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EXPERIMENTS IN CONTROLLED DIRECTIONAL RECEPTION SEISMIC METHODS AND DIGITAL PROCESSING, 1969-70

by

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SUMMARY

The Controlled Directional Reception (CDR) seismic method is a seismic reflection technique used widely in the USSR which is claimed to be successful in elucidating complicated geological structures. Basically it involves the summation of recorded seismic traces after introduction of various time delays between them so as to enhance in turn events with different apparent dips. With no prior knowledge of the Russian method, Dr W.A.S. Butement of Plessey Pacific Pty Ltd suggested to the Bureau of Mineral Resources the possible use of directional beaming methods in seismic prospecting.

An area at the northern margin of the Amadeus Basin where previous seismic work had indicated many steeply dipping seismic events was selected for BMR field trials of controlled directional reception methods in 1969. The technique used was based on both the ideas of Dr Butement and the method used in the USSR. During 1970 the recommended method of CDR trace summation processing was carried out and, for comparison, various digital processes were also applied to the data.

The field experiments using shot-hole and geophone patterns extended at right-angles to the traverse and approximately along formation strike yielded seismic data of improved quality compared to previous work. The trace summation processing segregated events according to their dip but supplied no additional information.

Digital processing including deconvolution and velocity filtering improved the quality of the data particularly in the region of poor quality close to the basin margin. The process Migration Stack, recently made available by Geophysical Service International, has been shown to provide a readily interpretable section but to have limitations.

The area at the northern margin of the Amadeus Basin was probably ill-chosen as a site for tests of the CDR method. An area where seismic events of different dips interfere should be selected for further tests.

1. INTRODUCTION

The Controlled Directional Reception (CDR) seismic method is the name given to a seismic reflection technique which has been used widely in the USSR. It is claimed to have been particularly successful in separating interfering events in regions of complicated geological structure.

Dr W.A.S. Butement of Plessey Pacific Pty Ltd in 1967 approached the Bureau of Mineral Resources (BMR) with suggestions for improvement in seismic prospecting techniques based on his experience with radar and sonar beaming methods. The particular technique suggested, involving both directional reception and non-specular reflection, was not, however, considered to be directly applicable to land seismic work.

A short field experiment was carried out in July 1969 following a recommendation for CDR work based on the ideas of Dr Butement (Appendix 1) and a desire to test the Russian method. The area selected for the work was at the northern margin of the Amadeus Basin near Owen Springs, 50 km west of Alice Springs, N.T., where a previous seismic survey indicated many steeply dipping events and possible complicated structure. Recording was along part of Line 3-3N of the Mount Rennie-Ooraminna Seismic and Gravity Survey (Geophysical Associates, 1967).

The data recorded were later subjected to CDR trace summation processing similar to that used in the USSR and to a sequence of digital processing. This report discusses the relative merits of these two approaches and the way in which the processed seismic data supplies information on the structure of the northern margin of the Amadeus Basin near Owen Springs.

Logistically the field experiment was part of Gosses Bluff Seismic Survey (Brown, 1971a) during which the CDR method was also used in an attempt to elucidate complicated structure near the centre of Gosses Bluff (Brown, 1971b).

2. PREVIOUS CONTROLLED DIRECTIONAL RECEPTION WORK

The members of the US exchange delegation in petroleum geophysics who visited the USSR in 1965 reported (Keller et al., 1966) that "the most outstanding difference between US and Soviet practice in reflection shooting is their widespread use of the Rieber method, which they designate as Controlled Directional Reception....". Rieber (1937) established some of the basic principles of the method but it was never used extensively in the USA. Riabinkin developed the Russian version of the technique and has written a comprehensive treatise on the subject (Riabinkin et al., 1962). Translation from the Russian of the table of contents and of the chapter describing field techniques appears as Appendix 2 to this Record.

The Russian CDR shooting arrangment normally uses a spread of 36 geophones with the shot fired some distance from the end of the spread. The signals from nine adjacent geophones are recorded in variable area on 35 mm film, four film strips in all being required. The essential feature of the CDR method lies in the processing. The nine traces on a film record are summed using an optical system with movable slits which can be adjusted so as to introduce any desired amount of moveout across the record. Events recorded are thus segregated on the basis of apparent velocity and in this way it is possible to distinguish reflections with different dips in zones of complicated geological structure.

The method is reputedly most successful and a great deal of CDR work has been reported from the USSR. For example, processing of CDR recordings has been discussed by Puzyrev (1961); many investigations using CDR are reported in Zhigach (1963). Experiments with the CDR method in India (Nomokonov et al., 1968) "proved the utility of the CDR technique in detailing steeply dipping and complex geological structures."

The widespread use of the CDR method in the USSR and in particular the optical processing techniques involved must be seen in context of the Russians' belated introduction, relative to western countries, of magnetic recording, and playback with dynamic corrections. Digital recording and processing techniques are even now still in their infancy in the USSR.

The seismic technique suggested by Dr Butement in personal communication with the Secretary, Department of National Development, was to set out a line of explosive charges intersecting at right-angles a line of geophones. Simultaneous detonation of such a line of charges would concentrate the energy into a vertical plane perpendicular to the line. Detonation of the charges with delays introduced between them would concentrate the energy into a half-cone beam whose axis is the line of charges. He suggested introducing delays into the outputs of the geophones so that, after paralleling these outputs, a reception half-cone beam with axis the line of geophones would be set up. Because the line of charges and the line of geophones are at right-angles, energy would be recorded only from a "narrow cigar-shaped lobe" where the transmission and reception half-cones overlapped. In this way, by adjusting the parameters of the shot and geophone lines, multi-directional scanning from a single location was proposed in order to build up a three-dimensional picture of the sub-surface. Dr Butement's ideas involved the utilization of non-specular as well as specular reflections.

The method described was not considered by BMR officers to be directly applicable to land seismic work using existing equipment. However, recommendations for experimental CDR work based on the ideas of Dr Butement were made (Appendix 1).

3. OBJECTIVES

The prime objective of the work was to assess the effectiveness of controlled directional reception seismic techniques in a region of complicated geological structure.

Later was added the objective to use modern methods of digital processing to enhance the recorded data and to compare the effectiveness of this with normal analogue processing and CDR trace summation processing.

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4. CONTROLLED DIRECTIONAL RECEPTION EXPERIMENTS

Location

The experiments in controlled directional reception methods were carried out at the northern end of Line 3-3N of the Mount Rennie-Ooraminna Seismic and Gravity Survey (Geophysical Associates, 1967). Shot-points 323-329, referred to as Traverse 3-3N (Plate 1), were re-surveyed for the experiments and correspond very closely to SPs 23-29 of Line 3-3N. This location was selected for the following reasons, in order of importance:

1. Previous seismic work indicated many steeply dipping events whose quality changed from very good to very poor over a short distance as the basin was approached (Plate 2). Thus there was a problem to elucidate complicated detailed structure near the northern margin of the Amadeus Basin at this point.

2. Previous seismic work also indicated that surface noise was not a serious problem.

3. It was fairly close to Gosses Bluff, the location of BMR seismic operations at the time, and had easy access.

4. A cleared line and some elevation control was available.

5. The structure of the basin margin was already broadly understood.

Field technique for CDR profiling

The experiments in controlled directional reception were planned on the basis of the recommendations drafted by Robertson (Appendix 1) using a simple technique initially. The basic cross arrangement was employed with the geophone spread along Traverse 3-3N and the shot-holes in a line at right-angles (Plate 3B). All events were known to be dipping to the south, therefore the shot-holes were located off-end at the southern end of the geophone spread rather than in the centre. Charges detonated simultaneously in the line of shot-holes concentrated the energy into the vertical plane through the traverse. The number of holes used was fewer than recommended because of very hard drilling conditions. By also extending the geophone groups perpendicular to the traverse only, there was no spatial filtering in the plane of the traverse, and thus no discrimination against events of any dip. Normal progression shot-point by shot-point provided a continuous profile, for which a conventional analogue playback from magnetic tape appears in Plate 4.

Field technique for CDR shot delay experiments

Some experiments in beaming energy from the shot in directions other than the vertical were also conducted, as recommended in Appendix 1. At SP 325 a line of shot-holes was drilled along the traverse and the geophone spread was laid at right-angles to the traverse (Plate 3A). By introducing delays of several milliseconds between the charges, the energy was concentrated into a half cone beam whose axis was the line of charges. The larger the delay introduced between adjacent charges, the greater was the angle between the beam and the vertical plane through the geophone spread, or in other words the smaller the apical angle of the cone. Records from shots with different charge-to-charge delays are shown in Plate 5.

The delays were introduced with measured lengths of Cordtex, a detonating fuse with detonation velocity of 6700 m/s. Two different arrangements were necessary for connecting up the Cordtex. For a charge-to-charge delay of 7 ms or greater it was possible to use a single strand along the surface with separate strands connecting this down each hole to the charge and to use a single detonator at the position of the first charge, that is at the southern end. For a delay of less than 7 ms it was necessary to use a progressively longer length of Cordtex and a separate detonator for each charge. This method required a very much larger quantity of Cordtex even for quite small delays. The lengths of Cordtex on the surface had to be buried in order to reduce noise and the risk of fire. In fact the Cordtex was not buried deeply enough as indicated by the air wave recorded (Plate 5).

The record from the single-hole shot shows reflections and other events received from all directions. The records from the four 7-hole shots show the result of beaming energy in four different half-cone beams. Each event, labelled in Plate 5, has an amplitude maximum for a particular charge-to-charge delay corresponding to an angle of maximum energy return.

No CDR processing has been applied to these data.

CDR processing technique

The essence of the CDR method as used in the USSR lies in the processing, and involves the summation of groups of adjacent traces with different time delays introduced between them in order to enhance in turn events of different dip and to attenuate events of unwanted or non-linear dip.

The data from Traverse 3-3N were processed by analogue stacking using as input FM magnetic tapes; in the Russian method the summation is normally done optically. The result of CDR trace summation processing of the data presented in Plate 4 is shown in Plate 6. Each trace on the latter plate is the result of a 24-trace summation, that is the stacking together of all the traces of one record after appropriate time delays have been introduced. For each record, that is for the data recorded at each shot-point, this summation was carried out 19 times, after the introduction of trace-to-trace time delays (or shifts) ranging from zero to 9 milliseconds in steps of half a millisecond.

When an event across the input traces is in phase after introduction of a certain delay, an amplitude maximum will occur after stacking. Such maxima have been circled in Plate 6; no dip migration has taken place. The most prominent maxima are seen to be directly relatable to the principal events in Plate 4 and are labelled correspondingly. Further, the delay corresponding to the maximum for each event is seen to be essentially the same as the delay for the same event found in the shot delay experiments (Plate 5).

5. DIGITAL PROCESSING AND LASERSCAN EXPERIMENTS

LaserScan Processing

Before commencing the digital processing, an attempt to improve the event continuity in the poor quality region between SPs 328 and 330 was made using the LaserScan optical processing equipment (Dobrin, Ingalls, and Long,

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1965). Spatial filtering with a 90° stop wedge was used to attenuate any events with dip contrary to that of the main events seen on the section. Plate 7, showing the result of this processing, demonstrates some improvement in continuity between SPs 328 and 330. This gave reason to be optimistic that digital processing techniques might improve the quality of the data in this region even further.

Digital Processing - general

The principles of the digital processing of seismic data are described by United Geophysical Corporation (1966) and Silverman (1967). BMR's early experience is discussed in relation to data from the Roma Shelf Seismic Survey, 1967-68, by Brown and Willcox (1973). The digital processing of the data from Traverse 3-3N was carried out under contract by Geophysical Service International (GSI) in Sydney. The sampling interval on transcription was 2 milliseconds and the anti-alias filter was 168 Hz.

Plates 8, 9, 10 and 11 show the results of the various stages of digital processing. The significant processes applied are indicated on each plate under "Processing Information." In addition to these processes trace equalization, which matches trace levels both along and between traces, has been used to improve the uniformity of the section. This effect is most clearly demonstrated by comparison of Plate 8 with Plates 4 or 7, showing that particularly low level areas have been increased in amplitude.

Deconvolution

Time-variant deconvolution (Clarke, 1968) with a 30-point operator is seen in Plate 8 to have slightly improved the definition of the events and their continuity on the right of the section.

Velocity Filtering

Further improvement in continuity was obtained (Plate 9) by application of digital velocity filtering (Embree, Burg and Backus, 1963). This process has the same aim as LaserScan spatial filtering, namely to pass events of certain dips (apparent velocities) and reject events of other dips. In this particular application an 8-trace Pie-slice was used, that is eight input traces contributed to produce each output trace; the parameters of the velocity filter applied were varied in time and space.

Two general comments on velocity filtering are relevant to the appreciation of the results. Firstly, velocity filtering works most successfully on data which conform to the assumed model in which the events to be passed or rejected have linear dip and constant amplitude. Secondly, because it involves considerable trace-to-trace mixing, there is a danger that spurious event segments may result on the output section; in Plate 9, event continuity over less than eight traces may be spurious.

Migration

Because the events seen on the section are mostly steeply dipping, migration was essential in order to display events at their true position. Until recently the only way of performing migration was to pick event segments and migrate these using wavefront charts either manually (Hagedoorn, 1954) or by computer (Musgrave, 1961) or using mechanical devices such as the Sinclair Dip Plotter (Seiscor, 1960).

The process of Migration Stack (Rockwell, 1971) migrates all the data on a section without previous picking of the events. Each input trace is used to generate a kind of wavefront chart composed of a number of traces which is equal to the aperture of the process. This is done by applying normal moveout formulae incorporating the velocity function applicable to the area. Each output trace position is then occupied by a sequence of corrected traces, the number of which is again the aperture of the process, except for taper-on and taper-off effects. These traces corresponding to each output trace position are then stacked together, initially by straight stacking within sub-groups or "sectors" of 12 adjacent traces, followed by specially weighted "inversity" stacking of these straight stacked traces.

The effect of Migration Stack is to migrate dipping events to their true sub-surface position and to collapse diffraction patterns into points. This means that complex event patterns from structures such as tight folds and faults are "sorted out". The process is, however, fairly sensitive to velocity, so that the accuracy of the sub-surface picture obtained is only as good as the velocity function supplied.

