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COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

RECORDS 1958, No. 28

AN EXPERIMENTAL
SEISMOGRAPH SURVEY AT
HEYWOOD,
WESTERN DISTRICT BASIN,
SOUTH-WESTERN VICTORIA



by

K. B. LODWICK and K. R. VALE

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ABSTRACT

An experimental seismograph survey was carried out near Heywood in the Western District Basin, south-western Victoria, during November and December, 1956 by the Bureau of Mineral Resources, Geology and Geophysics. The work was requested by Frome-Broken Hill Pty. Ltd. and was intended primarily to ascertain if reflections from deeper sediments could be recorded through a surface layer of basalt which covers considerable areas in the Western District of Victoria.

Several short traverses were shot during the survey at places where a variety of surface conditions for seismic exploration could be tested. Pattern and air-shooting techniques were tried as well as the conventional single shot-hole technique.

Good reflections were recorded from depths down to eleven thousand feet in areas where there was no basalt. Some apparent reflections of poor quality were recorded at times as great as 5 seconds after the shot was fired. An attempt has been made to correlate the reflections with stratigraphic horizons.

Reflections were obtained from strata beneath a basalt cover in some places when explosive charges were fired in single shot-holes; reflection quality was improved when pattern and air-shooting techniques were used.

It was not possible to record reflections through a cover of tuff containing basalt bands on the slopes of Mt. Clay. Pattern and air-shooting were tried unsuccessfully.

Sub-surface information in the Heywood area is obtainable by seismic exploration and techniques for gaining the best information from the seismic method are discussed.

1. INTRODUCTION

Heywood is in south-western Victoria, about sixteen miles from the coast and about fifty miles from the Victoria-South Australia Border. It is situated in a sedimentary basin in which Tertiary marine sediments are exposed on the surface. For the purposes of this report, this basin will be called the Western District Basin.

The choice of the name "Western District Basin" was made following a paper by Dr. D. E. Thomas on underground water in Victoria (1954-55). The name is used for convenience and is not meant to be a firm name applied by the Bureau to the area defined in Section 3 of this report. It is realised that the choice of the name of the basin is not a good one, as "Western District" applied to Victoria only whereas structurally the basin extends into South Australia. Sprigg (1952) points out that the basin is not a simple extension of the Murray Basin around the nose of the Dundas Highlands and Grampian Ranges but is separated from the Murray Basin by the Padthoway Horst. Sprigg (1952) called the area to the south of the Padthoway Horst the Gambier Sunklands. The extension of the Gambier Sunklands into Victoria followed from natural geological reasons. Boutakoff has used another term "The Portland Sunklands" to describe the area east of a tectonic swell called the Dartmoor ridge.

Although "Portland Sunklands" and "Gambier Sunklands" are appropriate local names they do not adequately describe the area between Port Phillip Bay in Victoria and Robe in South Australia. In an unpublished map drawn by the Geological Section of the Bureau the name "Otway Basin" is shown corresponding to the area. This name does not seem appropriate as it originated from the Otway Ranges which according to Thomas (1954-55) "introduce some structural complications" in the area described by him as the Western District Artesian Basin.

Interest in this basin as a potential oil-bearing area stems from an investigation by Dr. Wade in 1915. Since then, several petroleum geologists have investigated the area, and the most recent geological mapping has been done by the Department of Mines, Victoria, in collaboration with the Department of Mines, South Australia (Boutakoff and Sprigg, 1953).

Several bores have been drilled in the Basin, the deepest being at Nelson where Tertiary rocks are believed to be more than 7,000 feet thick.

Geophysical work in the basin has been carried out by Zinc Corporation Limited (airborne magnetometer survey), the Bureau of Mineral Resources (ground magnetic and gravity surveys), the South Australian Mines Department (gravity survey), and Frome-Broken Hill Pty. Ltd. (gravity survey).

An experimental seismic survey, which is the subject of this report, was made by the Bureau of Mineral Resources in November and December, 1956. The application for the survey was made by Frome-Broken Hill Pty. Ltd., through the Department of Mines, Victoria. Frome-Broken Hill Pty. Ltd. has a Petroleum Exploration Permit (No. 5) covering the Heywood area.

Much of the basin is covered by flows of basalt from Pliocene and Pleistocene volcanoes and the main object of the seismic survey was to determine whether it is possible to obtain reflections from sediments beneath the basalt. The success of the seismic experiments over the basalt-covered country near Heywood would result in the earlier advancement of exploration for petroleum by Frome-Broken Hill Pty. Ltd. as surface geological methods are severely handicapped and the potential

methods (gravity and magnetic) of geophysical prospecting are difficult to interpret for sedimentary structure particularly in areas with basalt capping.

The results of the test were discussed with officers of the Frome-Broken Hill Company and copies of the records and other data were made available to the Company shortly after the completion of the tests, for interpretation by the Company's principals in New York. The results of the tests were considered sufficiently encouraging to warrant a more extensive survey and the Company has engaged a contractor who is at present carrying out a seismic survey in the Western Districts Basin.

2. GEOLOGY

The Western District Basin extends from the border area between South Australia and Victoria eastward on the south side of the Western Highlands to Port Phillip Bay, where it merges with the Port Phillip Basin. The limit of its extension under the Southern Ocean is not known. The Otway Ranges and the Barrarbool Hills complicate the structure of the basin on the eastern side (Thomas 1954-55). The fact that this basin contains Tertiary marine sediments aroused interest in the possibility of occurrences of petroleum.

Boutakoff (1952) described the area between the Dundas Highlands in the north and the coast in the south as a series of terraces with major faults forming the boundaries between each terrace. Terrestrial Jurassic sediments crop out on the northern margin of the Western District Basin and form the uppermost terrace, which is known as the Dundas Tablelands (Boutakoff, 1952). These Jurassic sediments are currently considered to form the basement of the basin as far as the possibility of oil is concerned. The Dergholm and Normanby Platforms are two sections of the next terrace and both have Tertiary sediments exposed on the surface. The lowest land terrace is the coastal plains, which are covered by Quaternary dune limestone, sand and swamps. The basin is thought to extend on to the continental shelf, where sediments are still being deposited.

The Western District Basin is divided by the Dartmoor Ridge into two sections, the Mount Gambier Sunlands and the Portland Sunlands. This is pointed out by Boutakoff (1952) on the evidence of bore hole data, and a gravity (Bouguer Anomaly) map of the basin prepared by the Bureau but not yet published (Wiebenga, 1957), shows the Dartmoor Ridge as a prominent feature.

The Bouguer Anomaly map indicates that the deepest part of the basin is on the eastern side of the Dartmoor Ridge, between Heywood and Port Fairy. On the western side of the Dartmoor Ridge, a deep trough runs south-east from near Mt. Gambier, north-east of Nelson, towards Portland.

The two main stratigraphic groups in the basin are :-

1. The Knight Group, which consists of grits, glauconitic sands and carbonaceous shales. The age of this group is thought to be Eocene and Palaeocene.
2. The Glenelg Group, which contains fossiliferous marine limestones, argillaceous limestones, marls and clays. The Glenelg Group is the Victorian equivalent of the South Australian Gambier Limestone and is thought to be about Oligocene age.

An unconformity separates the Knight Group from the Glenelg Group (Boutakoff and Sprigg, 1953).

The greatest known thickness of the Knight Group was encountered in the Nelson bore, where it was found to be more than 6,329 feet. The drill was still in the Knight Group when operations ceased. The Glenelg Group was penetrated to a depth of 2,265 feet in the Portland No. 1 Bore without striking the base of the Group; this is the greatest recorded thickness of the Glenelg Group (Boutakoff and Sprigg, 1953). Another bore drilled in North Portland by Producing Oilfields (Condon et al, 1957) to 2,835 feet was probably still in the Glenelg Group when operations ceased. The fossiliferous content of the strata below 2,000 feet is not known (Crespin, 1954).

During Upper Pliocene and Pleistocene times, lava was poured out from many volcanic craters such as Mt. Eccles and Mt. Eckersley, and much of the Tertiary sediments around the volcanoes was covered. Tuffaceous material associated with these volcanic outbursts was mapped by Boutakoff during a geological investigation of south-western Victoria and South Australia made jointly by the Victorian and South Australian Mines Departments (Boutakoff and Sprigg, 1953).

