lines of 10 holes as in diagram x = 20 ft, y = 15 ft.	16 geophones  2 lines of 8 geophones as in diagram. x = 20 ft, y = 30 ft
Other details Depth : 8 to 9 ft. Total charge: 50 x $2\frac{1}{2}$ = 125 lbs	Spread : 2 x 12 traces, Shot at centre. Original filter : K24 - K120 Playback filter : K30 - K92

Conclusion:

The high frequencies disappeared, but the low frequency noise seems more pronounced, for no clear phase alignment appeared. Shooting above the first consolidated layer introduces much stronger organised noise.

The conclusion is clear : it is necessary to have holes reaching and even penetrating the first consolidated bed.

Test sheet 3·

Aim : Test of holes and geophones in line : spatial filter with Kc large. Multiplication.

Hole pattern	Geophone pattern
5 or 10 holes in line parallel to the traverse	16 or 24 geophones in line parallel to traverse.
(A) 5 holes with 30 feet between holes Kc = $\frac{1}{300}$	(a) 16 geophones with 10 feet between geophones Kc = $\frac{1}{320}$
(B) 10 holes with 15 feet between holes Kc = $\frac{1}{300}$	(b) 23 geophones per trace with 7 feet between geophones Kc = $\frac{1}{336}$

Other details

Depth : 105 ft

Total charge: 100 lbs

Spread : 2 x 12 traces with shot at centre and 150 feet between traces

Original filter: K18 - K160

Playback filter: K36-K92

Conclusions:

(1) These tests allow an interesting comparison of the multiplication of units with Kc constant. The multiplication varies from 5 x 16 = 80 to 10 x 24 = 240.

(2) The improvement is slight. The high frequencies remain on the monitor record. There was a single pickable reflection at 0.35 second.

These records could also be compared with the records from the traverse shot with 16 geophones per trace and a single hole 105 feet deep. The improvement is not great despite the multiplication 24 x 10 = 240 and 16 x 1 = 16 and the use of supplementary spatial filtering at the shot-point.

(3) 50% mixing produces improvement. No ground mixing.

(4) Drilling of 10 holes to 105 feet takes a long time (average of three days per shot-point).

Test sheet 4

Aim : Test of holes and geophones in line : spatial filter with Kc small. Multiplication.