Certain other limitations of the process must also be realized. Because, like velocity filtering, Migration Stack involves considerable trace-to-trace mixing, bursts of noise may be "smeared out" on the migrated section to appear as spurious events. The process only treats two dimensions and thus assumes that all events were recorded in the plane of the section. High frequencies tend to be attenuated by the stacking process, giving the output section a low frequency character. Spurious results may be obtained from taper on and taper off effects over those traces within half the aperture of the process from each edge of the input data.

Migration Stack is the name of the method used and patented by GSI. Other companies now have very similar processes available. Notable is that developed by the Institut Francais du Petrole (IFP) and referred to as Impulse Seismic Holography (Fontanel and Grau, 1969, and Fontanel, 1971).

The data from Traverse 3-3N as output from time-variant deconvolution was processed through Migration Stack using the maximum aperture available of 192 traces, that is 96 traces either side of each input trace. The resulting migrated time section is shown in Plate 10, and after time-depth conversion, the data appear as a migrated depth section in Plate 11. Notes on the success of the Migration Stack were supplied by GSI and appear as Appendix 3.

Plate 12 shows the velocity function used in the migration and depth conversion and also the horizontal distance in terms of number of traces that an event of given reflection time and dip will migrate for the velocities used. The maximum aperature of 192 traces, used in an attempt to migrate the steeper dips, was still insufficient to migrate the steepest events N1 to 4, which were thus attenuated in the stack.

6. DISCUSSION OF TECHNIQUES AND RESULTS

CDR techniques

The field shooting and recording technique using lines of shot-holes and geophones perpendicular to the traverse attenuated energy travelling other than in the vertical plane through the traverse, whereas all energy travelling in that plane suffered no spatial filtering. Also, the large number of shot-holes and geophones supplied substantial random noise attenuation. The analogue playback of the data (Plate 4) is considered by these means to have achieved higher quality than the previous data (Plate 2) recorded on this traverse using single shot-holes, in-line geophone patterns,and lower-fidelity recording equipment.

The CDR trace summation processing resulted in clear maxima (Plate 6), each of which corresponds to an event prominent on the analogue playback. However, no additional information is evident. If there had been events on the analogue section which interfered with each other, rather than being roughly conformable, a better test of the capabilities of the trace summation processing technique would have been obtained.

The shot delay experiments conducted at SP 325 recorded different events from different angles according to the charge-to-charge delay introduced. An event was recorded with a charge-to-charge delay approximately equal to the trace-to-trace delay for which that event gave a maximum in the trace summation processing at the same shot-point. Thus directional beaming in transmission and reception gave equivalent results.

Digital processing

The digital processing provided data enhancement in several ways: Deconvolution and velocity filtering were able to extend the continuity of some of the events into the poor quality region. Migration Stack translated events of moderate dip to their true position in depth (as long as it can be assumed that a two-dimensional representation was adequate and that the velocity function used was accurate) and collapsed a prominent diffraction pattern (N5); however, the steepest events (N1 to 4) could not be migrated with the routine used and have been attenuated. A much more uniform trace amplitude over the section was achieved than was possible using analogue techniques. Finally, the presentation of the final section (Plate 11) in terms of depth, rather than time, was an aid to interpretation.

The steepest events (N1 to 4) attenuated by the Migration Stack process may not be reflections but rather reflected refractions. The following are reasons to support this possibility:

1. Their straightness and approximate parallelism is more characteristic of refractions than reflections. However, their apparent velocities lie between 6400 and 8200 m/s, which is higher than would be expected for horizontally travelling reflected refractions in the plane of the section.

2. On the original record section recorded on Line 3-3N (Plate 2) there appears to be interference in the region SPs 20-22 between the southern extension of events N1 to 4 and reflections which are recorded from there over a considerable part of the traverse, suggesting that events N1 to 4 are not continuous with them.

3. If these events were to be considered reflections, their location and attitude after migration would be difficult to reconcile with present knowledge of basin margin structure.

4. Various possible structural models can be proposed to explain these events as reflected refractions. The most feasible is that there are a series of faults along and parallel to the Hugh River (Plate 1) which makes an angle of about 30° with Traverse 3-3N. Refracted energy travelling horizontally at 5300 m/s, the measured near-surface velocity, and reflected from such faults would be recorded on Traverse 3-3N with an apparent velocity of 6600 m/s, that is within the range observed.

Structure at basin margin

Traverse 3-3N lies close to the northern margin of the Amadeus Basin and its direction is approximately perpendicular to the regional strike. The surface geology across the basin margin was known (Wells, Forman, Ranford and Cook, 1970) and actual formation dips seen in outcrop on the northern extension of the traverse were supplied by Geophysical Associates (1967).

By reference to the previous data recorded on this traverse and adjacent traverses (Geophysical Associates, 1967), reflections R1 to 3 were tentatively identified as follows:

R1 - near base of Mereenie Sandstone (Horizon A)

R2 - within Horn Valley Siltstone (Horizon B)

R3 - near base of High River Shale (Horizon D)

This permitted the construction of a schematic cross-section across the basin margin (Plate 13) based on the reflections from Plate 11 and the surface geological information as above.

7. CONCLUSIONS AND RECOMMENDATIONS

The area selected at the northern margin of the Amadeus Basin was not ideally suitable for testing the effectiveness of the CDR method, as events were not truly interfering. However, the CDE trace summation processing was successful in segregating the events recorded according to their dip, although it supplied no information additional to the conventional analogue playback section.

Additional information was extracted from the data by applying modern digital processing methods not normally used in CDR work. The Migration Stack process was found to provide a particularly useful aid to interpretation as long as its limitations are fully realized.

The experiments proved that directional beaming of seismic energy in both transmission and reception can be achieved. Therefore, the basic idea of Dr Butement to scan the sub-surface successively in different directions from one location is feasible after modifications to accommodate existing equipment. It may have application in special cases. No tests have been carried out into the feasibility of recording non-specular reflections.

Further experimental recordings to test the CDR method should be made in an area of complicated structure where seismic events do interfere each other. The technique used should be similar to that outlined above using shot-hole and geophone patterns oriented at right-angles to the traverse. However, two changes to the field procedure should be considered in the light of the Russian recommendations (Appendix 2), namely that AGC should not be used and the geophone spread should be shorter.

As part of such further experimental testing of the CDR method, digital processing techniques should again be used in comparison with CDR trace summation methods in an attempt to extract the maximum amount of information on the structure of the test area.

8. REFERENCES

BROWN, A.R., 1971a - Gosses Bluff Seismic Survey, NT, 1969, Bur. Miner. Resour. Aust. Rec. 1971/4 (unpubl.)

BROWN, A.R., 1971b - A detailed seismic study of Gosses Bluff, Bur. Miner. Resour. Aust. Rec. 1971/141 (unpubl.)

BROWN, A.R., and WILLCOX, J.B., 1973 - Roma Shelf Seismic Survey, 1967-68 - Report on Analogue and Digital Processing, Bur. Miner. Resour. Aust. Rec. (in prep.)

CLARKE, G.K.C., 1968 - Time-varying deconvolution filters, Geophysics, 33, 936-44.

DOBRIN, M.B., INGALLS, A.L., and LONG, J.A., 1965 - Velocity and frequency filtering of seismic data using laser light, Geophysics, 30, 1144-78.

EMBREE, P., BURG, J.P., and BACKUS, M.M., 1963 - Wide-band velocity filtering - the Pie-slice process, Geophysics, 28, 948-74.

FONTANEL, A., and GRAU, G., 1969 - Application of Impulse Seismic Holography, Institut Francais du Petrole, Report No. 17 353 (unpubl.)

FONTANEL, A., 1971 - Holoseismics, Institut Francais du Petrole, Report No. 19 340 (unpubl.)

GEOPHYSICAL ASSOCIATES PTY LTD, 1967 - Mount Rennie - Ooraminna Seismic and Gravity Survey 1966, Oil Permits 43 and 56 NT, for Magellan Petroleum (NT) Pty Ltd, Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Report (unpubl.)

HAGEDOORN, J.G., 1954 - A process of seismic reflection interpretation, Geophysical Prospecting, 2, 85-127.

KELLER, G.V., and members of US exchange delegation in petroleum geophysics, 1966 - Tour of petroleum geophysics activities in the USSR, Geophysics, 31, 630-7.

MUSGRAVE, A.W., 1961 - Wave-front charts and three dimensional migrations, Geophysics, 26, 738-53.

NOMOKONOV, V.P., RAMAKOTAIAH, G., RAO, N.D.J., and SHENAI, K.R., 1968 - Results of experiments with Controlled Directional Reception (CDR) method in Karaikal area, Canvery Basin, Bull. Oil Nat. Gas Comm. India, 5, 2, 49-56.

PUZYREV, N.N., 1961 - Interpretation of reflection shooting data, US Joint Publications Research Service, Washington.

RIABINKIN, L.A., NAPALKOV, I.V., ZNAMENSKI, V.V., VOSKRESENSKI, I.N., and RAPOPORT, M.B., 1962 - Teoria i praktika seismicheskogo metoda RNP (Theory and practice of the Controlled Directional Reception seismic method), Gostoptechizdat, Moscow.

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RILBER, F., 1937 - Complex reflection patterns and their geologic sources, Geophysics, 2, 131-60.

ROCKWELL, D.W., 1971 - Migration Stack, Oil and Gas Journal, 69, No. 16

SEISCOR, 1960 - Manual of operation for Sinclair Dip Plotter, type CKB, Seiscor, Tulsa, Oklahoma, U.S.A.

SILVERMAN, D., 1967 - The digital processing of seismic data, Geophysics, 32, 988-1002.

UNITED GEOPHYSICAL CORPORATION, 1966 - A pictorial digital atlas. United Geophysical Corporation, U.S.A.

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

ZHIGACH, K.F., (Ed) 1963 - Industrial and exploratory geophysical prospecting, Consultants Bureau, New York.

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APPENDIX 1

Recommendations for CDR work

by C.S. Robertson

Dr W.A.S. Butement of Plessey Pacific Pty Ltd wrote to the Secretary, Department of National Development, on May 9, 1967, enclosing a proposal entitled "Seismic surveying - improvements in technique." The two most important concepts involved in Dr Butement's ideas were directional beaming of seismic energy and non-specular reflection.

Experiments to determine the importance and the mechanisms of non-specular (non-mirror-like) reflection in the field may be difficult to devise and carry out, except in rather exceptional areas where geological conditions are very simple and well known. In any case it would first be necessary to make a thorough study of the Russian literature dealing with the subject. Consequently no recommendations for field tests on non-specular reflection can be given at this stage.

On the other hand the value of directional beaming and reception of seismic energy in structurally complicated areas can probably be tested quite effectively using conventional seismic equipment with little or no modification. The first requirement for such tests is a suitable area, which should have the following characteristics:

1. Reflections able to be recorded from a number of different directions at about the same time. Such reflections may not be very clear on conventionally-obtained cross-sections, but the latter should give some indication of structural complexity.

2. Surface noise not a serious problem at the times at which reflections are sought. This will mean that attenuation of horizontally-travelling noise does not have to be considered to any great extent in the design of arrays. Arrays to attenuate horizontal events will tend to attenuate energy beamed at directions other than the vertical.

Certain areas near the northern margin of the Ngalia Basin or near Gosses Bluff may prove to be suitable test areas for directional recording.

It is proposed that the large cross arrangement suggested by Dr Butement be used, with modifications to accommodate existing BMR seismic equipment. The objective will be multi-directional scanning from a single location.

Suitable delays between explosive charges can be introduced by connecting them with Cordtex lines of calculated length. However, it is not possible with existing equipment to introduce delay units between geophones during recording in the field. On the other hand it is possible to introduce delays between individual traces on playback and to sum them after delay. This is the basis of the test technique proposed.

It would be possible to apply Dr Butement's proposal for scanning the sub-surface with intersecting half-cone beams. This would require that the line of charges be fired with delays between individual shots. The

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geophones would be recorded separately on different traces and these could be delayed and added in the playback centre to give the effect of reception half cones. However, this method would have the following disadvantages:

1. Using Cordtex to produce delays between shots, the delay would be $\frac{l_c}{V_c}$ where l_c = length of Cordtex

   V_c = detonation velocity of Cordtex

   Now zero delay can be produced by firing the charges simultaneously with wire connections, and large delays can be produced with long lengths of Cordtex. But because of the fixed detonation velocity of Cordtex, small delays can only be obtained by placing the charges fairly close together. If a long charge array is used to get a narrow-beam of energy, large numbers of charges are required for beaming in directions close to the vertical.

2. To ensure that the two half-cone beams (one transmission and the other reception) intersect each other, either one or both of the cones must enclose a fairly large angle. For directions close to the vertical or close to the two planes through the charges and geophones there is no problem, but it is not possible to scan in certain directions using this method. For example, in the vertical plane at 45° to the line of shots and the line of geophones it is not possible to scan in directions which are more than about 20° from the vertical. Now for scanning rough near-horizontal geological horizons using non-specular reflection as Dr Butement intended this does not matter. But for scanning structural features such as fault planes, steep folds etc. in complicated areas (without relying on non-specular reflection) this is a disadvantage.

Whereas the method of shooting with delays between explosive charges may eventually prove to be the most efficient for scanning in all directions, it is considered that for initial tests a simpler technique may be preferable. This would be to use a linear array of about 20 charges extending over about half a mile and to fire them simultaneously. The effect would be to concentrate source energy in a plane at right angles to the line of charges and parallel to the line of geophones. Since each geophone output would be recorded separately, the geophones would record energy from all directions within the vertical plane through the geophone line. Then in the playback centre various delays would be introduced between traces before addition. In this way a "reception beam" could be made to scan various directions within the vertical plane through the geophone spread. The 24 traces of a record could be summed 6 or 8 at a time, so that the original 24-trace record would be reduced to a directional seismogram of 4 or 3 traces for each directional scanned.

Thus only one shot would be required to record from all directions within a single plane. For a second shot the positions of the shots and the geophones in the large right-angled cross arrangement could be interchanged and directions in a plane perpendicular to the first scanned as before by processing in the playback centre. Now in many areas two shots, beaming energy in two planes at right-angles, might be sufficient to build up a reasonable three-dimensional picture of structure, especially if the strikes of various geological features are known and the cross array is oriented accordingly. In other areas it might be necessary, in using this technique, to beam energy in 4 planes at 45°, in 8 planes at $22\frac{1}{2}^{\circ}$, or in a number of planes orientated in special ways to fit in with the structure of the area.