The Tertiary rocks in the deeper parts of the Western District Basin, as well as being masked on the surface by coastal dunes and swamps, have the added disadvantage, as far as prospecting is concerned, of being covered in part by lava flows.

3. PROGRAMME

The Heywood area was selected as a suitable location for the experimental seismic work, firstly because it was covered by Petroleum Exploration Permit (No. 5) held by Frome-Broken Hill Co. Pty. Ltd., secondly because basalt was known to overlie much of the area, and thirdly because a gravity survey (Wiebenga, 1957) had indicated that the deepest part of the basin was in this area.

Prior to the commencement of the survey, Mr. J. Bain, geologist of Frome-Broken Hill Co. Pty. Ltd. mapped the surface boundaries of the basalt flows and tuff in the Heywood area to assist in drawing up the programme of seismic experimental work.

Traverses were pegged at 110-ft. intervals. Every twelfth peg ($\frac{1}{4}$ mile) was a shot point. The first twelve pegs on each side of a shot point were geophone stations for that shot point. The 24 geophone stations are called a "spread".

Traverse A was sited along a road where there was no basalt cover over the Tertiary rocks. (Plate 1), to ascertain whether reflections could be recorded from the Tertiary sedimentary section under the most favourable surface conditions for recording and shooting. Traverse B was selected so that the first two holes shot were on similar country to that on traverse A; the remainder of traverse B was on an area with basalt cover. The difference in results from differing surface conditions could thus be observed. Traverse C was on the slopes of Mt. Clay, over tuffaceous material which is covered in places by aeolian sands. Traverse D was in an area which is covered by a vesicular basalt flow (stony country), which apparently originates from Mt. Eccles.

The location of the traverses, as described above, is thought to be such that experimental data from a range of the different types of volcanic cover likely to be encountered in the Heywood area have been obtained.

The thickness of the surface volcanic material on traverses B, C and D was not known at the beginning of the survey. On scanty evidence from water bores, the basalt on traverse B was estimated to be about 70 feet thick. Geological evidence that traverse B was surveyed over basalt was obtained from a quarry where about 15 feet of weathered basalt is exposed. Drill logs from the shot holes along traverse B showed that no basalt was encountered in shot holes 9 to 14. Weathered basalt cuttings were obtained from shot holes 15 to 17, and cuttings of unweathered basalt were obtained only from shot holes 18 and 18A. The weathered condition of the basalt made it difficult to determine the true thickness of the basalt on traverse B. It is thought that in some holes where bands were recorded in the drill logs as "sandstone" the bands are weathered basalt (see Appendix A).

The drill logs revealed that on traverse C, clay and basalt bands alternate. The basalt on traverse D is unweathered and vesicular. The two holes drilled on traverse D showed that the basalt is more than 35 feet thick.

A refraction traverse was shot over Jurassic sandstones at Digby to determine their velocity. These sandstones are thought to underlie the Tertiary sediments of the basin.

4. FIELD WORK

The seismic party arrived at Heywood on 9th November, 1956. Shooting started on 14th November, 1956 and was completed on 7th December, 1956. The party comprised two geophysicists, one surveyor, two drillers, an observer, a shooter, a mechanic and seven field assistants. A field headquarters was established in Heywood and accommodation for the entire party of fifteen was arranged at the Heywood Hotel.

The Party's equipment included a Failing 750 drill, which was engaged on two shifts for part of the survey, and T.I.C. model 521 recording equipment. Later T.I.C. model 621 equipment was used for some of the recording, but this was in the nature of experiment and testing of the equipment.

About 8 miles of traverse, in four different areas, were shot during the survey. After permission had been obtained from the Portland Shire Council, the traverses were laid out along roads. Surveying was done by a surveyor and assistant from the Commonwealth Department of the Interior, and drilling was done by the Petroleum Technology Section of the Bureau of Mineral Resources. The deepest shot hole drilled was 200 feet and the total footage drilled was approximately 5,600 feet. Samples were taken at various depths in the shot holes and were sent to the Geological Section of the Bureau for investigation. Samples from the shot holes were sent also to Frome-Broken Hill Pty. Ltd.

Plate 1 shows a copy of the geological sketch map prepared by Mr. Bain and the layout of the traverses shot at Heywood. Mr. M. Murray, a geophysicist of Standard Vacuum Oil Co. of America, who was at the time attached to Frome-Broken Hill Pty. Ltd., was present as an observer for part of the survey. Dr. Heyl, exploration manager for Frome-Broken Hill Pty. Ltd., visited the party during the survey.

The Portland Harbour Trust gave the party permission to store the main supply of explosive used on the survey in its magazine at Blacknose. The seismic party's portable

magazine was stationed in the grounds of the Portland Shire Council's magazine at Heywood, and was used to store small quantities of explosive for the immediate requirements of the seismic party. This portable magazine was replenished from time to time from the explosives stored at Blacknose. The type of explosive used during the Heywood survey was "Geophex", made by Nobel (Australasia) Pty. Ltd., a subsidiary company of Imperial Chemical Industries of Australia and New Zealand Ltd.

5. RESULTS

(a) Computing Methods.

On the profiles shown on plates 4 and 5, the reflections are plotted using an unmigrated correlation method. In this method, reflection time to the geophones closest to the shot point (centre time) is plotted vertically below the shot point, and the times to the furthest geophones (end times) are plotted vertically below the midpoint of the geophone spreads. All line-ups of troughs (legs) of each reflection were plotted. Each reflection was graded according to the system set down by Gaby (1947). This grade and the times are shown on each reflection.

An analysis of the differences (ΔT) between centre and end times of all good reflections was made to find a general relation between ΔT and the reflection time, T , ($T - \Delta T$ analysis). From this analysis it was possible to :-

- (1) Determine a spread correction to be applied to the end times of each reflection before plotting.
- (2) Calculate a velocity distribution with depth, so that the reflection times could be plotted according to a depth scale rather than a time scale. This was done in the absence of velocity data from bore holes.

(b) T - ΔT Analysis.

The $T - \Delta T$ curve obtained from the best reflections recorded on traverses A and B at Heywood is shown on Plate 6. On Plate 7, the average velocity is plotted against depth and the variation of velocity with intervals of depth is also plotted against depth. This second curve is called the interval velocity curve. Plate 8 shows the reflection time plotted against depth.

The interval velocity curve (Plate 7) indicates a sudden increase in the velocity of the strata at a depth of about 2,300 feet. This change may be related to the stratigraphic boundary between the Glenelg and the Knight Groups. The error in the depth estimate of this change is probably about ± 500 ft. A calculation of the depth of the Knight-Glenelg discontinuity was made from gravity data using an empirical formula derived by Wiebenga (1957). This calculation places the depth to the top of the Knight Group at approximately 2,000 feet in the Heywood area. The error in Wiebenga's formula is estimated at about ± 400 feet. Thus a reasonable estimate of the depth to the top of the Knight Group near Heywood would be between 2,000 and 2,500 feet. The Portland No. 1 bore was still in the Glenelg Group at 2,265 feet. Since this report was drafted another

bore has been drilled near Portland but no stratigraphic information is available yet.

Some caution should be exercised in interpreting the T- Δ T analysis as the data used in drawing up the curve are not sufficient to give a statistically reliable result. The survey at Heywood was limited in extent and the reflections from only ten different shot points were used to carry out the T- Δ T analysis. The velocity information after 1,600 milliseconds (about 6,500 feet deep) will be particularly unreliable as the Δ T values are small and there are few points plotted after that time. The T- Δ T, velocity and depth curves are shown as a broken line after 1,600 milliseconds.

A comparison between the interval velocity curve and the velocity obtained from the refraction shots at Digby is made under Section 5(g).

(c) Traverse A.

Plate 4 shows a profile of reflections recorded along Traverse A and on Plate 3A photographs of the best records obtained from each shot hole along Traverse A are shown. The traverse runs in an east-west direction along a road between Heywood and Bessie Belle (see Plate 1). Two and a half miles of traverse were shot on clayey soil where there is no basalt.