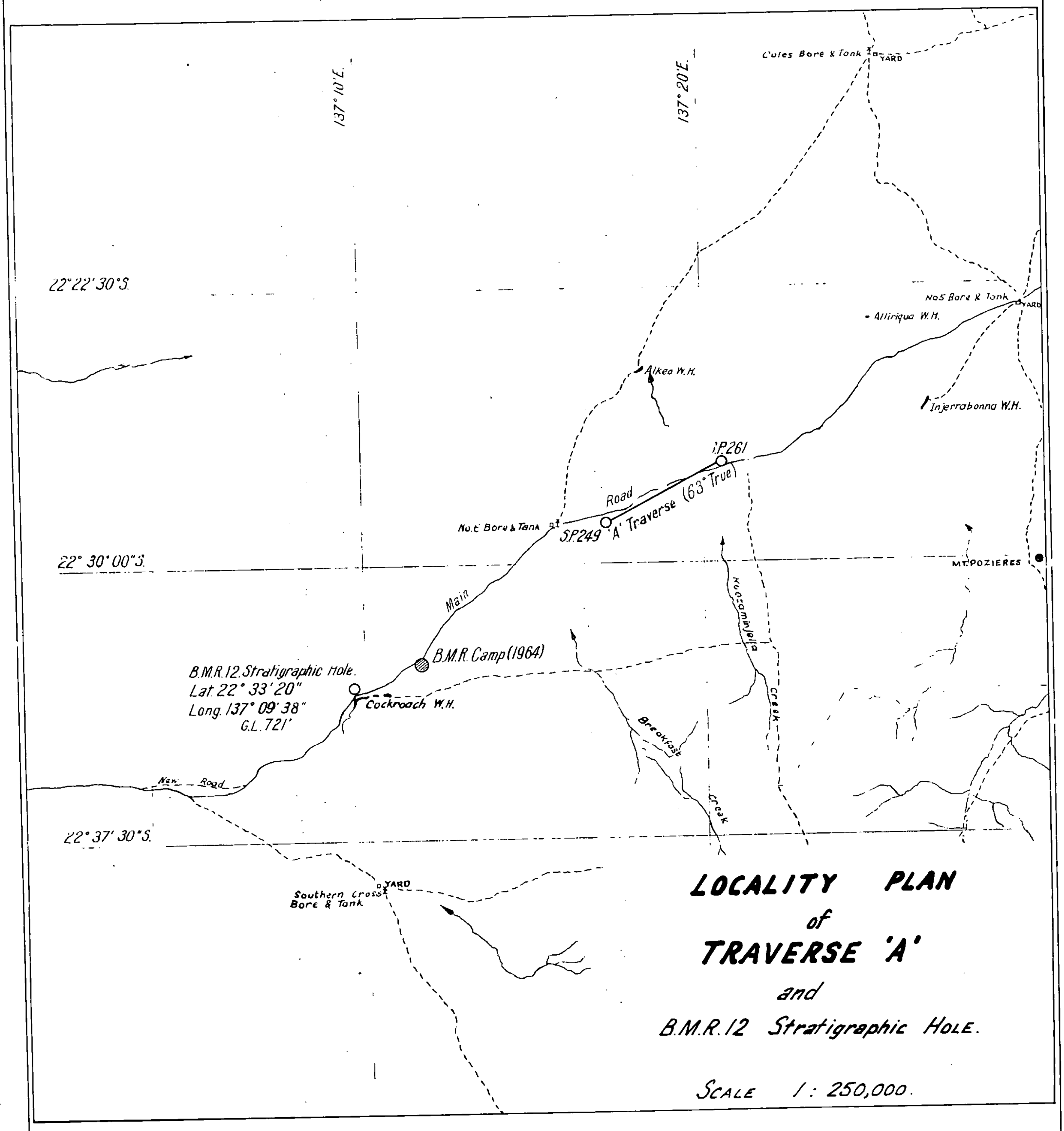
Hole pattern	Geophone pattern
5 or 10 holes in line parallel to traverse. (A) 5 holes with 60 feet between holes $Kc = \frac{1}{600}$ (B) 10 holes with 30 feet between holes $Kc = \frac{1}{600}$	16 or 24 geophones in line parallel to the traverse. (a) 16 geophones per trace with 20 feet between geophones $Kc = \frac{1}{640}$ (b) 24 geophones per trace with 14 feet between geophones $Kc = \frac{1}{642}$
Other details Depth : 105 ft. Total Charge : 100 lbs	Spread: 2 x 12 traces with shot at centre and 150 feet between traces Original filter : K18 - K160 Playback filter : K36 - K92

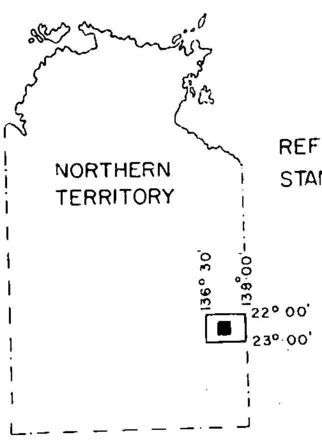
Conclusions:

Same comparison as for test sheet 3, but with Kc halved, both for the shot-point and for the geophone group. Slight difference in multiplication.

(1) There is little difference from the records of test No. 3. The spatial filtering has little effect on the quality of the records.

(2) The high frequencies persist.