In applying this directional recording technique it would not be possible to use conventional geophone arrays aligned along the geophone spread since these would tend to attenuate the energy sought in directions other than the vertical. However, it would be advantageous to use suitable arrays perpendicular to the geophone line as these would effect considerable cancellation of random noise and some cancellation of shot noise. Using the technique proposed by Dr Butement it would not be possible to use geophone arrays extended perpendicular to the geophone spread (or of large extent in any direction) because of their attenuating effect on energy sought.

Apart from field considerations, the method of recording energy in one single plane at a time would appear to have a very important advantage over Dr Butement's method as regards the final plotting of data in three dimensions. In the former method the recorded data for each plane can be plotted using conventional dip-plotting methods on a sheet of plane, rigid material such as cardboard or perspex and the various sheets representing different planes fixed together to make a three-dimensional model. In Dr Butement's method, involved computations are required to compute directions representing the intersections of pairs of half-cones. It is by no means clear after this is done how the results can be plotted in three dimensions or otherwise presented so as to allow geological interpretation.

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APPENDIX 2

Theory and practice of the Controlled Directional Reception seismic method

L.A. Riabinkin, I.V. Napalkov, V.V. Znamenski, I.N. Voskresenski and M.B. Rapoport, Gostoptechizdat, Moscow, 1962

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Translated by C.S. Robertson

Note: Russian text held by BMR library. Literal translation of Preface, Introduction, Chapter 1 and Chapter 3 also held by BMR Library.

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CHAPTER 3 - PARTICULARS OF FIELD OPERATIONS WITH THE CDR METHOD

Literal translation by Commonwealth Department of Immigration

Revision of text by A.R. Brown

At present the controlled directional reception of seismic waves has been developed basically with regard to reflected waves, and that is why the method of CDR field observations is in many ways similar to that of MRW (Method of Reflected Waves) or normal reflection shooting. However, conducting field work by the CDR method has certain merits: in the application of reproducible records, and also in the interpretation of CDR results. Very careful selection of shooting parameters is important; observation systems differ slightly, especially the introduction of elevation and weathering corrections.

15. Conditions of Excitation and Reception of Vibrations

The success of work conducted by the CDR method depends largely on the selection of proper conditions for the shot and receivers. This involves choice of depth of shot, selection of directional increments in the reception of vibrations, and choice of parameters of the recording equipment.

Disturbing Role of Intense Low-velocity Interference. The possibility of generating intense, low-frequency interference waves at the time of the shot must be completely eliminated. Notwithstanding the marked difference between the apparent velocities of surface waves and useful waves, their superposition has an adverse effect on the results of the CDR method because of the great intensity of the surface waves. A superimposed intense interfering wave makes difficult the separation of weaker useful waves on the summed record. This is because the non-optimum summation of an interference wave may yield a more intense maximum than the optimum summation of a useful wave. In one case an interference pattern may appear on the summed record, in another the useful waves may not appear at all.

p.168 Figure 95 shows some results of summing of laboratory recordings, partly borrowed from work (58, p. 153) and illustrating the disturbing role of the intense interference waves.

Fig. 95a shows a superposition on reflected waves, R', R'' and R''', having infinite apparent velocities, of two low-velocity interference waves, L_1 and L_2, with velocities of 500 and 400 m/s. This form and relative intensity of the reflected and the low-frequency wave was obtained with two-dimensional modelling.

The result of summing recordings with equal weights is shown in Fig. 95b. Reflected wave R' is showing only weakly on the summed record in the superposition zone; waves R'' and R''' are distorted and weakened by the effect of the noise, produced by the non-optimum summation of the low-frequency waves. It should be noted that the summations of some of the noise events resemble summations of useful events. In Fig. 95c the corresponding summed record is shown, obtained with the application of the triangular weighting distribution. As is known (88), this method of summation is used in order to separate one maximum from the side lobes of other maxima. The

reflected waves on Fig. 95c are not separated on the summed record;
p.169 consequently the use of summing according to the triangular law does not seem to be the proper means of discriminating against the intense, low-frequency, interference waves.

Means of Supressing Low-velocity Interference. When obtaining the first seismic recordings it is essential to attenuate intense low-velocity interference waves. To do this, as is generally known, the depth of the shot is increased and also the detectors are grouped more closely together.

Even when summation is not used, it is recommended that two or three detectors are used per channel to average the conditions of positioning of seismic receivers.

A long spread of receivers is not recommended with the CDR method. However, in certain cases, in regions with small dips and in the presence of many interference waves, which are more intense than the reflected waves and have greater apparent velocities, a long spread is advisable (59). In this way the relative amplitude of reflected waves and interference waves is changed and it becomes possible to increase greatly the number of useful waves visible on the summed record.

Parameters of the Recording Equipment. The choice of field filters is made during experimental work, and very often the best filters for CDR are those which are optimum for use in normal reflection shooting on the same traverse. Also, when assessing the effectiveness of different field filters, examination of summed records may help in the choice of optimum filters during ordinary seismic reconnaissance, because the understanding of the interference wave pattern will indicate objectively the best means of suppressing different interference waves by frequency filtering.

During recording it is necessary to use the semiautomatic amplitude regulators. The application of AGC is undesirable. We know that during ordinary seismic reconnaissance the effect of AGC can lead, on the one hand, to suppression of weak, useful waves and on the other hand to the averaging out of significant amplitude variations. In this way it may be impossible to distinguish recorded waves of basically different intensity, and their dynamic characteristics are in large measure lost. Just as the effect of AGC during ordinary seismic reconnaissance can lead to suppression of weak waves that follow intense ones, in the CDR method, with the object of resolving waves superimposed or very close in time, the weak waves after AGC action will be more suppressed and their summation thus distorted.

Notwithstanding this, it is sometimes necessary to apply AGC, in so far as it is connected with ERU(?) on the new seismic stations. It is then very important to choose the AGC parameters that will give the least wave distortion.

Mixing is not recommended, especially when working with the CDR method in complicated areas where superimposed waves with small apparent
p.170 velocities are recorded. Use of common mixing with a large coefficient (higher than 25%) is not permissible.

16. Observation Systems

Size of Summation Base. The peculiarity of the CDR system of field operations is that it consists of a continuous line of short observation elements, δx, called summation bases, that is spreads of receivers, each of which will contribute to one summation. The time of arrival of a wave on the summed record is measured to the centre of the base, the same as for a group of seismic receivers. The difference in time of arrival of a wave at receivers at opposite ends of the base, δt, characterizes the apparent velocity, v_K, of the progress of the wave along the base (spread):

$$v_K = \frac{\delta x}{\delta t} = \frac{(n-1)\Delta x}{\delta t} = \frac{\delta x}{(n-1)\Delta t} = \frac{\Delta x}{\Delta t}$$

where n is number of summed channels, Δx is distance between adjacent receivers, Δt is increment in time of arrival of wave at adjacent receivers.

Choice of the dimensions of the summation base is very important. It depends on the frequency composition of the available signal because the directional characteristics are determined by the size of the base and the observable wavelength. To record waves within the medium frequency band the base is usually in the range 120-200 m, within the low frequency band 400-800m, and within the high frequency band 60-120m. Nine receivers are laid out on the summation base at equal intervals.

The base should be such that the wavefronts recorded within its boundaries can be considered as flat. This imposes a limit on the size of the base.

The size of the summation base influences the resolving power of CDR with respect to the direction of waves falling on the base. Therefore, the base should be chosen as large as possible, consistent with the wavefronts falling within its boundaries appearing flat. Nevertheless, under certain conditions and when the summation base is too large, the curvature of the wavefront is significant, which has an adverse effect on the final results of summation. It is important to take into account wavefronts from the side when recording waves from non-reflecting boundaries.

As a result of numerous experiments with the CDR method in different regions, an optimum size for the summation base was established, which is of the order of 200 metres for the medium frequency band. Experiments carried out in Actubinskoe Priurale and Saratovskoye Zavolzhe with bases larger than 200 metres for a band of the same frequency have shown
.171 that they are unsuitable; on the other hand a reduction of the base to 160 metres and sometimes even to 120 metres in some regions (Southern Emba (59), Bashkiria) gave favourable results. These examples show that it is necessary, when working in a new area, to first carry out experiments to determine the best size of summation base.

Size of Shot-point Interval. Because the length of the base is predetermined it is necessary to choose a shot interval that will be suitable for all summation bases in a given area, and it is also desirable that the central seismic receiver of one base is always at the shot-point. The recording of waves over reciprocal paths is useful in the interpretation of CDR data because it makes it possible to relate the times of waves recorded at the seismic receivers which are situated at shot-points. If the conditions of work do not allow the preservation of shot-point interval for all the summation bases, it is possible to use overlapping summation bases such that the central detector is at the shot-point. It is also important to ensure that the relative positions of the first and last detectors on the summation base are always the same. The first seismic receiver is usually placed to the south or west, the last one to the north or east. This ensures correct determination of the time increment along the base by the mere direction of arrival of waves.

The size of the shot-point interval depends, with the CDR method, on two factors: geological peculiarities of the region and specific peculiarities of the CDR method itself. Let us consider the influence of each of these factors.

It has been established that the degree of complexity of a seismic recording, because of the superimposition of a great number of interference waves on useful reflected waves, grows with increase in distance between shot and detector. This first of all leads to deterioration of resolving power of the CDR method; secondly, because of the great number of separate waves on the summed record, the process of identification of waves reflected from significant horizons amongst the interference waves becomes more complicated. The degree of complication of a seismic record, under different geological conditions, varies differently with shot-point interval. It is therefore necessary to choose the optimum size of shot-point interval in every region on the basis of experimental results. An optimum shot-point interval is considered to be one which will yield the best recording conditions and, following wave separation with the help of CDR apparatus, the best reflection quality on significant horizons. Such a shot-point interval will produce the most simple summed records (the number of waves separated by the CDR apparatus is not great, but their correlation from one record to another
p 172 is most reliable). With more complicated geological conditions the size of shot-point interval must be less. For instance, when working with the CDR method in Aktubinskoe Priurale, the optimum shot-point interval on the fold slope is considered to be 400 metres, and in parts adjoining the anticline 600 metres. In the most complicated conditions of Bashkirskoe Priurale the optimum shot-point interval is 200 metres.

Choice of Observation Systems. CDR field work is carried out along longitudinal and non-longitudinal profiles, that is with detectors laid out in line with or transverse to the traverse.

On longitudinal profiles, with which the bulk of CDR work is being done, the same systems of observation are applied as in normal reflection shooting. Observation system should be chosen on the basis of analysis of results of specially conducted experimental work. Nevertheless, on the basis of experience in the use of the CDR method in regions with varied geological conditions, it is possible to offer the following recommendations for the choice of observation systems:

1. In work following the most simple system of continuous profiling, three-hole patterns may well be used on traverses where comparatively simple conditions are expected: comparatively simple summed records, small number of separate waves, and easy correlation of waves to form a cross-section. Such traverses may be, for instance, adjoining parts of anticlinal folds, where superimposed waves are comparatively not so numerous, or in regions with calm tectonics, but where there is observed superimposition of useful waves of a certain type (for example, separable reflected refractions).

2. In the case of complicated summed records with many intersecting events and when difficulties arise in the correlation of waves and the construction of cross-sections, using the most simple system of observation, it becomes necessary to use a pattern of two lines of five holes. Traverses with complicated wave pattern may be observed in regions where seismic boundaries are not of great extent or have a complicated form (e.g. summits of folds with intricate structure, zones of disjunctive faults), and where non-reflecting boundaries occur (e.g. erosion surfaces, boundaries of shelves, ore and saline cores, foundations of platforms, corrugated layers in fold regions, flat boundaries of a steep angle unconformity or facial irregularity with abrupt changes of elasticity along interfaces).

The application of double profiling on such lines permits wider variation of the relative positioning of shot and detectors, as a consequence of which favourable conditions for the generation and recording of useful waves may be created. Besides, during the resolution of superimposed waves by the CDR method, the relationship between the phases of superimposed waves is of great importance. The resolution of waves improves when the superimposed waves arrive at the central seismic receiver with a certain delay in relation to one another. Varying the relative position of shot and detectors may prove
p.173 favourable for the resolution of such superimposed waves.

In cases when the wave pattern is simple and the number of superimposed waves is not great, it is necessary to replace complicated systems of observation by simpler ones.

<u>Non-longitudinal Observations</u>. Non-longitudinal observations are set up on short profiles whose length equals the length of the summation base so that the centres of bases of longitudinal and non-longitudinal profiles coincide to form so-called crosses. The basic value of non-longitudinal profiles lies in the examination whether the paths of waves used for interpretation lie in the vertical plane of the longitudinal profile. At the same time the crosses may be utilized to supplement information on the structure of the region, that is by making use of spatial interpretation. Non-longitudinal profiles are situated around shot-points, and observation on them is carried out with shots situated at their centre, and also at remote points of the longitudinal profile. To check if the recorded waves lie in the vertical plane of the profile, the summed records are used from such observation crosses. From them corresponding waves are compared. If the time increment of a wave arrival, determined on a non-longitudinal summed record, equals zero, then the above requirement is fulfilled. In the contrary case, when $\delta t \neq 0$, the path of the wave lies in a plane inclined to that of the profile. With a medium velocity of wave

propagation, e.g. 3,000 m/s, the time increment δt of arrival of a wave whose path lies in a plane inclined at an angle of no more than 10 degrees from the perpendicular, will be about 9 milliseconds. If the profile lies along the strike of the rocks there are many waves that have on summed records from non-longitudinal bases, time increments within the range 0-9 milliseconds; waves whose time increments are greater than 9 milliseconds, and where a longitudinal profile is also involved, must be excluded. The importance must be stressed of comparing corresponding waves on longitudinal and non-longitudinal summed records obtained from the one shot; it is therefore necessary to strive to obtain two records simultaneously on both intersecting bases, longitudinal and non-longitudinal.

17. Introduction of Static Corrections During Summation

The introduction of corrections for surface conditions (elevation and weathering), when working with the CDR method, has not received until recently its due share of attention. Field work used to be carried out in regions of small elevation changes and consistent weathering along the profile. When sharp changes of surface conditions within some bases led to the complexity of summed records, they could be excluded from interpretation because of their small numbers, sometimes even without explanation of the causes of their complexity. But with a general application of the CDR method arose
p.174 the necessity to work in regions with not only complicated geological conditions at depth, but also with complicated surface conditions. In such cases introduction of corrections is essential. Introduction of these corrections is provided for by the construction of a summation block. Corrections are introduced by the relative displacement of summing slits.