Reflections obtained were of good quality, especially in the early part of each record. Reflections of doubtful quality were noticed as late as 5 seconds.

From a study of the records of Plate 3A and the profile on Plate 4, there is some evidence that a change in reflection "character" and in the consistency of plotted dips occurs at about 0.9 seconds (about 3,000 feet). This apparent change may have geological significance and may perhaps correlate with the interface between the Knight and the Glenelg stratigraphic groups. This subject was discussed in Section 5(a) dealing with interval velocities.

After 0.9 seconds (below about 3,000 feet), reflections are of fair quality, but they are not as numerous and their dips are not as uniform as in the earlier part of the record.

After 2.3 seconds (below about 11,000 feet), the quality is poorer and the number of reflections is significantly less than above this depth. This discontinuity, the depth to which may have an error of $\pm 1,000$ feet, may perhaps correspond to the top of the Jurassic sediments. That the Jurassic sediments may be this deep is suggested by the data for the Portland and Nelson bores.

The Portland No. 1 bore had not penetrated the full section of the Glenelg Group when drilling ceased at 2,265 feet, and the Nelson bore passed through 6,329 feet of the Knight Group without going right through it. Assuming that there is at least 6,329 feet of Knight Group below the Glenelg Group at Portland, the minimum thickness of the Tertiary sediments at Portland is 8,594 feet. Allowing for the possibility of extra thickness of the Glenelg and Knight Groups, the estimate from seismic results of 11,000 feet for the depth to the top of the Jurassic sediments is not unreasonable.

No reliable evidence regarding the thickness of the Tertiary sediments is forthcoming from the gravity survey of the

Western District Basin, as Wiebenga (1957) found that there was no significant density contrast between the Tertiary and Jurassic rocks. In calculations by Wiebenga of the depth to basement, the crystalline or metamorphosed Palaeozoic rocks are considered to be the basement of the basin.

The deficiency in the number and quality of reflections below S.P.6 on traverse A may be due to poor reflecting horizons and surface conditions, but it is more probably due to the recording equipment used. The model 621 T.I.C. equipment was used for the first time at S.P.6, and did not prove as reliable as the model 521 equipment.

The general direction of dip of the sediments beneath traverse A, although very slight, is to the west. This may be significant as it appears from the Bouguer Anomaly map that the Western District Basin deepens to the east along traverse A.

(d) Traverse B.

Traverse B (see Plate 1) is along a north-south road on the eastern side of the railway between Heywood and Milltown.

Shot points 8 and 9, at the southern end of the traverse, were in an area where there is no basalt cover. Shot holes 11 to 14 were thought to be on basalt but there is some doubt about this, as there are discrepancies between Mr. Bain's geological map and Dr. Boutakoff's. Cuttings from drill holes at shot points 11 to 14 did not indicate any basalt along this part of the traverse. Weathered and unweathered basalt cuttings were taken from shot holes 15 to 18A.

Plate 5 shows the reflection profile along traverse B and the best record from each shot hole is illustrated on Plate 3 (B and C).

Good-quality reflections, similar to those obtained on traverse A, were recorded at shot points 9 and 10 on traverse B. The profile changes at a depth of about 2,500 feet, below which reflections are less numerous and of slightly poorer quality; this discontinuity may possibly correlate with the apparent discontinuity at 3,000 feet on traverse A. A strong band of reflections at a depth of 1,000 feet is outstanding on the profile and records.

The profile representing the reflections recorded on the remainder of traverse B (shot points 11 to 18A) shows only one prominent band of reflections - at about 1,000 feet below the surface. A few sporadic poor reflections were also recorded. The band of reflections at a depth of 1,000 feet persists through traverse B regardless of the filter setting used on the recording equipment and the depth at which the shot was fired. The increase in the number and quality of reflections recorded at shot point 18 is due to a pattern shot fired at that hole. Pattern shooting, depth of shot, weathering and other technical data are discussed under a separate heading.

The lack of reflections between shot points 11 and 18A appears to be associated with the presence of basalt on that part of traverse B. It appears that the effect of the basalt on the signal-to-noise ratio of reflected energy is such that it does not prevent the reflections from the very good

reflecting horizon at about 1,000 feet being recorded, whereas weaker reflections from deeper strata are obscured.

The Bouguer Anomaly map indicates that northwards along traverse B the sedimentary basin becomes shallower and also that the sediments along traverse B are thinner than those along traverse A. In general, the reflections recorded along traverse B indicate a south component of dip.

(e) Traverse C.

Traverse C is along a winding road on the slopes of Mt. Clay, in the Mt. Clay State Forest (see Plate 1). Geological maps (Boutakoff, 1952 and Bain, 1956) show tuffs originating from the Mt. Clay volcano in the area. In places these tuffs are covered by aeolian sand. Drill logs from the seismic shot holes record alternate bands of basalt and clay. Only a very few poor and doubtful reflections were recorded along traverse C.

Distortion of the sub-surface strata, which could cause a scattering of reflected energy, may account for the deficiency in number and quality of the reflections recorded along traverse C even if the area were not basalt-covered. The strata near the old volcano (Mt. Clay) may have been distorted by the pressures associated with the volcanic activity. Boutakoff (1952) suggested that the Kanawinka fault may continue under Mt. Clay, eventually appearing as the western margin of the continental shelf under Bass Strait and the west coast of Tasmania. (The gravity results, however, do not support this theory.)

Photographs of the best records obtained from each shot hole on traverse C are shown on Plates 3E(6) to 3F(2).

(f) Traverse D.

Traverse D lies along a north-south road across a vesicular basalt flow from Mt. Eccles (see Plate 1). Owing to the slow rate of drilling along traverse D, only two holes (28 and 29) were drilled and shot. The two holes were 35 feet deep and both bottomed in basalt.

Some reflections of poor quality were recorded from strata beneath the basalt. Copies of the records from the two shot holes are shown on Plate 3G. Pattern and air shots are discussed under Section 6(d).

(g) Velocity Measurements in the Jurassic Sediments at Digby.

One mile of traverse was surveyed in a north-easterly direction over an outcrop of Jurassic sediments near Digby, between Heywood and Casterton (see Plate 2). Charges were shot in drill holes at each end of the traverse to determine the velocity of seismic waves through the Jurassic sediments from the times that the refracted waves were recorded at each geophone.

The times that the refracted waves were recorded at each geophone are plotted on Plate 11 against the distances of the geophones from the shot point. Two sets of points are shown. The points marked with a cross represent recorded times of arrival of refracted waves. The points marked with a circle are corrected for weathering (Dix, 1952, p. 73), assuming that a single-layer condition applies. A velocity

of approximately 7,200 feet per second was calculated for the Jurassic sediments. The velocity is very much lower than the 14,400 feet per second corresponding to a depth of 11,000 feet on the interval velocity curve (Plate 7). A depth of 11,000 feet is considered to be a reasonable estimate for the top of the Jurassic sediments at Heywood.

Lithological changes may account for such a large difference in the two values of the velocity in the Jurassic sediments, but the depth of burial of the Jurassic rocks at Heywood is the more likely explanation. Faust (1951) points out that Jurassic sandstones and shales with a velocity of about 8,500 feet per second at a depth of 1,000 feet could be expected to have a velocity of about 14,000 feet per second at a depth of 11,000 feet.

The extrapolated part of the interval velocity curve may be drawn a little high but, allowing for the unreliability of the T- Δ T analysis, is of the order of the velocity to be expected when a sandstone or shale with a velocity of 7,200 feet per second on the surface is buried to a depth of some thousands of feet.

6. TECHNIQUES USED AND THEIR INFLUENCE ON RECORD QUALITY.

(a) Traverse A.

Good records were obtained from single shot holes on traverse A and the depth of the shot below weathering did not appear to be critical. Records were taken from shots at depths ranging from 10 to 100 feet. Surface shots were fired using a close geophone spacing to determine the velocity of the weathered layer. This was found to be about 1,500 feet per second, and the thickness of the weathered layer is about 10 to 15 feet. The velocity of the sub-weathering (Dix, 1952, pp. 77 and 89) was 5,000 to 6,000 feet per second.