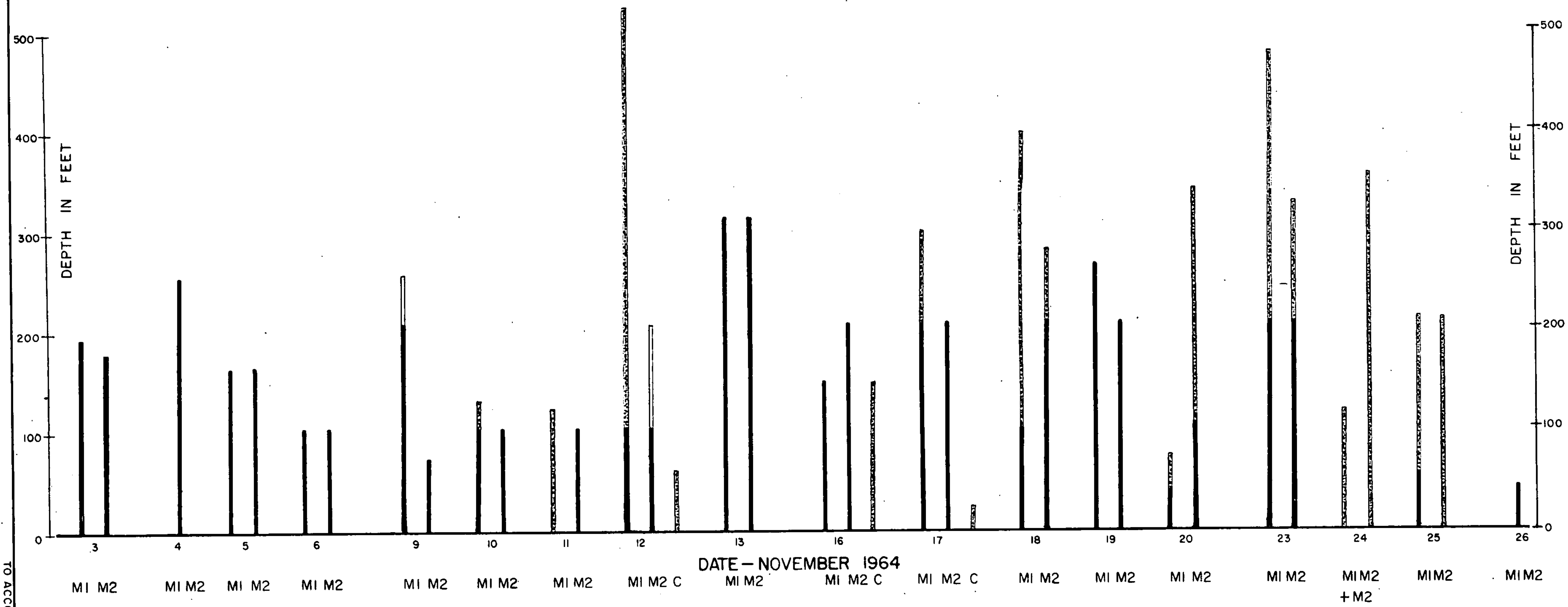


REFERENCE TO AUSTRALIA STANDARD 1:250,000 MAP SERIES: TOBERMORY

TO ACCOMPANY RECORD No. 1966/75

Prepared by Survey Branch, Dept. of the Interior, Canberra. 1964.