Characteristics of Directional Summation of Waves with Non-linear Phase Axes. The problems of summation and resolving power of the CDR method were examined above.

The influence of surface conditions during reception of flat waves is analogous to the introduction of various time delays into the traces, which leads to the examination of the summation effect of waves with non-linear phase axes.

In work (58) general correlations are given and the influence on CDR recordings of time distortions of phase axes within the limits of the summation base is shown quantitatively by several examples. The bending of a phase along a base brings about distortion of the characteristics of directional summation. Fig. 96 shows the characteristics of directional summation of an impulse wave using nine channels. It shows the instantaneous directional characteristics for an impulse whose shape is that of a half period of a 50-Hz sine wave (I) and instantaneous directional characteristics for the same wave (II, III, IV), distorted by time displacements, which are expressed by the corresponding functions a, b, c. The following peculiarities of characteristic distortion by time displacements stand out:

1. The ordinate of the central maximum is decreased; in cases III and IV it only reaches 5.

2. The ordinate of the first secondary maximum in case III is considerably increased.

3. Marked increase in the amplitude of the first secondary maximum appears to one side of the central one (II and III).

4. In case III the central maximum is shifted considerably along the abscissa.

5. The central maximum of directional characteristics is extended
p.175 along the abscissa (II and III) and can become split (IV), in which case the concept of central and secondary maxima of directional characteristics becomes lost.

It becomes clear from the characteristics above that the introduction of delays into channels diminishes the amplitude after summation and thus influences the resolving power of CDR. Summation maxima may be seen on a greater number of summed traces than suggested by the theory of flat waves. Not just one, but several (2 or 3) summation maxima on the summed record may result from the same wave, and they can be in phase or in anti-phase with each other.

We shall demonstrate some of these situations directly on the summed records. Figs. 97-100 show samples of summed records obtained on traverses with variable elevation and weathering while working with the CDR method in Bashkiria.

1. Summation maxima on summed records are "doubled" (fig. 97a); for every time interval corresponding to one flat wave there appear two waves. This case corresponds to curve IV in fig. 96 and is a most frequent
p.176 type of distortion on summed records caused by surface conditions.

2. Summation maxima on summed records are "trebled" (fig. 98a); there are three waves visible for each time interval.

3. Waves at small time intervals hardly show at all (fig. 99a), whereas at large time intervals they have long phase axes with large phase distortions. This case corresponds partly to curve III in fig. 96 and the difference in wave distortion for different time intervals is explained by the difference in curvature of reflected waves coming from different depths.

4. There is not a single wave (fig. 100a) on the summed record that achieves the maximum amplitude.

These examples prove the important fact that the great complexity of summed records is not always connected with great complexity of wave pattern resulting from geological conditions at depth, so that the interpreter who is about to plot the structure on a cross-section from a complicated summed record must be sure that this complexity is not caused by surface conditions. One of the signs of distortion by surface conditions is the uniform character of the distortion of all waves on the summed record. In many cases signs of such distortions are obvious on the summed records.

p.177 Let us now consider the methods of application of corrections.
This process can be divided into two operations. First, introduction of
so-called static channel corrections into every channel so as to cause the
front of the oncoming wave to be flat. When doing this, the relative delay
at opposite ends of the summation base is taken as zero. Second, introduction
of corrections for the general incline of the base to the reflecting horizon.
We will examine them separately.

For the introduction of static channel corrections it is necessary
to know the elevation profile, and the extent of the weathered layer and its
velocity. Most frequently the weathering is determined by the method of first
breaks or by seismic coring of shot-holes. A complete study of weathering
leads to a great increase in the cost of the work, and, as there are usually
fairly large intervals between such complete weathering determinations, the
interpolation between determinations involves errors, especially in cases of
complicated weathering structure. Weathering depth and velocity of elastic
waves are not exactly determined by a complete weathering study. That is
p.178 why, notwithstanding the successful use of such weathering study data (58,
page 131), there were cases when, after the corrections, the summed records
became quite uninterpretable. Therefore, simple methods of continuous
elevation and weathering determination are preferable.

<u>Determination of Static Channel Corrections.</u> For determination of static
corrections it is common to use first breaks on seismic records, obtained at
the same time as seismic films (95). A benefit of this method is the fact
that data from repeated observations may be used.

Let ABC and A'B'C' represent the elevation and base of weathering
profiles for summation bases δx_1 and δx_2 (fig. 101). The shot occurs in
the middle of base δx_1 below the base of the weathering. In this case the
time of arrival at the detectors of the direct wave coming from the shot at
point O will vary as a result of changes in elevation and weathering
approximately in the same way as the times of arrival of reflected waves
coming from depth. We shall find time corrections, which shall be applied
to the summing slits, supposing that the elevation and base of weathering are
p.179 flat and correspond to straight lines AB, BC and A'B', B'C'. We will make
the usually accepted assumption that rays from the base of the weathering are
travelling vertically, and we shall find time corrections for each channel
directly from the seismograms by determining the deviations of the elevation
and base of weathering profiles from straight lines connecting the ends of
bases. To do this, straight lines are drawn on seismograms joining the first
breaks of first and ninth channels (considering distances between detectors
to be equal) and the difference in time for every channel between the first
break and the straight line are found. These are the corrections which it
will be necessary to introduce into every channel when summing. It should be
noted that it is not always possible to use the correction method just described,
because of the condition that the shots must occur below the weathering at
considerable depth. If the first breaks are caused not by the direct wave
but by one refracted by a shallow boundary, then, by making use of the

linearity of the time-distance plot, the static corrections may be deduced in the same way. The only exception is in those regions of first breaks where interference of waves occurs. It is important not to confuse them with regions where distortions are introduced by surface conditions; because of this, it is important to construct first-break plots.

The methods used in Bashkiria satisfy these conditions; here the shots occur below the weathering at depths of 50 to 60 m, while the length of one branch of the time-distance plot is up to 500 m. That is why in Bashkiria corrections for surface conditions are introduced during professional work according to the described method. Examples of summed records after application of static corrections are shown in figs. 97b - 100b. From the appearance of the records (compared with figs. 97a - 100a) a simplification of wave pattern is seen; these summed records are further utilized for interpretation.

<u>Introduction of Corrections for Slope of Summation Base.</u> The question of corrections for general slope of base, i.e. detector spread, considering that elevation and base of weathering are flat within the limits of the base, was dealt with in work (9). It presumes that the structure of the weathering and velocities v_o and v_1 are known. Then the final correction for slope of the base is given by the sum of corrections $d(\delta t)_p + d(\delta t)_R$ for base of weathering and elevation respectively.

These corrections are calculated with the help of the following formulae:

$$d(\delta t)_p = \Delta L\sqrt{\left(\frac{1}{v_1}\right)^2-\left(\frac{\delta t}{\delta x}\right)^2} \quad ; \quad d(\delta t)_R = \frac{\Delta H}{v_o}$$

p.180 where ΔL is difference in height of the base of the weathering at the ends of the base, δt is measured time increment along the base, ΔH is elevation difference between the ends of the base.

This correction is introduced by a displacement of the zero time increment line ($\delta t = 0$) on the summed record up or down.

If the value δt in the CDR method is taken as positive and if a wave arrives earlier at the first detector, then the correction sign is positive when the value ΔL represents the difference in height of the first seismic receiver over the position of the last. And the channel correction convention is such that waves recorded with a positive δt are displaced on the summed record above the zero line, whereas those with negative δt below it. Total correction is equivalent to the algebraic sum of both corrections.

If the static channel corrections were determined from first breaks on seismograms, while velocities v_o and v_1 were unknown, then determination of the total correction for slope of elevation and base of weathering is possible only for positions where there was at least one central base during the running of the profile. If elevation and base of weathering are horizontal,

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the times of arrival of direct waves at the extreme receivers of the central base must be equal. Any difference between such times gives a correction which must be introduced into the zero line of the summed record. The same correction can then be introduced into summed records obtained from the same base but with different shot-points. This method was successfully used in Bashkiria, because the shot-point interval was 200 m, i.e. shots occur in the centres of all bases.

Because the introduction of channel corrections into summing slits leads to distortion of the zero increment impulse (line $\delta t=0$) on the summed record, it is recommended that the following procedures be followed for finding the maximum amplitude of the zero impulse:

1. To sum the seismic film twice: without corrections and with corrections. During this the pencil of the summator follows each time right to its limit hard against its rest, and fixes a uniform position. The zero line, $\delta t=0$, is then brought over from the initial summed record to the one with corrections.

2. To fix to the starting part of the film drum of the summator a screen of opaque material with seven triangular teeth facing the central channels; first and ninth channels stay uncovered. This means that the seven central channels in their initial part do not get summed by the light-beam, because of the opaque part of the drum, whereas the side slits leave on the summed record two rows of impulses, crossing each other on the line $\delta t=0$.

Example of Effectiveness of Introduction of Corrections. An example is shown of a plot of one of the CDR profiles (Krasnodar region), where the channel corrections were calculated from first breaks on the seismic records and the corrections for the general slope of the base were determined from known weathering velocities. It became clear from the examination of summed records
p.181 and the first breaks on the seismic records that it was necessary to introduce channel corrections on two bases only, shown by thick lines in fig. 102. On summed records for these two bases without introduced corrections, waves were isolated satisfying all features of waves in CDR, however, their corresponding reflection segments, shown by wavy lines in fig. 102, are spread without order over the cross section. Here also are shown reflection segments from corrected summed records. They appear along the boundaries already delineated from other bases, where the introduction of corrections was not necessary.

Fig. 95. Seismogram (a) with superimposition on weak reflections R of intense, low-velocity interference L, and summed records, with equally-weighted (b) and non-equally-weighted (c) summations.

Fig. 96. Instantaneous directional characteristics of the summation of an impulse wave. I - flat wave; II, III, IV - same wave, but with delay functions, corresponding to time displacements a, b, and c (according to (58)).

Fig. 97. Summed records.
a - without corrections for elevation and weathering;
b - with corrections (in ms) for six channels;
second channel -4, third -5, fourth -8, fifth -6,
sixth -4, seventh -3.

Fig. 98. Summed records.
a - without corrections for elevation and weathering;
b - with corrections (in ms) for two channels:
fourth channel +8, fifth channel +12.

Fig. 99. Summed records.
a - without corrections for elevation and weathering;
b - with corrections (in ms) for six channels:
third channel -6, fourth -10, fifth -12, sixth -10
seventh -10, eighth -6.

Fig. 100. Summed records.
a - without corrections for elevation and weathering;
b - with corrections (in ms) for four channels:
third channel +8, fourth +13, fifth +5, sixth +3.

Fig. 101. Illustration of the method of
determination of static channel corrections.

Fig. 102. Plot of CDR profile with introduced
corrections for elevation and weathering.
1 - reflection segments from bases that required
no corrections; 2 - reflection segments from bases
without corrections; 3 - reflection segments from
bases after introduction of corrections; 4 - bases
where corrections were introduced.

APPENDIX 3

Notes on the Migration Stack of Traverse 3-3N (Owen Springs)

by J. Wardell, Geophysical Service International, Sydney

These notes describe the results of Migration Stack (Plate 10) with reference to the Migration Nomogram (Plate 12).

Input Data. The input section (Plate 8) has been processed through static and dynamic corrections and time-variant deconvolution. Since it was evenly modulated and did not show excessive high-frequency noise, no further equalization or bandpass filtering was considered necessary before migration.

Migration parameters.

Aperture - 192 traces

Velocity function - Two-way Time (s)	Velocity (m/s)
0.0	3350
2.0	5150
4.5	6070

Comments.

1. Due to the 192 trace aperture, with an input section of only 168 traces, the migrated section is all taper-on or taper-off. This accounts for many of the odd features on the section.

2. The changes in character at 12-trace intervals (e.g. at 1.5 s, SP 323-325) are due to the inversity scaling where all traces in a sector are not live.

3. From 1.4 to 2.7s, SP 323-325 there are no genuine data, since all input events will migrate out of this zone due to their dip.

4. Above about 0.4 s, many of the sharply curved events are due to noise being "smeared" along wavefront curves.

5. In general, most of the data down to 1.4 s (e.g. R1) have migrated correctly. Character changes on the event at 1.2 s, SP 327 (R2), are again probably due to the inversity scaling of partly dead sectors.

6. The event at 1.5 s, SP 323 on input (R2) migrates to SP 324-327 and its apparent extension beyond these points may not be genuine.

7. The event of 2.1 s, SP 323 (R3) migrates to SP 325-327.

8. The output event at 2.0 - 2.05 s, SP 327-330 is mostly a "smear" of the short input event at 2.05 s, SP 328.

9. The output event at 2.25 s, SP 327.5 - 329 is probably genuine, at least over SP 327.5 - 328.5 and comes from the diffraction which peaks at this point on the input section (N5).

10. The stronger events in the 2.5 - 3.0 s zone are mostly "smears" of the short input segments (e.g. N6).

11. The very steeply dipping events (about 6-7 ms/trace) between 1.5 and 2.6 s at SP 323 (N1 to 4) are too steep (at this depth) to be migrated by this routine, and are severely attenuated by the stacking process. They show indicated dips in the 40^{o} - 50^{o} range and the deeper ones would migrate some 200 - 300 traces, that is completely off the section beyond SP 330, if the process were capable of handling this dip.

Plate 12 shows the half-aperture needed to migrate an event of given dip at a given time. Conversely, it shows the distance that an event of given time and dip will migrate. (This plot is computed for the velocity function shown.)