The drill encountered heavy clay for the first 10 to 20 feet, below which the formation is mainly limestone with hard bands. Difficulty in maintaining circulation of drilling fluid was experienced in some places, but when bentonite was mixed with the drilling mud the difficulty was usually overcome.

The optimum filter setting used on the T.I.C. recording equipment for shot holes along traverse A was in the range L2 H3. Plate 9 shows the response curves for the different filter settings of the T.I.C. model 521 equipment.

A pattern shot consisting of thirteen shot points 50 feet apart in a star shape (see Plate 10) was fired at shot point 7 and a photograph of the record obtained is shown on Plate 3A(3). Plate 3A(4) illustrates the record obtained from a single shot hole at shot point 7 for comparison with Plate 3A(3). The thirteen charges of one and two-thirds lbs. each, which were used in the pattern shot, were set seven feet deep and exploded simultaneously. The signal-to-noise ratio of the record taken from the pattern shot is very much better than for a single shot. The results obtained from this pattern shot make it worth while considering the use of the method in any proposed survey of similar areas in the Western District Basin. The first seven feet can be drilled very easily and at little expense with a mechanical post hole digger.

(b) Traverse B.

Shot points 9 to 10 on traverse B were similar to the shot points on traverse A as regards drilling, shooting, and recording conditions. Records taken at shot point 10 for measuring the velocity and depth of weathering indicated that conditions were similar to those on traverse A.

A record taken over basalt at shot point 17 on traverse B indicated that there are three layers of low-velocity material overlying a sub-weathering layer of about 5,000 to 6,000 feet per second. The velocities of the three layers, from the surface downwards, were 800, 2,500 and 4,000 feet per second respectively.

Difficulty in maintaining circulation of the drilling mud in many of the holes along traverse B caused abandonment of some holes after a depth of 40 to 50 feet had been reached. New holes were drilled in the instances in which holes were abandoned.

The depth at which the explosive was fired appeared to make little difference to the quality of the records. Plates 3C(4) to 3C(9) and 3D(1) and 3D(2) show photographs of records taken at shot point 15 for various depths of explosive from 180 feet to 20 feet, and using a slight variation in filter setting. Plates 3D(3) to 3D(9) and 3E(1) to 3E(5) show photographs of records obtained at shot point 17 using a variety of filter settings, and keeping the depth constant as far as destruction of the shot hole by the explosions would allow. It will be seen that filter settings near the middle of the range available on the T.I.C. equipment give the best results. On the whole, however, variation of filter setting and depth of shot did not affect the quality of the reflections recorded to any marked degree.

A thirteen hole star-shaped pattern, with shot holes 50 feet apart and charges at a depth of ten feet, was fired at shot point 18 (see Plate 10 for lay-out of pattern). A photograph of the record obtained is shown on Plate 3B(3). The number of the reflections recorded increased using the pattern technique and there was a marked improvement in their quality. A comparison between a single-hole shot and the pattern shot may be drawn from the photographs on Plate 3B(2 and 3). The cross-section (Plate 5) shows an increase in the depth from which reflections were recorded; this is due to the improved quality of the record from the pattern shot.

The improved results obtained from the pattern-shooting technique signify that the method is applicable in the area. Even greater improvement in record quality may be expected by experimenting to determine the best spacing of shot holes, the best shot depth, the best type and size of pattern. The use of multiple geophone arrays may be expected to give further improvement in record quality over that obtained by using pattern shooting techniques.

(c) Traverse C.

Some holes on traverse C were drilled to more than 100 feet depth. A little difficulty was experienced through loss of circulation of the drilling fluid but this was overcome when bentonite was used. The formations through which the drill passed consist mainly of tuffaceous material with thin inter-bedded clays and basalt.

Velocity measurements of the weathered layers along traverse C were difficult, as the first refraction breaks were poor. This was probably caused by the thin beds of high-velocity basalt separating layers of lower-velocity material. Surface layers with velocities of 5,000 to 10,000 feet per second were measured, but these figures may be unreliable.

Few reflections were obtained and these ranged in quality from very poor to doubtful. The best records obtained from each shot hole on traverse C are shown on Plates 3E(6) to 3E(9) and 3F(1) and 3F(2). Shot point 25 was shot at depths ranging from 120 feet to 13 feet and no significant change was noticed in the records. These records are shown on Plate 3F(3 to 7).

The filter setting favoured on this traverse was L3 H2. Other filter settings were tried without improvement in record quality.

A thirteen-hole star pattern with 50-foot spacing between holes (see Plate 10) was fired with charges at a depth of ten feet at shot point 20. No significant improvement in the record was noticeable. An air shot was fired 1,200 feet from the traverse at shot point 20. Thirteen charges, 7 feet above the ground, were set out at 50-foot intervals in a star-shaped pattern (see Plate 10). The method failed to improve the quality of the record. Records obtained at shot point 20 are shown on Plate 3G(3 to 5).

After the failure to record reflections at shot point 20 by the methods described, a 36-hole diamond pattern was shot at shot point 26. The plan of this pattern is shown on Plate 10. Charges were at a depth of 20 feet. This method effected no improvement in the quality of the record and no reflections were recognisable. Other patterns were tried, namely 17 holes 35 feet apart in the shape of a cross, 5 holes 35 feet apart in the shape of a cross, and 3 holes 70 feet apart in line, but these were all unsuccessful. The plan of each of these patterns is shown on Plate 10. Photographs of the records obtained from pattern shots at shot point 26 are shown on Plates 3F(8) and 3F(9) and 3G(1) and 3G(2).

A shot was fired at shot point 26 with geophones at 25-foot intervals along traverse C and at right angles to traverse C from shot point 25. This lay-out is shown on Plate 10. It was hoped that information regarding the frequency and horizontal velocity of the noise which was probably masking reflections would be obtained but no conclusions were reached. Photographs of the records from this arrangement of geophones are shown on Plate 3G(6 and 7).

(d) Traverse D.

Drilling of shot holes on traverse D was very difficult; three and a half eight-hour shifts were spent in drilling two shot holes 35 feet deep through the vesicular basalt. Poor reflections were obtained from the single shot holes. Velocities measured in the basalt were 10,000 to 11,000 feet per second.

The basaltic country contains numerous depressions up to fifteen feet deep, some of which are partly filled with water. One of these depressions containing water was about 50 feet from the traverse on a line at right angles to the traverse from shot point 28. The pool was 30 feet in diameter and six charges were placed at equal intervals around the pool in 3 to 4 feet of water. Three

such arrangements of charges were detonated and a record was taken from each one using a different filter setting on the equipment. Photographs of the records obtained are shown on Plate 3H(3 to 5). Two records from a single shot-hole at shot point 28 are shown on Plate 3H(1 and 2) for comparison with the records from shots fired in the pool of water. Some improvement is apparent in the records from the multiple-charge water shots.

A 13-point, star-pattern air shot was fired from a position 1,000 feet from traverse D on a line at right angles to shot point 28. The charges were set 7 feet above the ground and 50 feet apart, and were detonated simultaneously. Plate 10 shows a plan of the type of pattern used. A photograph of the record obtained from the air shot is shown on Plate 3H(6). The first line-up of troughs on the record is from refracted waves. After about 0.35 seconds, reflections of very good signal-to-noise ratio were recorded before the air wave disturbed the record and masked the ground waves. The times that refractions, reflections and air waves can be expected are marked on Plate 3H(6). The results of the air shot showed that air-shooting techniques may be effective on the stony basalt-covered country around Heywood. A longer offset distance of the air shot would probably enable reflections to be recorded from a greater depth. In that case, however, refractions would be recorded for a greater length of time and early reflections would be masked. To record reflections from the full section of sediments, two air shots would have to be fired, one from a short offset distance of about 1,000 feet and the other from a greater offset distance of say 3,000 feet, depending on the velocities of the strata and the depth of the section.

(e) Equipment.

T.I.C. geophones with a frequency of 20 c.p.s. were used throughout the survey at Heywood. Four geophones were used on each trace; they were connected in a series-parallel arrangement and spaced five feet apart along the traverse. Unfortunately, the geophones were permanently connected in this arrangement and no others were available at the time to experiment with different arrays. It is thought that the use of larger numbers of geophones and differently spaced geophone arrays might improve record quality in the Heywood area.