F53/B3-94



LEGEND

- deep holes
- shallow holes
- re-drill

Mi	Drilled	by	Mayhew	Rig	No. 1
M2	"	"	"	"	No 2
C	"	"	Carey	Rig	

DRILLING PROGRESS CHART

FOR EXPERIMENTAL SEISMIC SURVEY
NEAR COCKROACH WATERHOLE N T
NOVEMBER 1964

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

TO ACCOMPANY RECORD No.1966/75

F53/B3-98

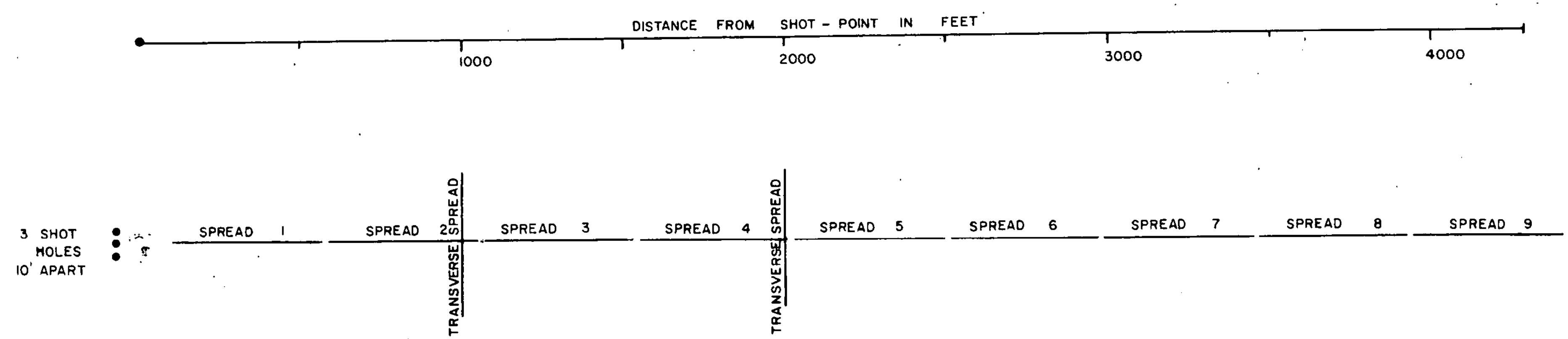
PLATE 2

Interval between traces 20ft, Depth of shot constant ≈ 100ft, Charge constant = 10 lbs,
No AGC or filtering on original recording or on playback in variable – area.

NOISE TESTS, COCKROACH WATERHOLE, NT 1964

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F53/B3–102
TO ACCOMPANY RECORD No. 1966/75

PLATE 4



SPREAD NO.	DISTANCE FROM SHOT - POINT
1	100 – 560 FEET
2	580 – 1040 "
3	1060 – 1520 "
4	1540 – 2000 "
5	2020 – 2480 "
6	2500 – 2960 "
7	2980 – 3440 "
8	3460 – 3920 "
9	3940 – 4400 "
TRANSVERSE	1000'
"	2000'

RECORDING DATA

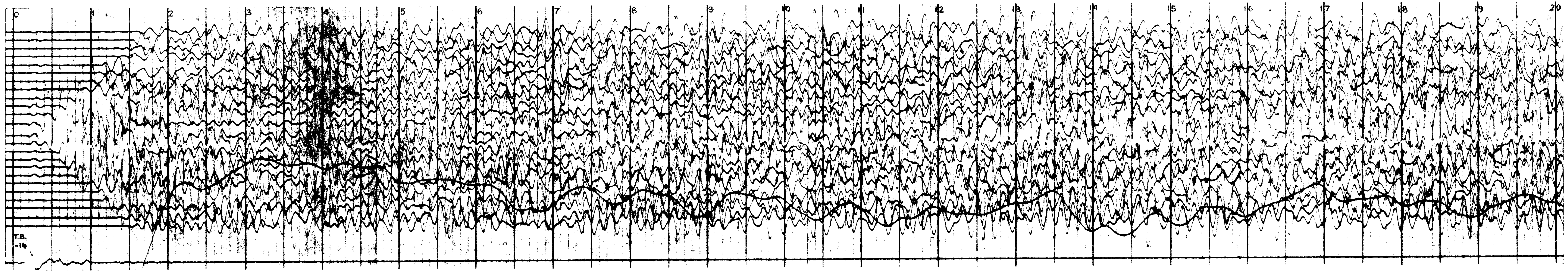
Geophones in groups of 8 bunched close together.
Trace interval 20 feet.
Charge size constant = 10 lbs
Charge depth approx. = 100 ft.
Shotholes fired singly.
No AGC
High and low cut filters OUT.