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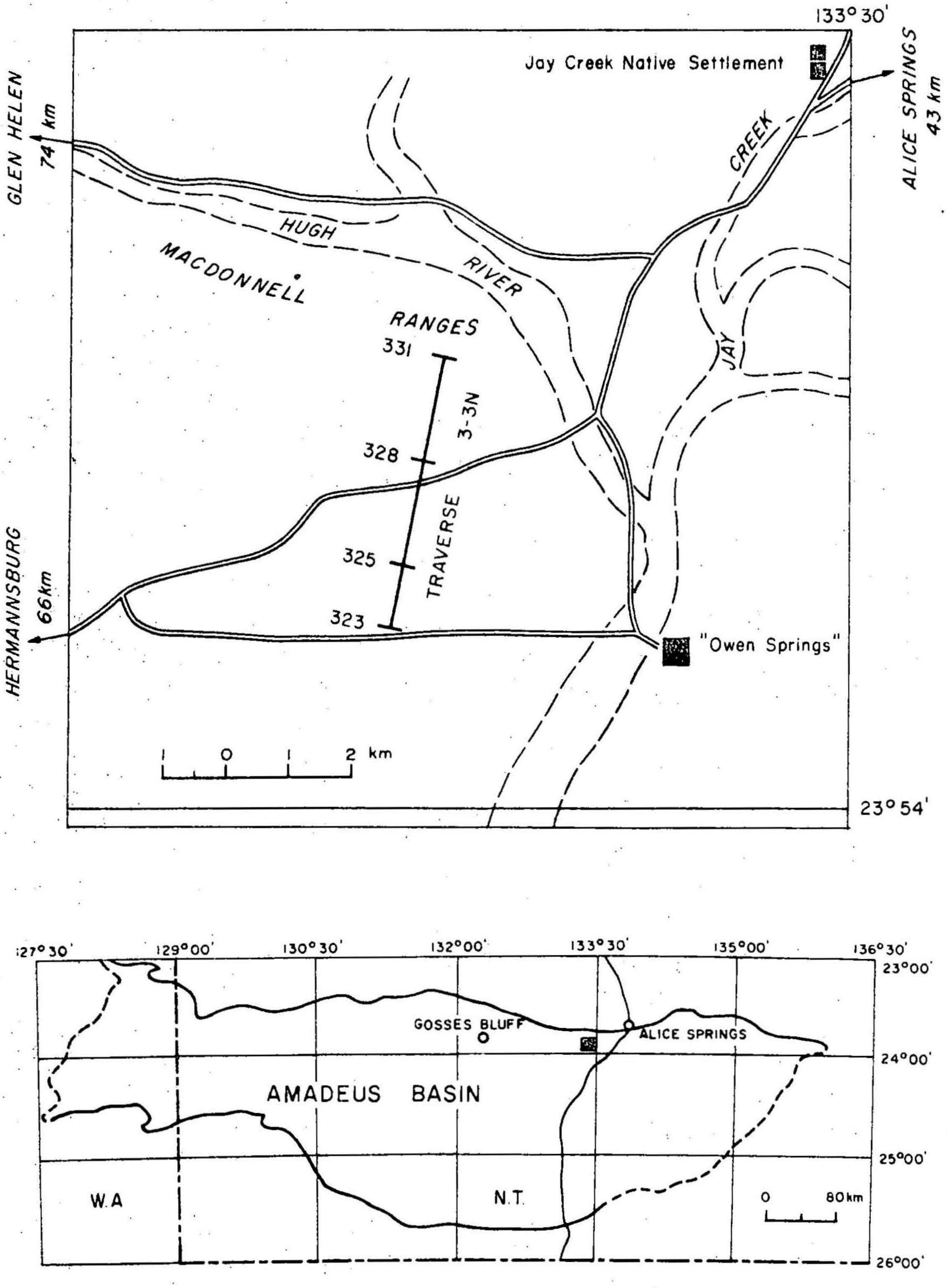
PLATE I



LOCALITY MAP
TRAVERSE 3-3N OWEN SPRINGS

To accompany Record No 1972/118

F53/B3-190A

To accompany Record No 1972/118

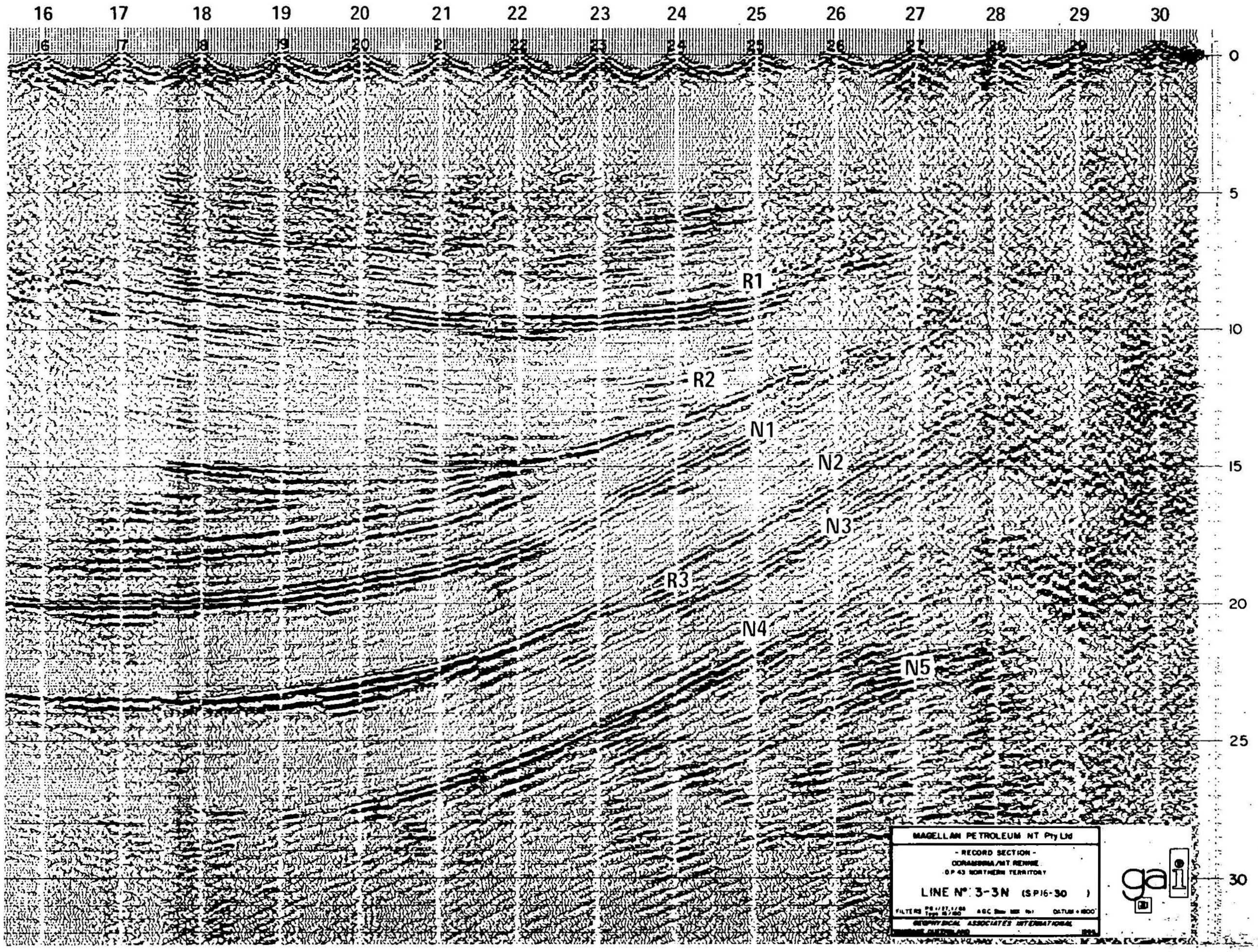
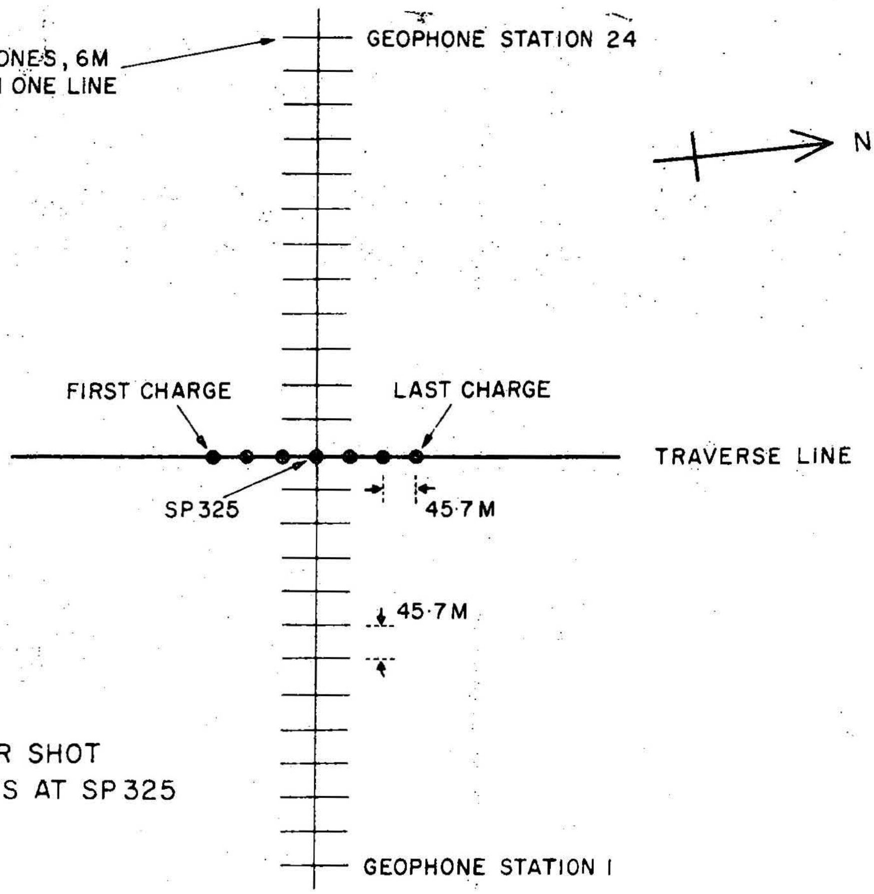


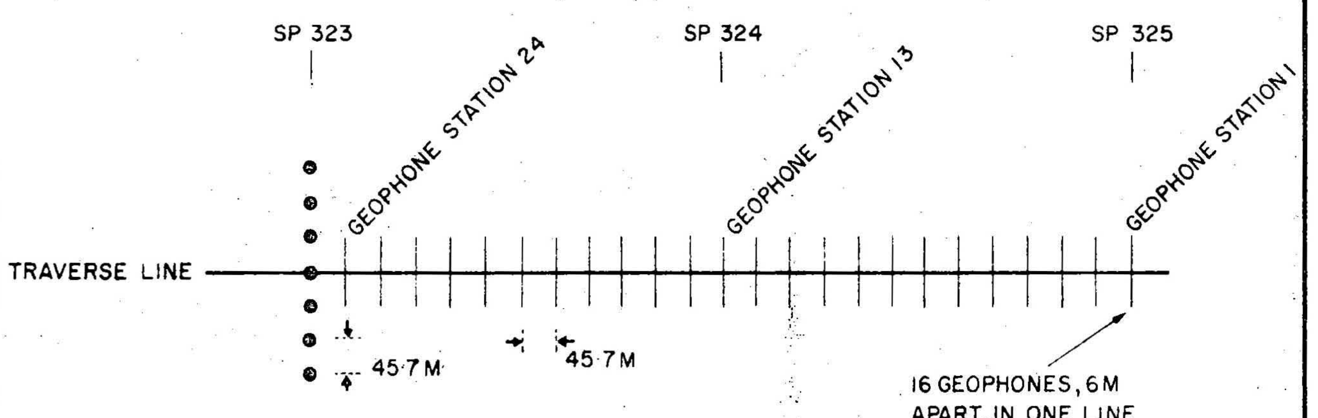
PLATE 2

F53/B3-197-1A

36



A. ARRANGEMENT FOR SHOT DELAY EXPERIMENTS AT SP 325



B. ARRANGEMENT FOR PROFILING, SHOT BETWEEN SPs 323 AND 329

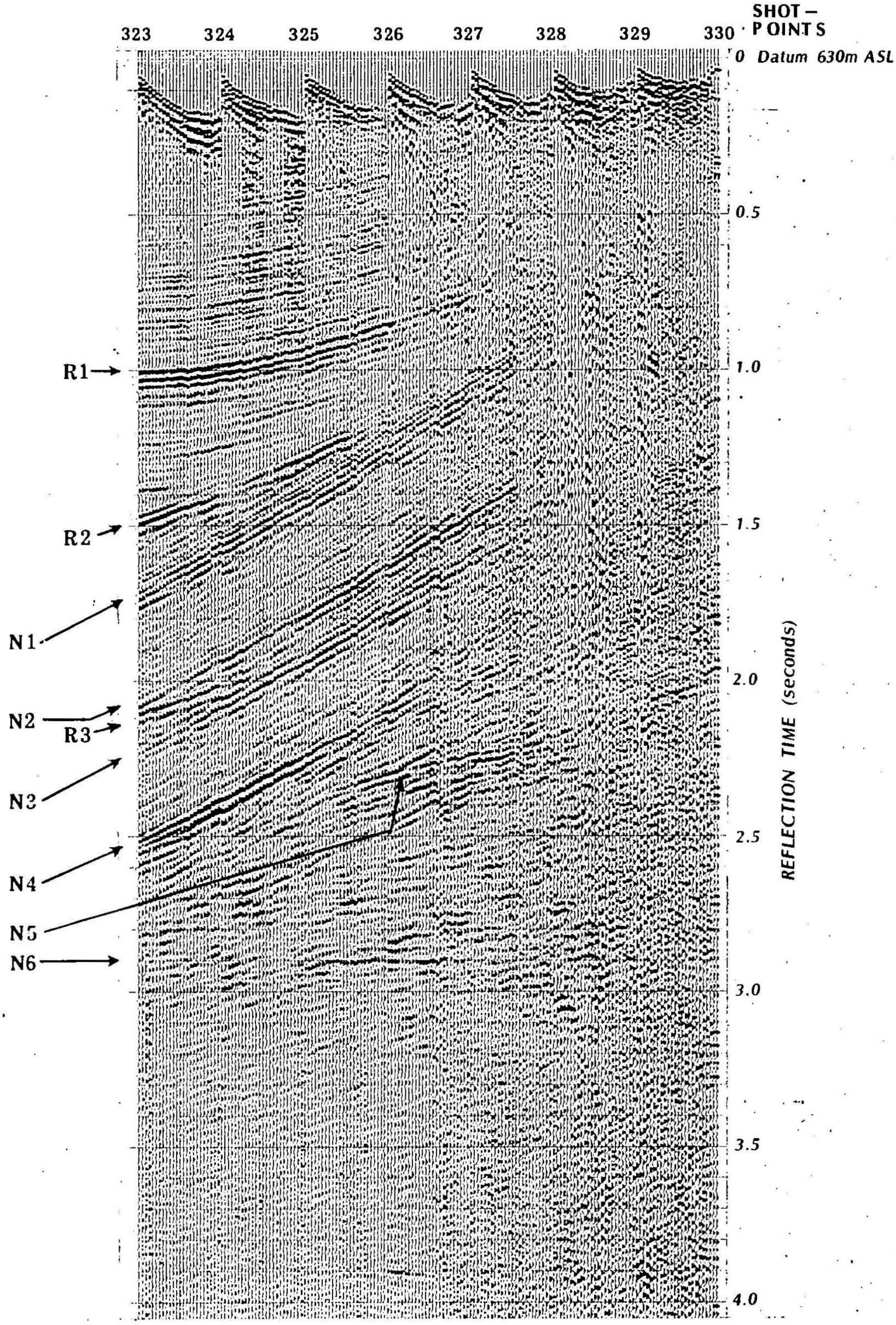
SHOT HOLE AND GEOPHONE ARRANGEMENTS USED ON TRAVERSE 3-3N, OWEN SPRINGS

To accompany Record No 1972/118

F53/B3-191A

PLATE 4

CORRECTED RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder: PMR-20

Amplifiers : PT-700

Prefilters : Out

Filters : L16-KK135

AGC : S

Gain Initial : -60/-50

Final : -10

Geophones : HS-J, 14Hz

Geophone Station Interval : 45.7m

Geophone Pattern :