A high-voltage blaster was used to explode the multiple-charge pattern shots. The charges were connected in series and no difficulty was encountered using this technique

7. CONCLUSIONS.

The results of the experimental seismic survey at Heywood indicate that the reflection method of seismic exploration is applicable in this part of the Western District Basin. Good reflections were obtained in areas where there is no basalt cover and techniques were evolved which enabled reflections to be recorded from deeper sediments through some types of basalt.

Except perhaps in the immediate vicinity of old volcanic craters, it is considered that the seismic reflection method will generally give results enabling any fairly pronounced sub-surface structures to be mapped, regardless of whether basalt flows are present at the surface.

Seismic surveys over the unweathered basalt flows in the Heywood district seem impracticable due to the rugged nature of the terrain. Travel over the unweathered basalt is almost impossible in most places and road-making would be very expensive. The cost of drilling would be prohibitive but reasonable results may be obtainable using air shooting techniques.

The seismic results along traverse A indicate the presence of a sedimentary section, possibly conformable and probably unaltered, more than 10,000 feet thick. The section may be all of Tertiary age, but it is possible that Mesozoic rocks are included in the estimated thickness.

The gravity results (Wiebenga, 1957) indicate that the deepest part of the Western District Basin appears to be between Heywood and Port Fairy, in the area known as the Portland Sunklands (Boutakoff, 1952). This is the area in which the seismic tests were made.

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APPENDIX 1.

SUMMARY OF DRILLERS' LOGS OF SHOT-HOLES

TRAVERSE	SHOT POINT	DEPTH	FORMATION
A.	2	0 to 30 20 - 60	Clay. Limestone with hard bands and clay.
Other shot holes on Traverse A were similar.			
B.	9	0 - 26 26 - 106 106 - 216	Clay. Limestone, sandstone and clay. Clay with sandstone bands.
B.	10	0 - 25 25 - 100 100 - 128	Clay. Clay with limestone and sandstone bands. Clay with sandstone bands.
B.	11	0 - 25 25 - 55 55 - 128	Clay. Fine clay. Clay and hard bands.
B.	12	0 - 25 25 - 44	Clay. Clay with limestone bands.
B.	13	0 - 30 30 - 116	Clay. No cuttings probably fine clay.
B.	14	0 - 54 54 - 192	Clay. Clay with limestone and sandstone bands.
B.	15	0 - 6 6 - 58 58 - 202	Clay. Weathered basalt. Clay with hard sandstone bands.
B.	16	0 - 9 9 - 26 26 - 56 56 - 202	Clay. Clay with sandstone bands. Weathered basalt. Clay with sandstone bands and small quantities of basalt.
B.	17	0 - 15 15 - 76 76 - 202	Clay. Weathered basalt. Clay with hard sandstone band.
B.	18	0 - 28 28 - 53	Clay. Basalt.
B.	18A	0 - 28 28 - 53	Clay. Basalt.
B.	22	0 - 46 46 - 85	Clay with sand. Basalt (hole caving in at 80 ft.)
C.	23	0 - 6 6 - 48 48 - 56 56 - 59 59 - 86	Sand. Clay with sandstone bands. Basalt. Clay. Basalt.

TRAVERSE	SHOT POINT	DEPTH	FORMATION
C.	24	0 - 38	Clay with sandstone bands.
		38 - 81	Basalt.
		81 - 83	Clay.
		83 - 87	Basalt.
		87 - 106	Clay.
C.	25	0 - 9	Sand.
		9 - 37	Clay.
		37 - 39	Blue Metal.
		39 - 100	Clay.
		100 - 158	Clay with hard limestone bands.
C.	26	0 - 3	Sandy Clay.
		3 - 48	Clay.
D.	28	0 - 35	Basalt.
D.	29	0 - 33	Basalt.

NOTE: The descriptions of the formations encountered are in general drilling terms. A more comprehensive examination of samples taken from the shot-holes at Heywood is being made by the Geological Section of the Bureau of Mineral Resources, and the geological description of the formations drilled will be known more precisely.

APPENDIX 2.

NOTES ON DRILLING TIMES OF SEISMIC SHOT HOLES.

The following table summarises the drilling time and footage drilled during the Experimental Seismograph Survey at Heywood. The table includes the time taken to redrill some holes and also the footage redrilled. Loss of circulation was the main reason for the redrilling of holes. Difficulty in maintaining circulation was encountered on traverses A and B and it was usually overcome by using bentonite in the drilling fluid or by drilling another hole a few feet from the original hole.

No. of operation shifts	23 equals	184 hrs.
Overtime		15 hrs.
Total time		199 hrs.
No. of holes drilled		131
Total footage		5,608 ft.
Drilling time		106 hrs.
Travelling and rigging time		42 hrs.
Time lost waiting for water		19½ hrs.
Time lost due to rig repairs		21 hrs.
Time lost due to miscellaneous causes		10½ hrs.
Average depth of hole		43 ft.
Deepest hole		216 ft.
Average penetration rate		53 ft. per hr.
Bentonite used		1¼ tons.

APPENDIX 3.

ANNOTATION OF PLATES 3A TO 3H WHICH SHOW PHOTOGRAPHS OF SEISMIC REFLECTION RECORDS

GENERAL NOTES:

The recording equipment used for each record was TIC model 521, except records shown on plates 3A(1), 3A(2) and 3A(5), for which model 621 equipment was used.

Shot point numbers, traverse, weight of charge in pounds, depth of shot, filter setting and pre-suppression are shown on the stamp at the beginning of each record. The heavy timing lines on each record represent time intervals of one tenth of a second. A plan of the traverses shot at Heywood is shown on Plate 1 and response curves for the different filter settings obtainable on the model 521 equipment are shown on Plate 9.

The records obtained from the TIC equipment are three times the scale shown on the photograph. The layout of pattern shots used at Heywood is shown on Plate 10.

PLATES 3A(1) TO 3A(9).

Records shown on these plates were obtained from Traverse A. Eight holes were shot at intervals of a quarter of a mile and the records are laid out with the record from the most easterly shot point (7B) as 3A(1). This sequence corresponds with the profile shown on Plate 4. Plate 3A(4) is a record from shot point 7 using a single hole and, for comparison, Plate 3A(3) is a record from a 13-hole pattern using the same spread of geophones used for the record of Plate 3A(4).

PLATES 3B(1) TO 3C(3).

The best records from Traverse B are shown on these plates. The records on Plate 3B(1) to 3B(9) are laid out with the record from the most northerly shot point (18A) at the top. Records from shot points 9, 10 and 11 are shown on Plates 3C(1), (2) and (3). The order has been inadvertently reversed. To correspond with the profile on Plate 5, Plate 3C(3) should be on top, 3C(2) underneath, and then 3C(1) to make the most northerly shot point on top and also to continue on from Plate 3B(9). The profile plotted from these records is shown on Plate 5. A comparison of a 13-hole pattern and a single shot-hole at shot point 18 is illustrated by Plates 3B(2) (single hole) and 3B(3) (pattern).

PLATES 3C(4) TO 3D(2).

The records obtained from shot point 15 at various depths are shown, beginning at Plate 3C(4) and continuing on to Plate 3D(2), and arranged with the deepest shot first. Some variation of filter setting was made while shooting up the hole.

PLATES 3D(3) TO 3E(6).

Plates 3D(3) to 3E(6) show records from shot point 17. Records were obtained using a wide range of filter settings and shot depths. The depth of shot was kept constant as far as practicable for a number of different filter settings.

PLATES 3E(7) TO 3F(2).

The records shown here were obtained on Traverse C. Shot point 21 was not shot. The records are arranged with the records from the most north-easterly end of the traverse on top.

PLATES 3F(3) TO 3F(7).

Photographs of records from shot point 25 using various filter settings and different depths of shot are shown on these plates.

PLATES 3F(8) TO 3G(2).