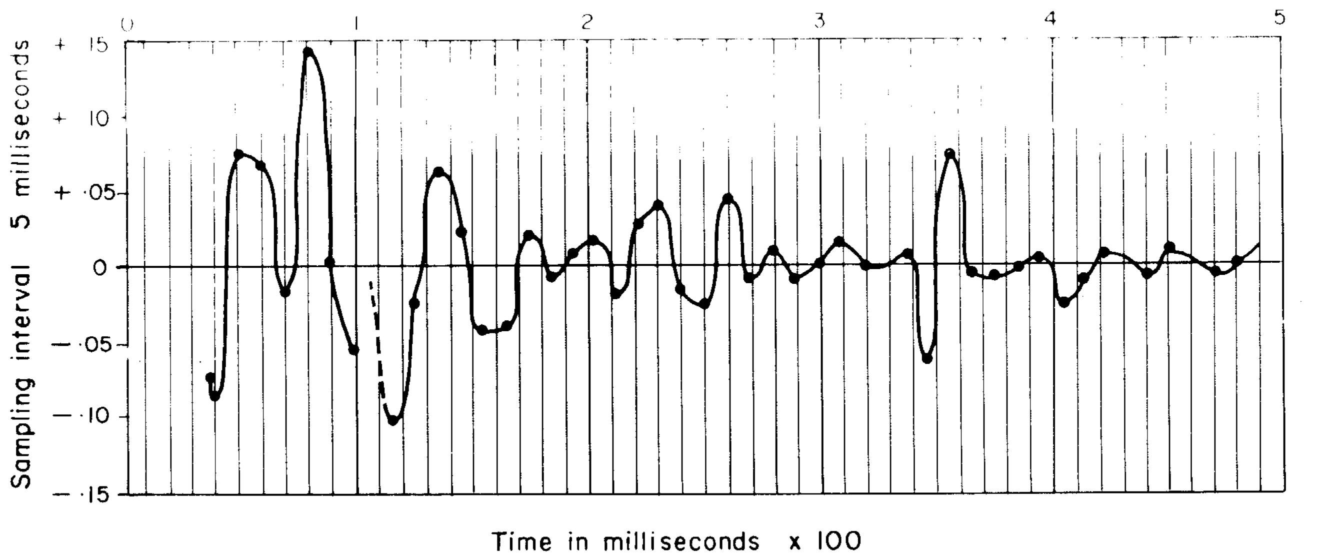
NOISE TEST SPREAD LAYOUT

TRAVERSE A, COCKROACH WATERHOLE
NT, 1964

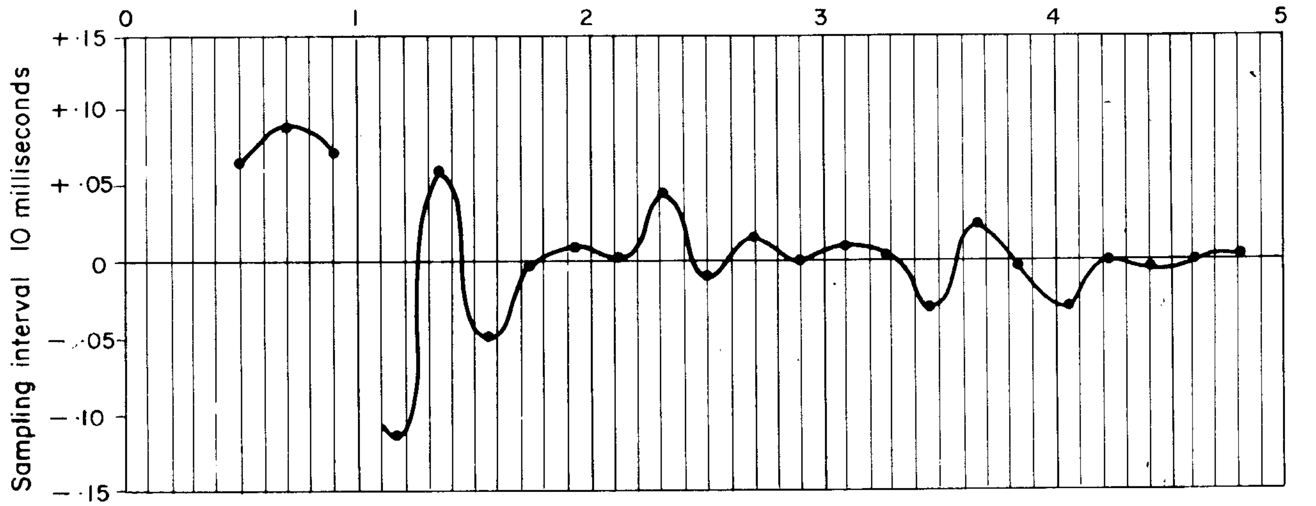
GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F53/B3-101
TO ACCOMPANY RECORD No. 1966/75

PLATE 5





Time in milliseconds x 100



COMPARISON BETWEEN SEISMIC RECORD AND COEFFICIENT OF REFLECTION DERIVED FROM SONIC LOG OF BMR 12 (COCKROACH) WELL

SEISMIC RECORD: SP256

20 holes 30′ deep in 4 rows of 5 parallel to traverse
32 geophones / trace in 4 rows of 8 parallel to traverse
Original filters : K24—K120   Playback filters : K36—K92

COEFFICIENT OF REFLECTION

Computed from sonic log using sampling intervals of 5 and 10 milliseconds and formula $R = \frac{V_2 - V_1}{V_2 + V_1}$

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics   F53/B3-97

TO ACCOMPANY RECORD No. 1966/75