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern :

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20-23m
Total charge 63-136kg

PROCESSING INFORMATION

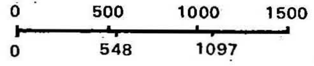
Analogue Processing by Bureau of Mineral Resources

Filter: LL20-KK78

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE (metres)



TRAVERSE 3-3N

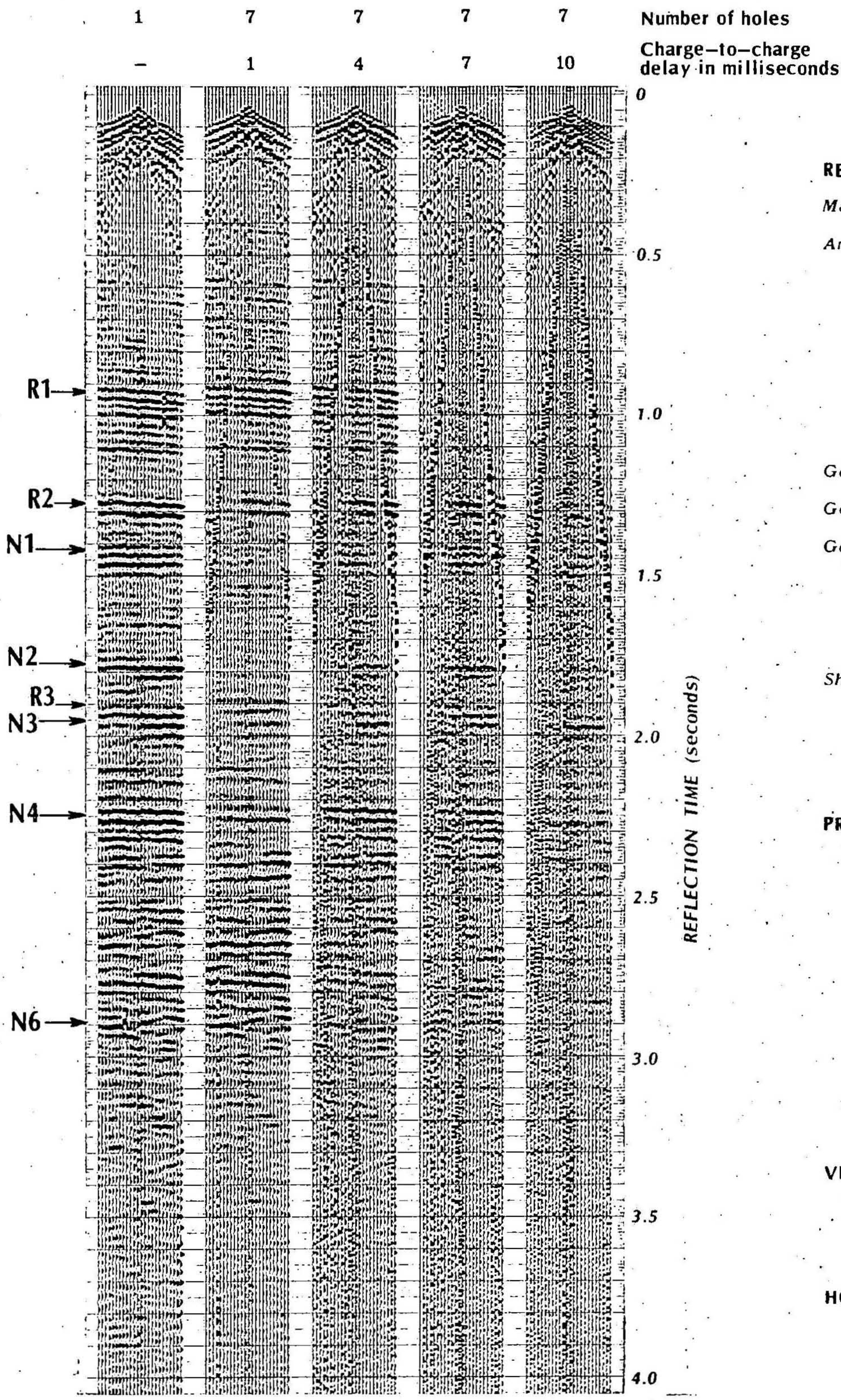
SPs 323-329

ANALOGUE PLAYBACK

38

To accompany Record No 1972/118

F53/B3-199A



CORRECTED RECORD SECTION
(Moveout only)

PLATE 5

RECORDING INFORMATION

Magnetic Recorder: PMR–20

Amplifiers : PT–700

Prefilters : Out

Filters : L16–KK135

AGC : S

Gain Initial : –60/–50

Final : –10

Geophones : HS–J, 14Hz

Geophone Station Interval : 45.7m

Geophone Pattern :

16/trace, 6 m apart, in line
Spread transverse
(See Plate 3A)

Shot Hole Pattern :

1 or 7 holes (as indicated), 45.7m apart, in line (See Plate 3A)

Depth 20–23m
Total charge 45–63kg

PROCESSING INFORMATION

Analogue Processing by Bureau of Mineral Resources

Filter: LL20–KK78

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE
(metres)

0 500 1000 1500
0 548 1097

TRAVERSE 3–3N

SP 325

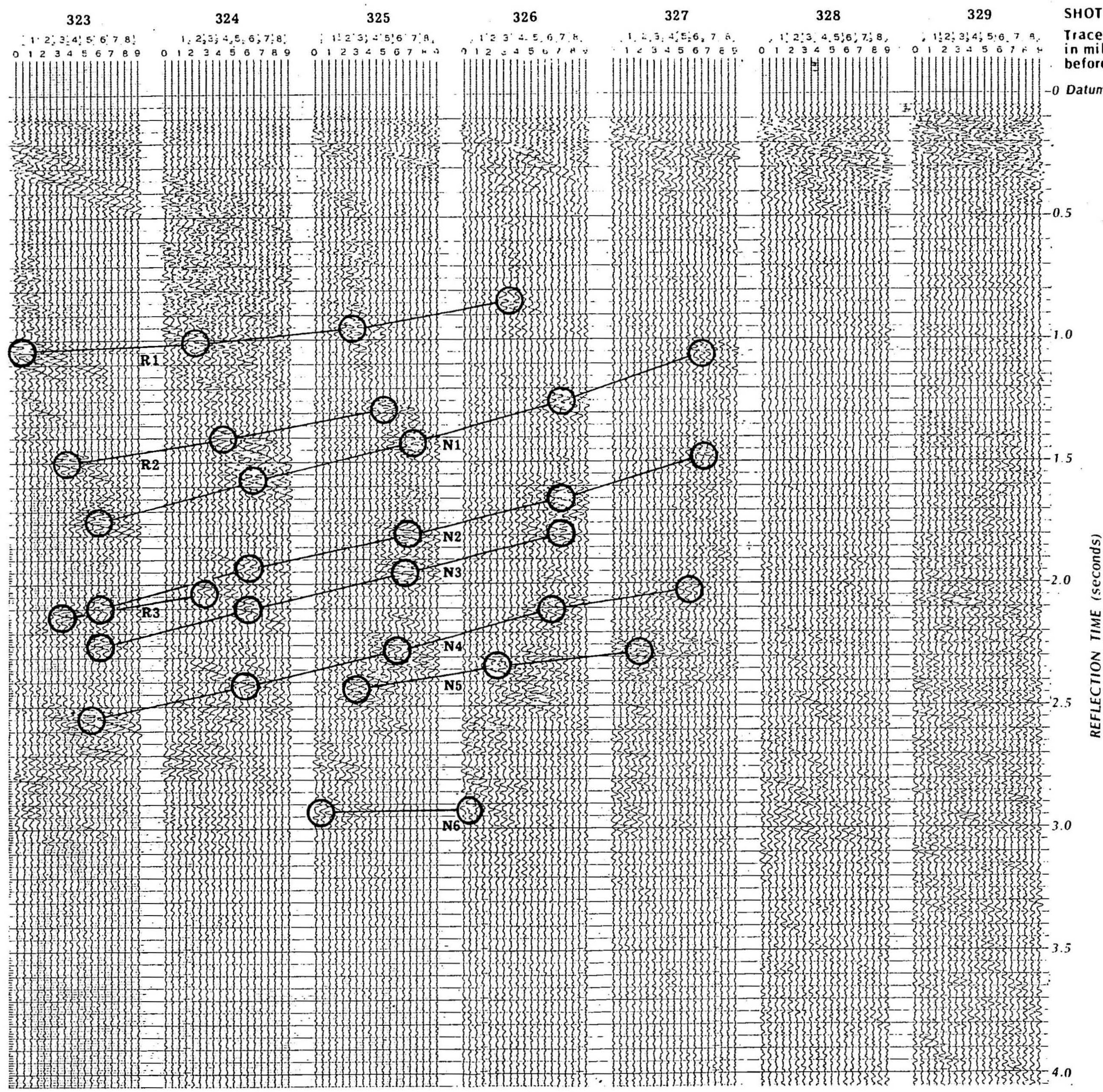
SHOT DELAY EXPERIMENTS

39

F53/B3–200A

To accompany Record No 1972/118

PLATE 6



CORRECTED RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder : PMR-20

Amplifiers : PT-700

Prefilters : Out

Filters : L16-KK135

AGC : S

Gain Initial : -60/-50

Final : -10

Geophones : HS-J, 14Hz

Geophone Station Interval : 45.7m

Geophone Pattern :

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern :

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20-23m
Total charge 63-136kg

PROCESSING INFORMATION

Analogue Processing by Bureau of Mineral Resources

24-trace summation after introduction trace-to-trace delays as indicated

Filter: LL20-KK78

VELOCITY INFORMATION

Analysis of dynamic misties

TRAVERSE 3-3N

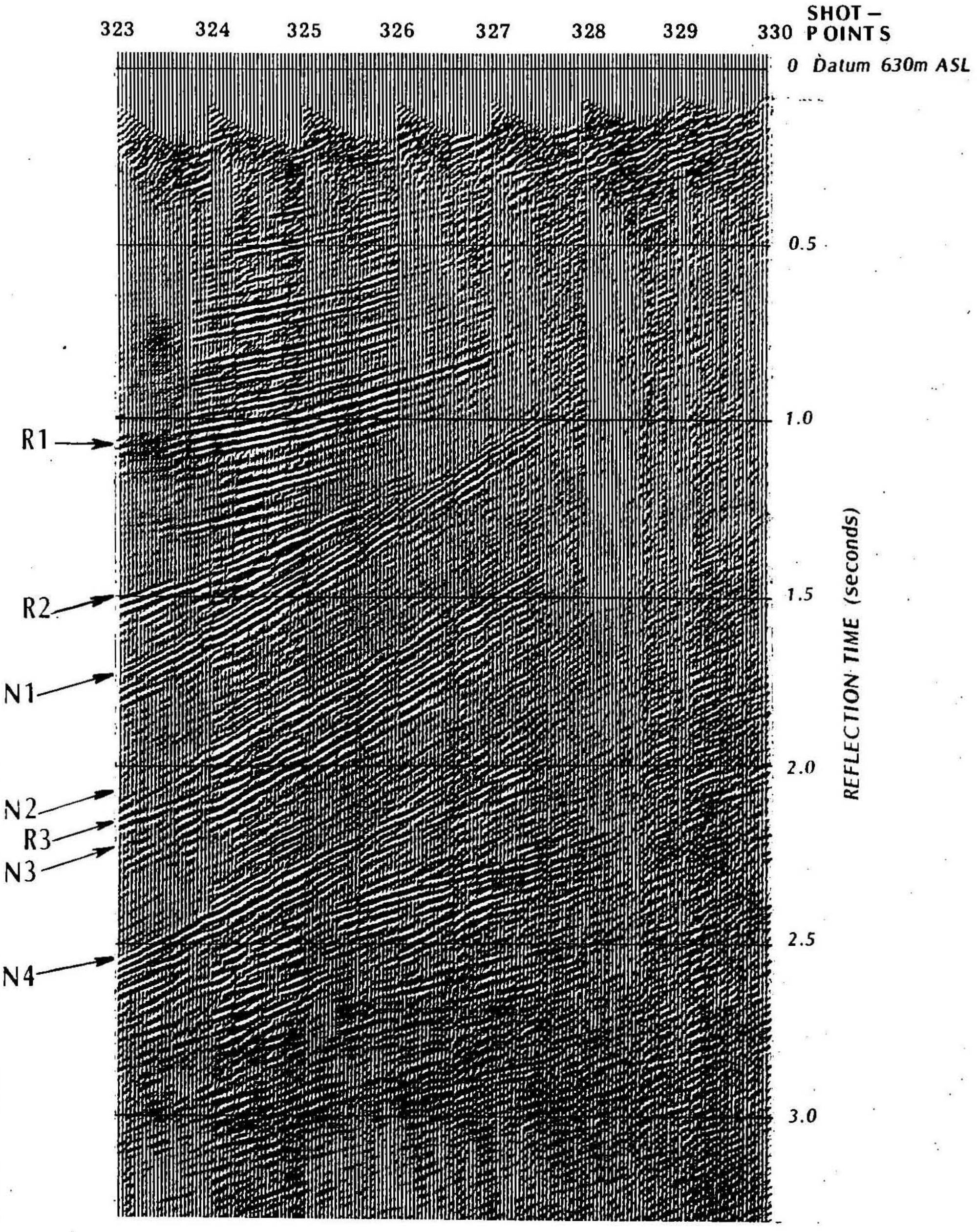
SPs 323-329

TRACE SUMMATION

40

To accompany Record No 1972/118

F53/B3-201



CORRECTED RECORD SECTION

PLATE 7

RECORDING INFORMATION

Magnetic Recorder: PMR–20

Amplifiers : PT–700

Prefilters: Out

Filters : L16 –KK135

AGC : S

Gain Initial: –60/–50

Final : –10

Geophones: HS–J, 14Hz

Geophone Station Interval: 45.7m

Geophone Pattern:

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern:

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20–23m
Total charge 63–136kg

PROCESSING INFORMATION

Optical Processing by Bureau of Mineral Resources

LaserScan Spatial Filtering (90° stop wedge)

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE (metres)

0 500 1000 1500
0 548 1097

TRAVERSE 3 – 3N

SPs 323–329

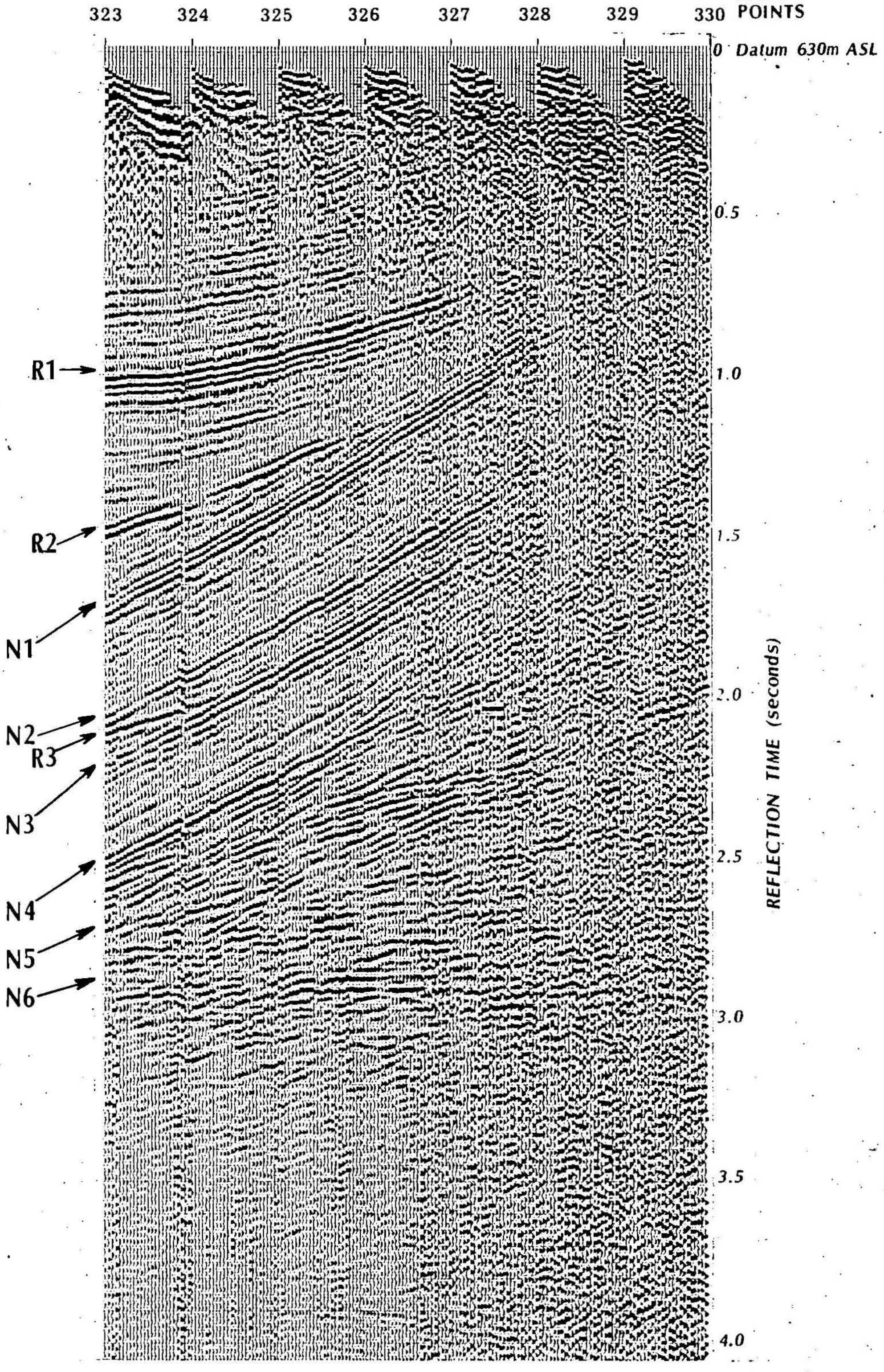
LASERSCAN SPATIAL FILTERING

41

To accompany Record No 1972/118 F53/B3–202A

CORRECTED RECORD SECTION

PLATE 8



RECORDING INFORMATION

Magnetic Recorder: PMR-20

Amplifiers : PT-700

Prefilters: Out

Filters : L16-KK135

AGC : S

Gain Initial: -60/-50

Final : -10

Geophones: HS-J, 14Hz

Geophone Station Interval: 45.7m

Geophone Pattern:

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern:

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20-23m
Total charge 63-136kg

PROCESSING INFORMATION

Digital Processing by Geophysical Service International

Time-variant Deconvolution (30 point)

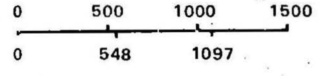
Filter: 20-50 Hz

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE

(metres)



TRAVERSE 3-3N

SPs 323-329

TIME-VARIANT DECONVOLUTION

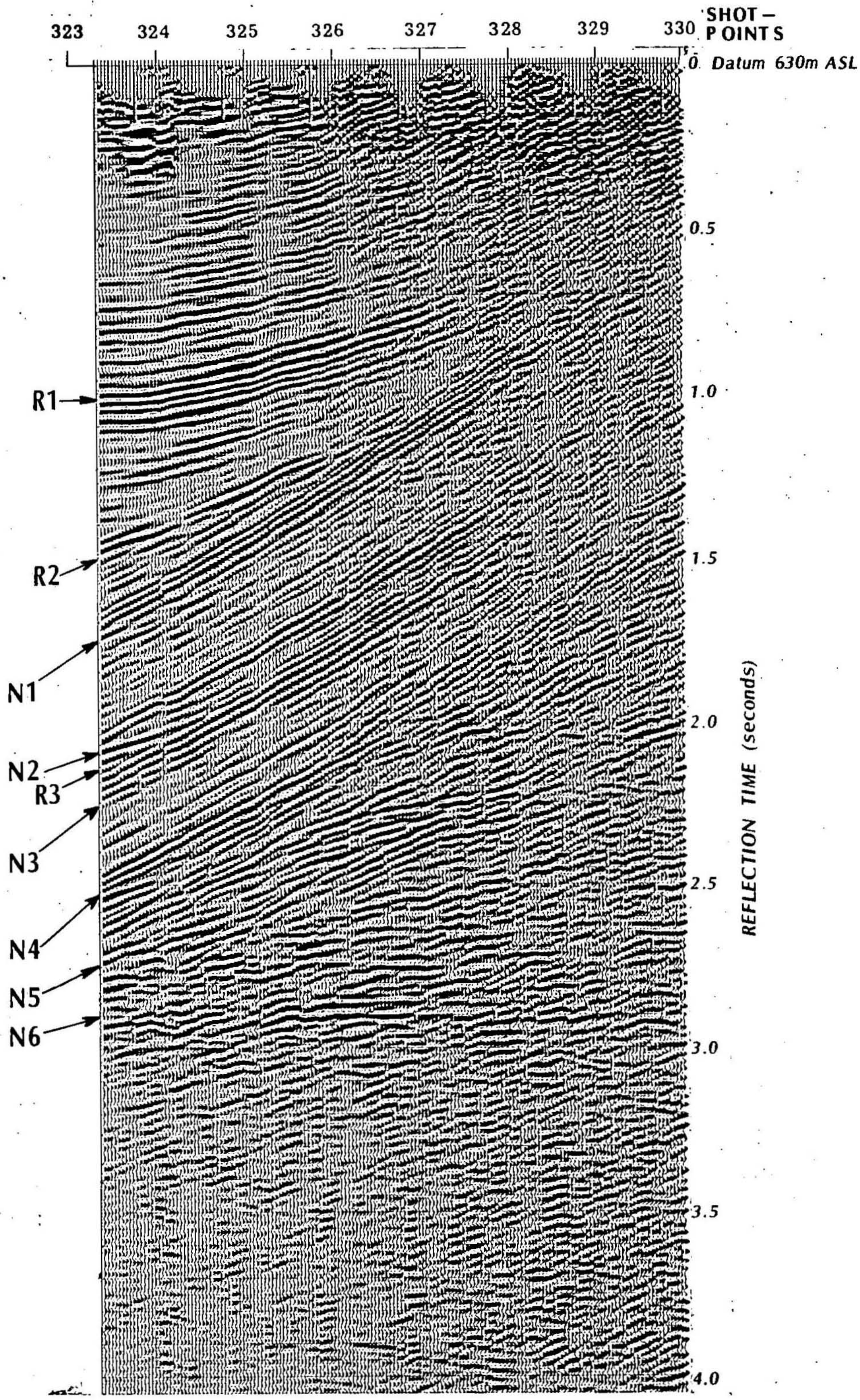
42

To accompany Record No 1972/118

F53/B3-203A

CORRECTED RECORD SECTION

PLATE 9



RECORDING INFORMATION

Magnetic Recorder: PMR–20

Amplifiers : PT–700

Prefilters: Out

Filters : L16 –KK135

AGC : S

Gain Initial: –60/ –50

Final : –10

Geophones: HS–J, 14Hz

Geophone Station Interval: 45.7m

Geophone Pattern:

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern:

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20–23m
Total charge 63–136kg

PROCESSING INFORMATION

Digital Processing by Geophysical Service International

Time–variant Deconvolution (30 point)

Time–variant Velocity Filter (Pie–slice)

Filter: 20–50 Hz

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE
(metres)

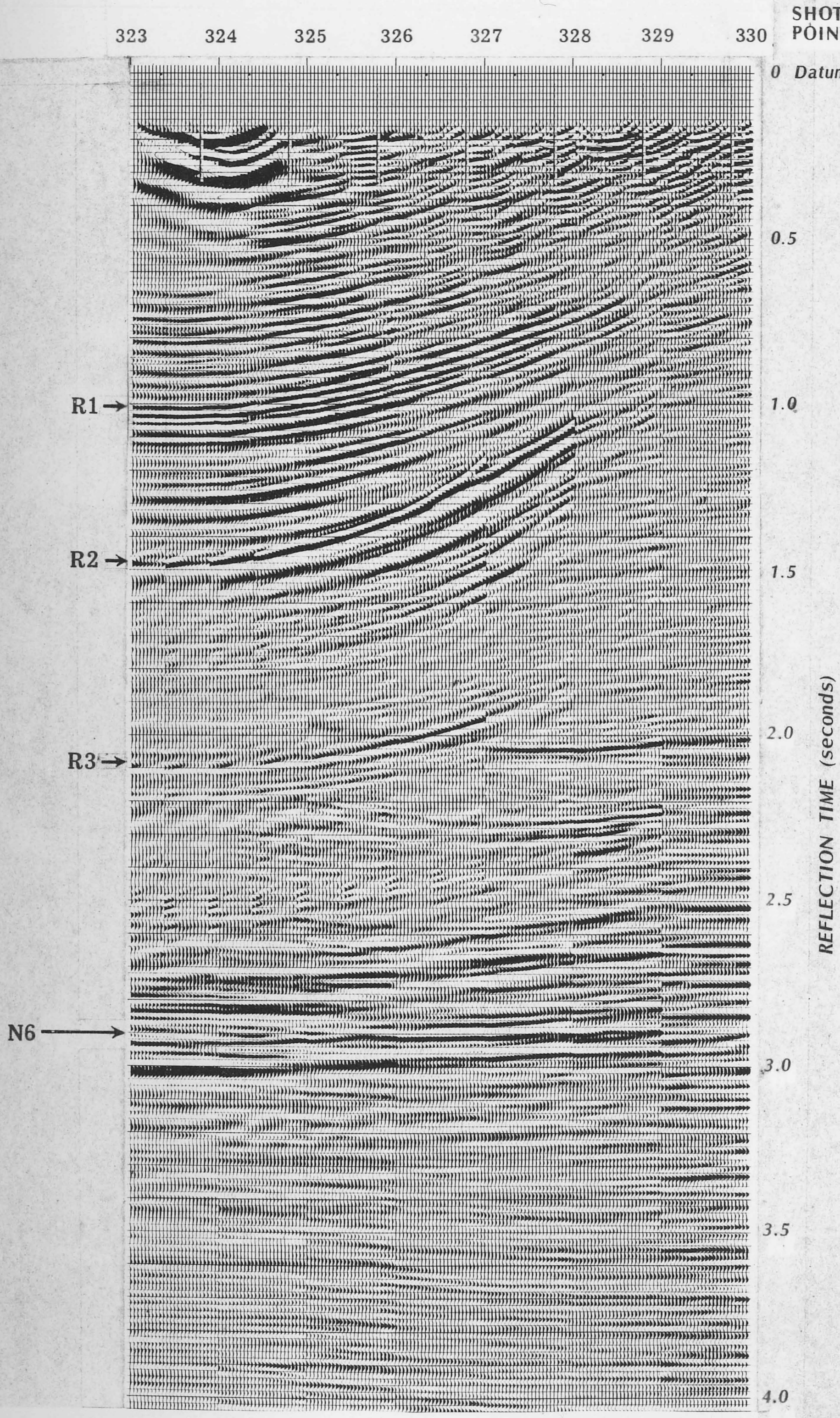
0	500	1000	1500
0	548	1097	

TRAVERSE 3 – 3N
SPs 323–329
TIME–VARIANT DECONVOLUTION PIE–SLICE VELOCITY FILTERING

43

PLATE 10

CORRECTED RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder : PMR–20

Amplifiers : PT–700

Prefilters : Out

Filters : L16 –KK135

AGC : S

Gain Initial : –60/–50

Final : –10

Geophones : HS–J, 14Hz

Geophone Station Interval : 45.7m

Geophone Pattern :