The four records shown were recorded at shot point 26. 3F(8) was obtained from a 36-hole diamond pattern, 3F(9) from a 17-hole cross pattern, 3G(1) from a 5-hole cross pattern and 3G(2) from a 3-hole in-line pattern. The plans of these patterns including the hole spacing are illustrated on Plate 10.

PLATES 3G(3) TO 3G(5).

The records shown in these plates were recorded at shot point 20. 3G(3) is a record from a single-hole shot, 3G(4) from a 13-hole pattern and 3G(5) from a 13-unit air shot, offset 1200 feet south-east of shot point 20.

PLATES 3G(6) TO 3G(7).

These two records were recorded by two 300-foot spreads of geophones, one at right angles to, and one along the traverse at shot point 25, from a charge of explosive set off in a hole at shot point 26. The purpose of the records was to analyse the noise frequency.

PLATES 3H(1) AND (2).

Both records were recorded at shot point 28 on traverse D, from a single shot-hole using different filter settings. Traverse D passes over hard vesicular basalt.

PLATES 3H(3) TO 3H(5).

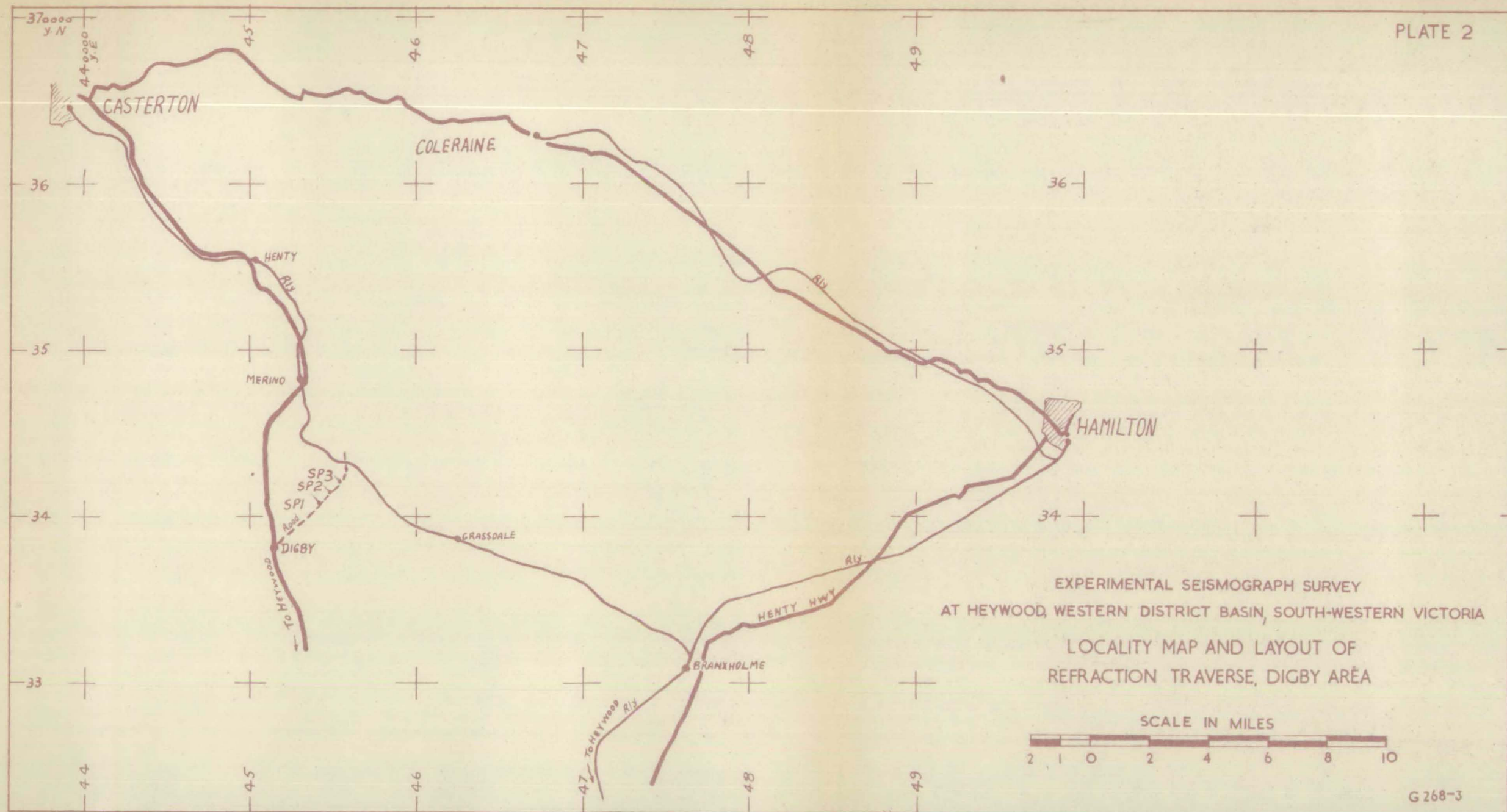
These records were obtained when charges of explosive were spaced about 15 feet apart in a pool of water and exploded. The charges were about 3 feet under water. The pool of water was in a depression in the basalt lava country about 50 feet away and at right angles to the traverse from shot point 28 on Traverse D.

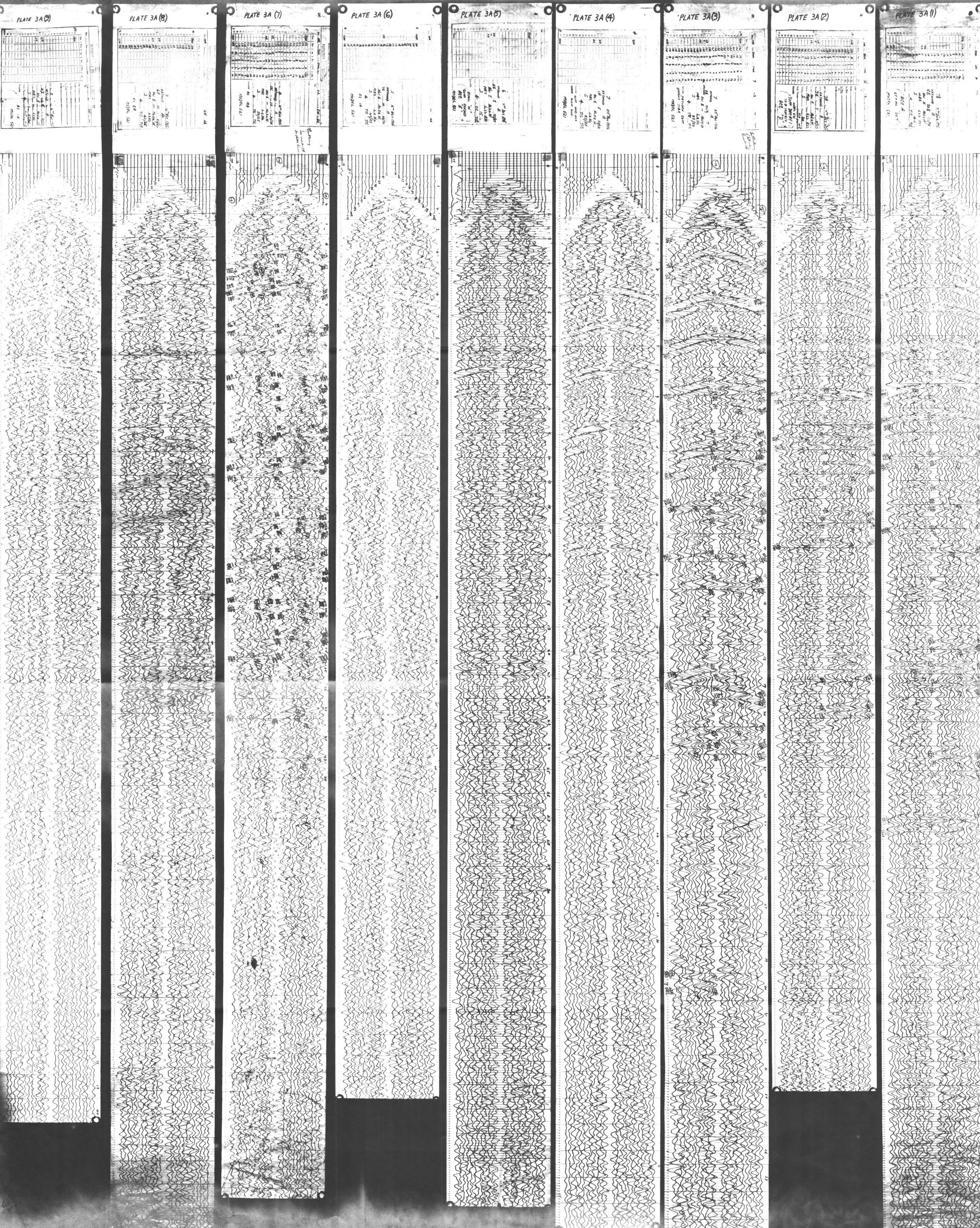
PLATE 3H(6).

This record was recorded from a 13-unit air shot offset at right angles 1,000 feet from shot point 28. The first energy to arrive was refracted and after this some reflections were recorded before the air-wave struck the spread. The times when energy would be expected to reach the geophones by refraction, reflection and through the air are marked on the record.

PLATE 3H(7).

This plate shows a record from a single-hole at shot point 29 on Traverse D.





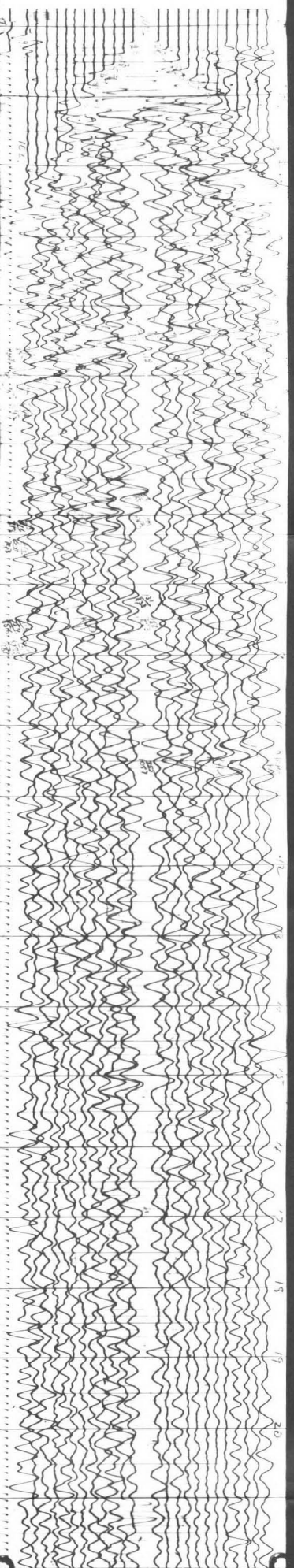
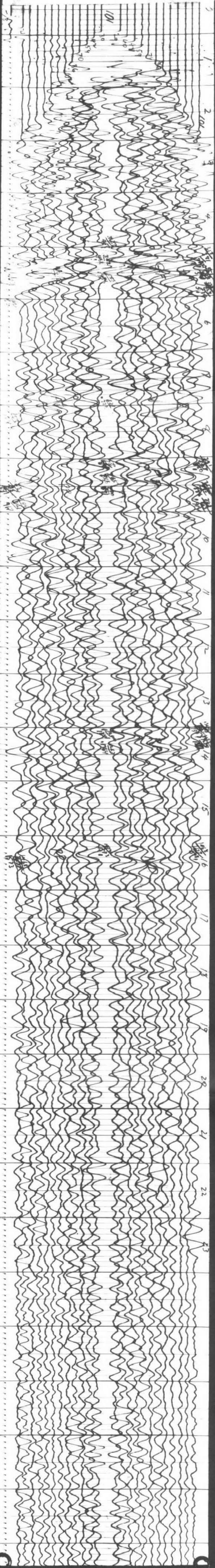
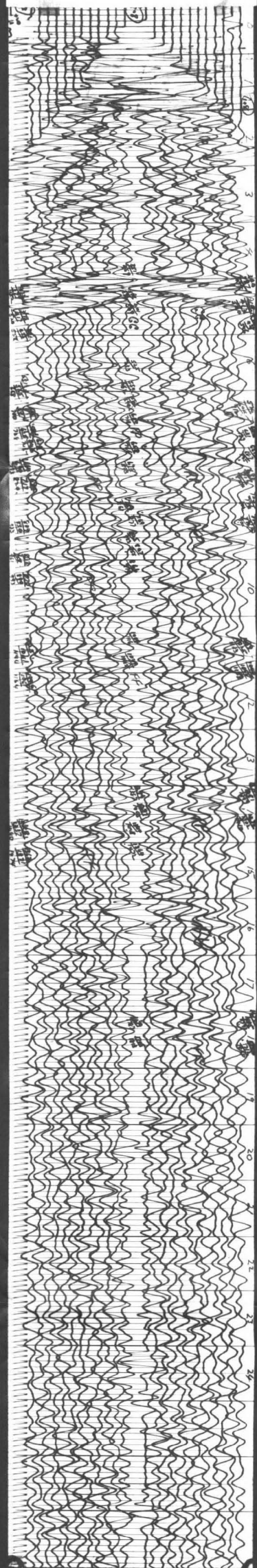