16/trace, 6m apart, transverse
(See Plate 3B)

Shot Hole Pattern :

5 or 7 holes, 45.7m apart,
transverse (See Plate 3B)

Depth 20–23m
Total charge 63–136kg

PROCESSING INFORMATION

Digital Processing by
Geophysical Service International

Time–variant Deconvolution
(30 point)

Migration Stack
(2 dimensions)

Filter: Out

VELOCITY INFORMATION

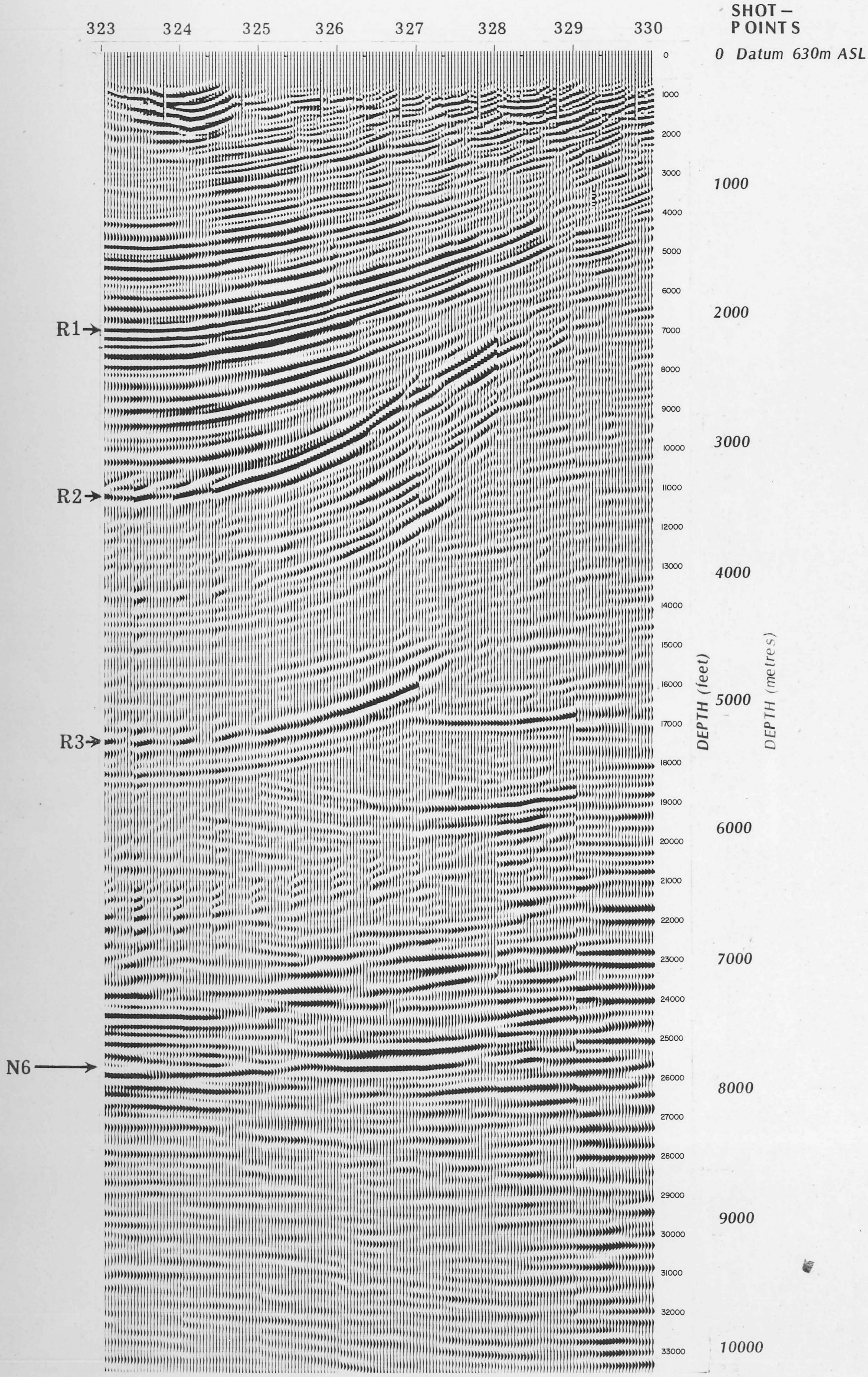
Analysis of dynamic misties

HORIZONTAL SCALE
(metres)

0 500 1000 1500
0 548 1097

TRAVERSE 3 – 3N
SPs 323–329
TIME–VARIANT DECONVOLUTION
MIGRATION STACK

To accompany Record No 1972/118 F53/B3–206A



CORRECTED RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: PMR–20

Amplifiers : PT–700

Prefilters: Out

Filters : L16–KK135

AGC : S

Gain Initial: –60/–50

Final : –10

Geophones: HS–J, 14Hz

Geophone Station Interval: 45.7m

Geophone Pattern:

16/trace, 6m apart, transverse (See Plate 3B)

Shot Hole Pattern:

5 or 7 holes, 45.7m apart, transverse (See Plate 3B)

Depth 20–23m
Total charge 63–136kg

PROCESSING INFORMATION

Digital Processing by Geophysical Service International

Time–variant Deconvolution (30 point)

Migration Stack (2 dimensions)

Time–depth Conversion

Filter: Out

VELOCITY INFORMATION

Analysis of dynamic misties

HORIZONTAL SCALE (metres)

0 500 1000 1500

0 548 1097

$\frac{V}{H} = \frac{10}{9}$

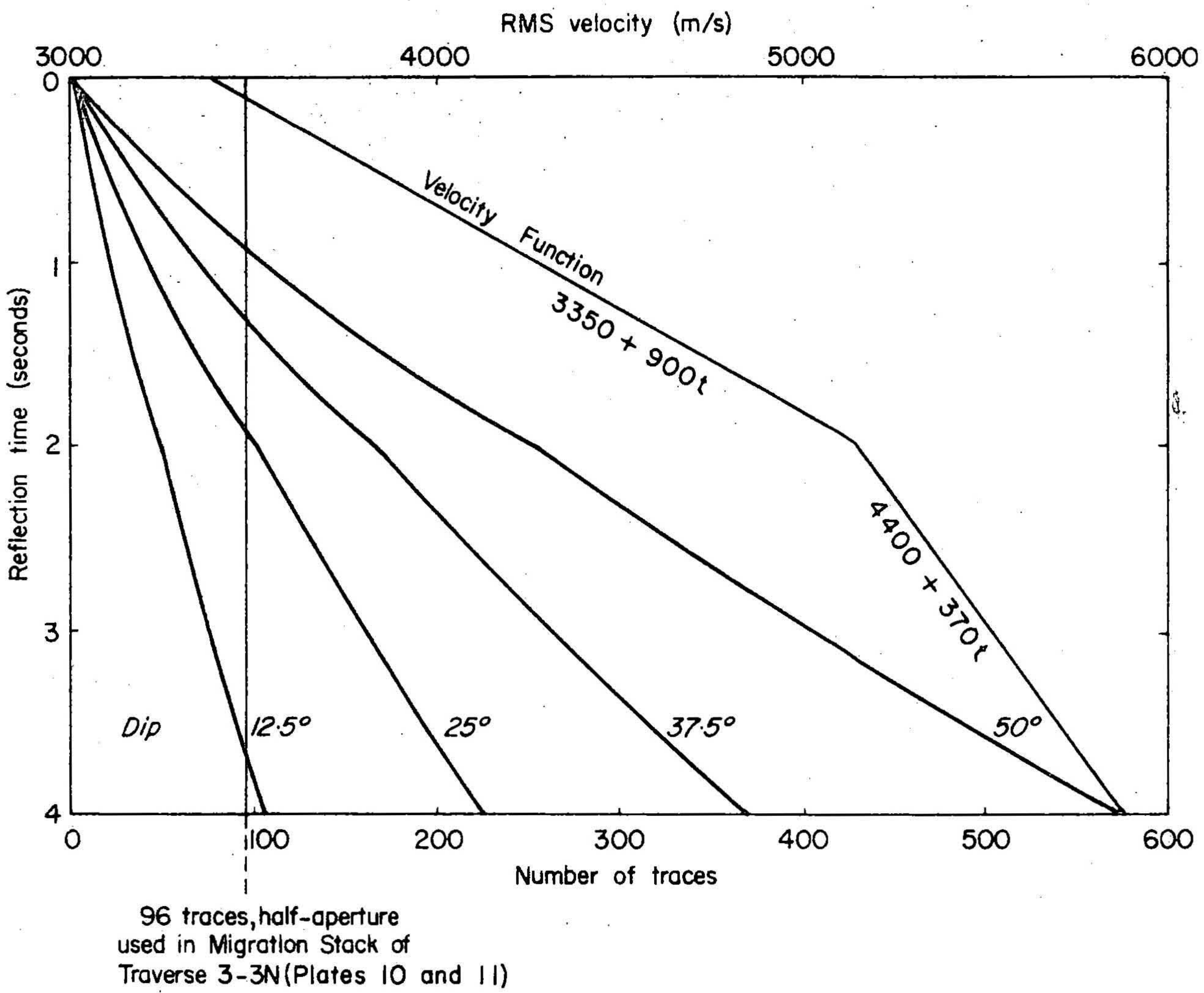
TRAVERSE 3 – 3N

SPs 323–329

TIME–VARIANT DECONVOLUTION MIGRATION STACK DEPTH CONVERSION

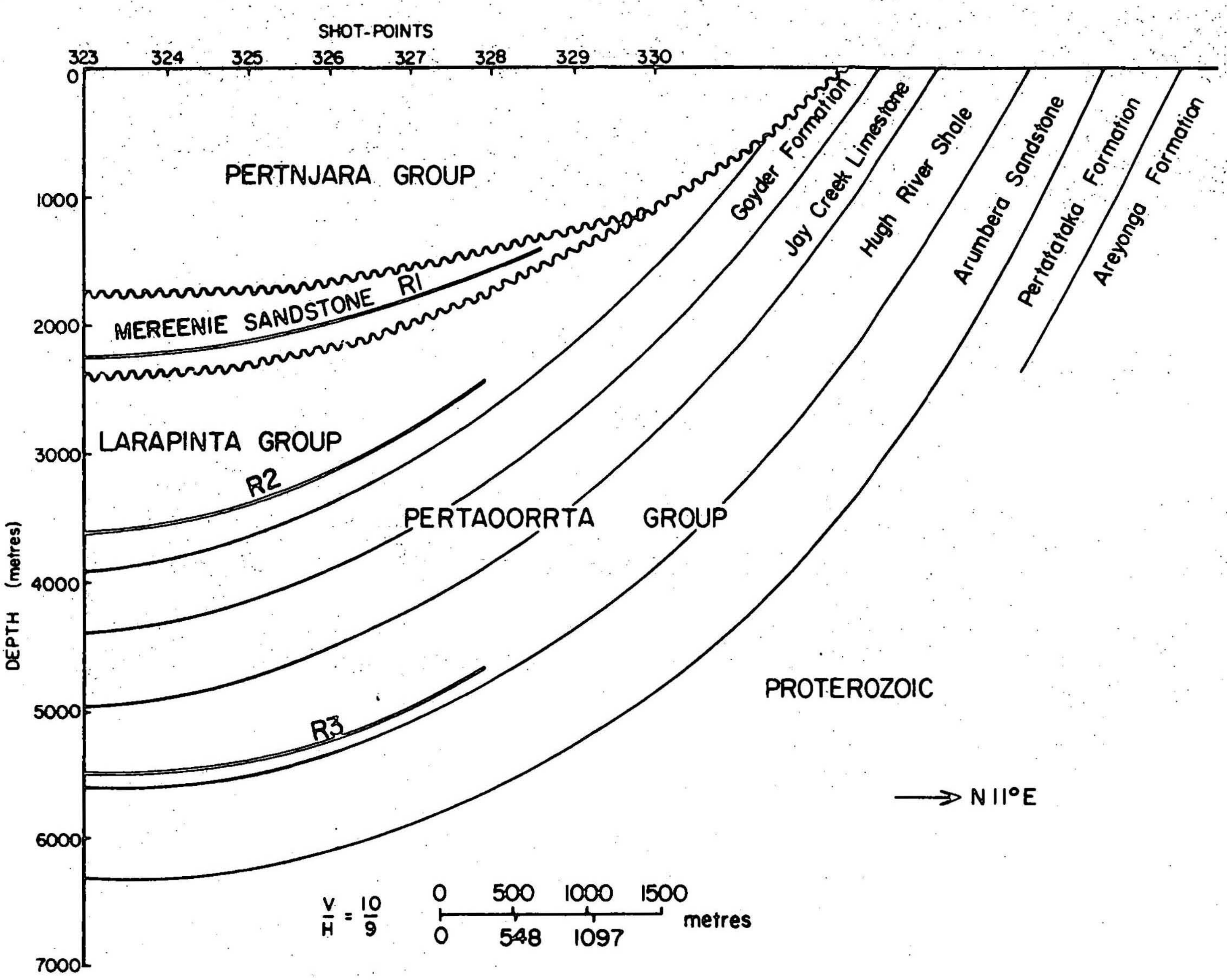
To accompany Record No 1972/118

F53/B3–205A



MIGRATION NOMOGRAM

Horizontal distance in terms of number of traces that an event of given reflection time and dip will migrate, that is half-aperture required in Migration Stack to migrate that event, computed for the velocity function indicated.



PROBABLE CROSS-SECTION ALONG TRAVERSE 3-3N OWEN SPRINGS

Based on surface geology and migrated seismic data (Plate 11)

To accompany Record No 1972/118

F53/B3-192A