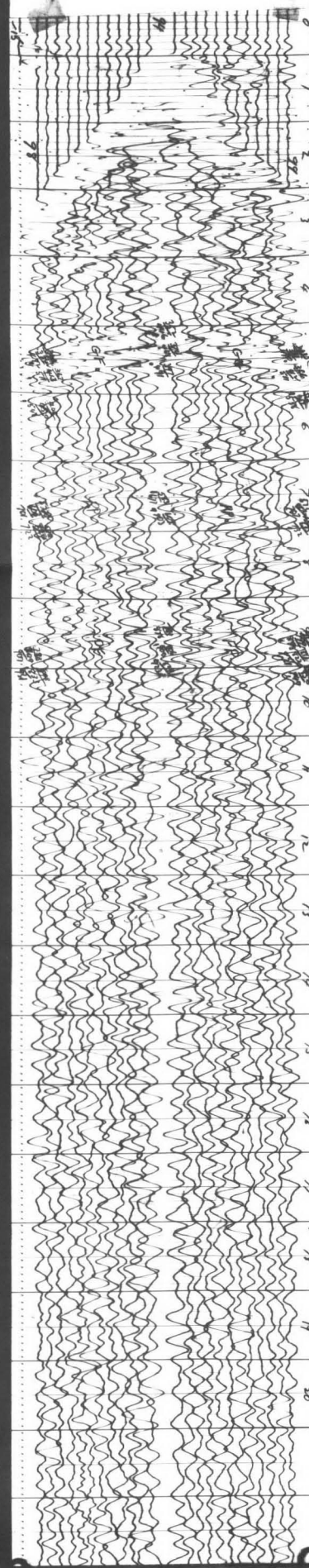
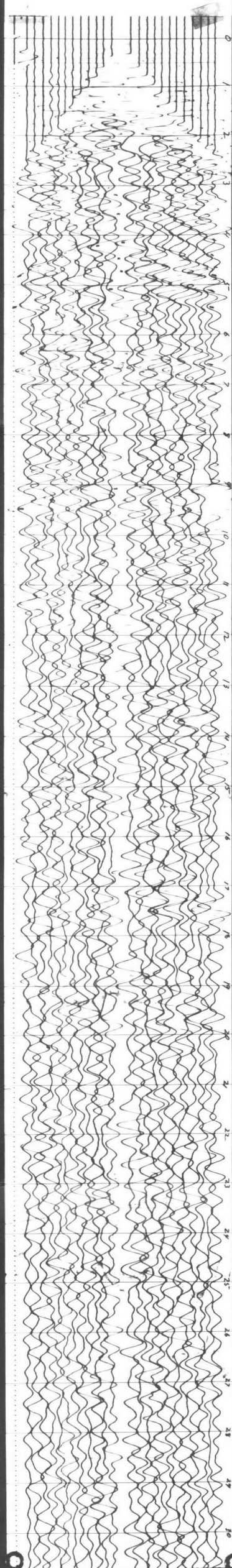
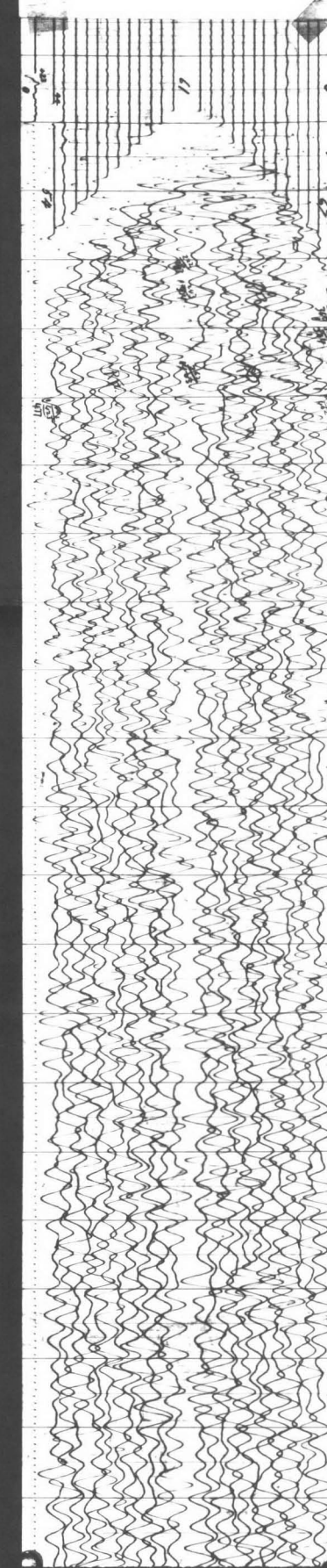
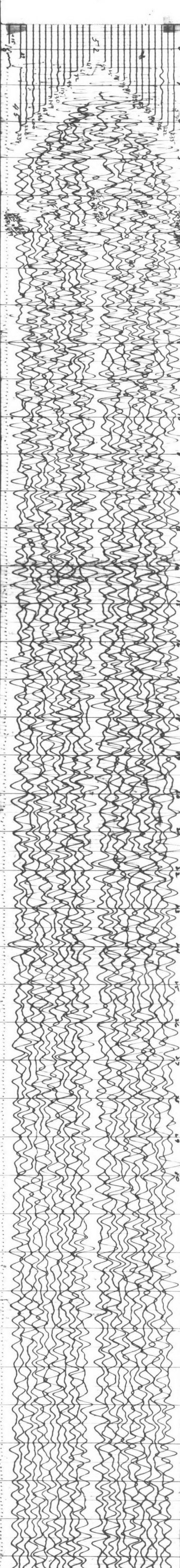
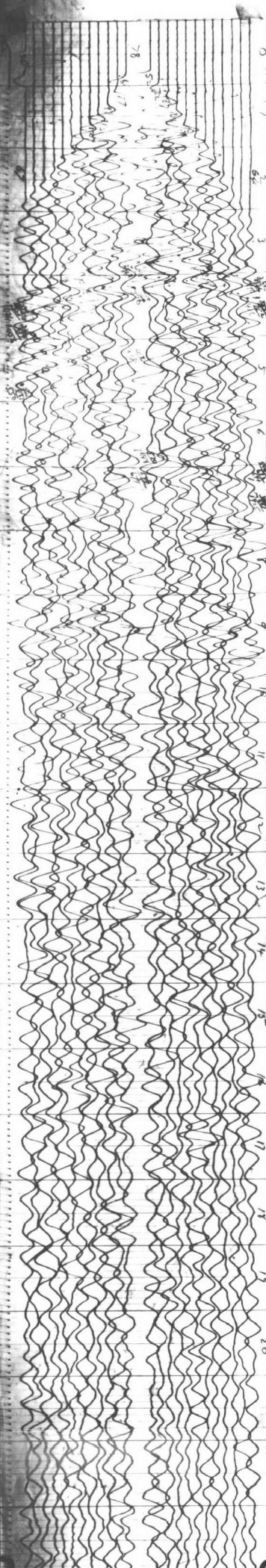
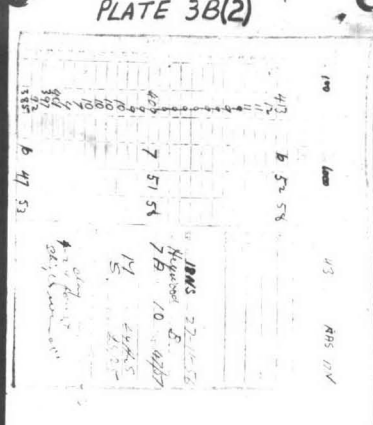
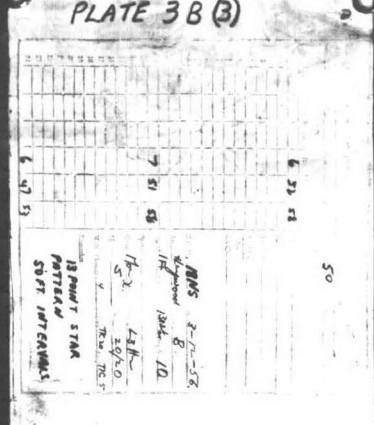
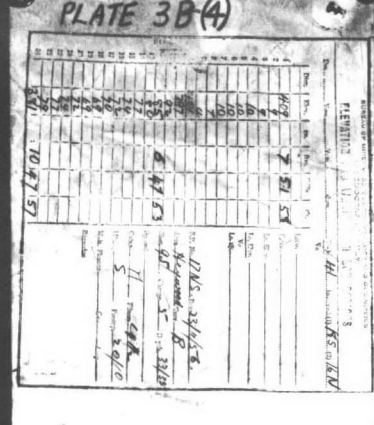
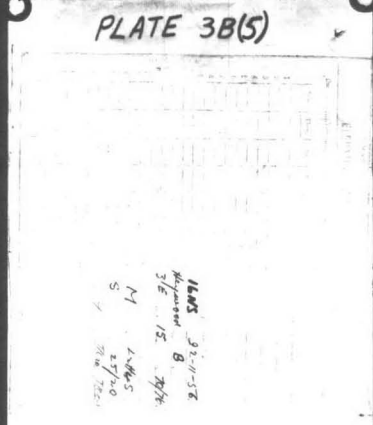
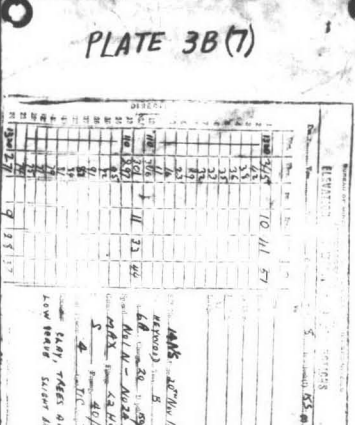
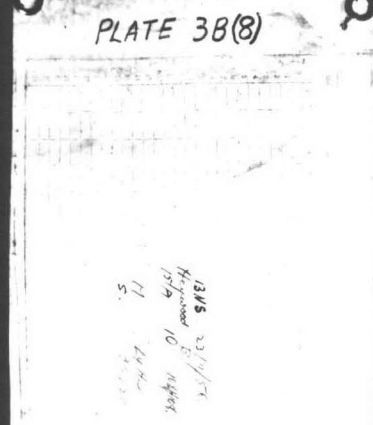
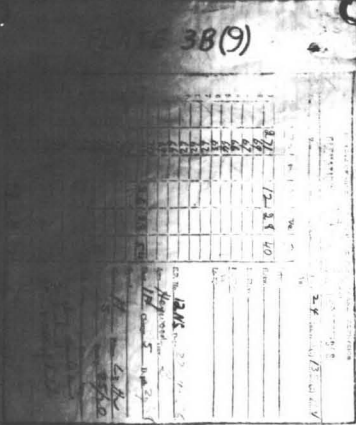


PLATE 3C(9)

PLATE 3C(8)

PLATE 3C(7)

PLATE 3C(6)

PLATE 3C(5)

PLATE 3C(4)

PLATE 3C(3)

PLATE 3C(2)

PLATE 3C(1)

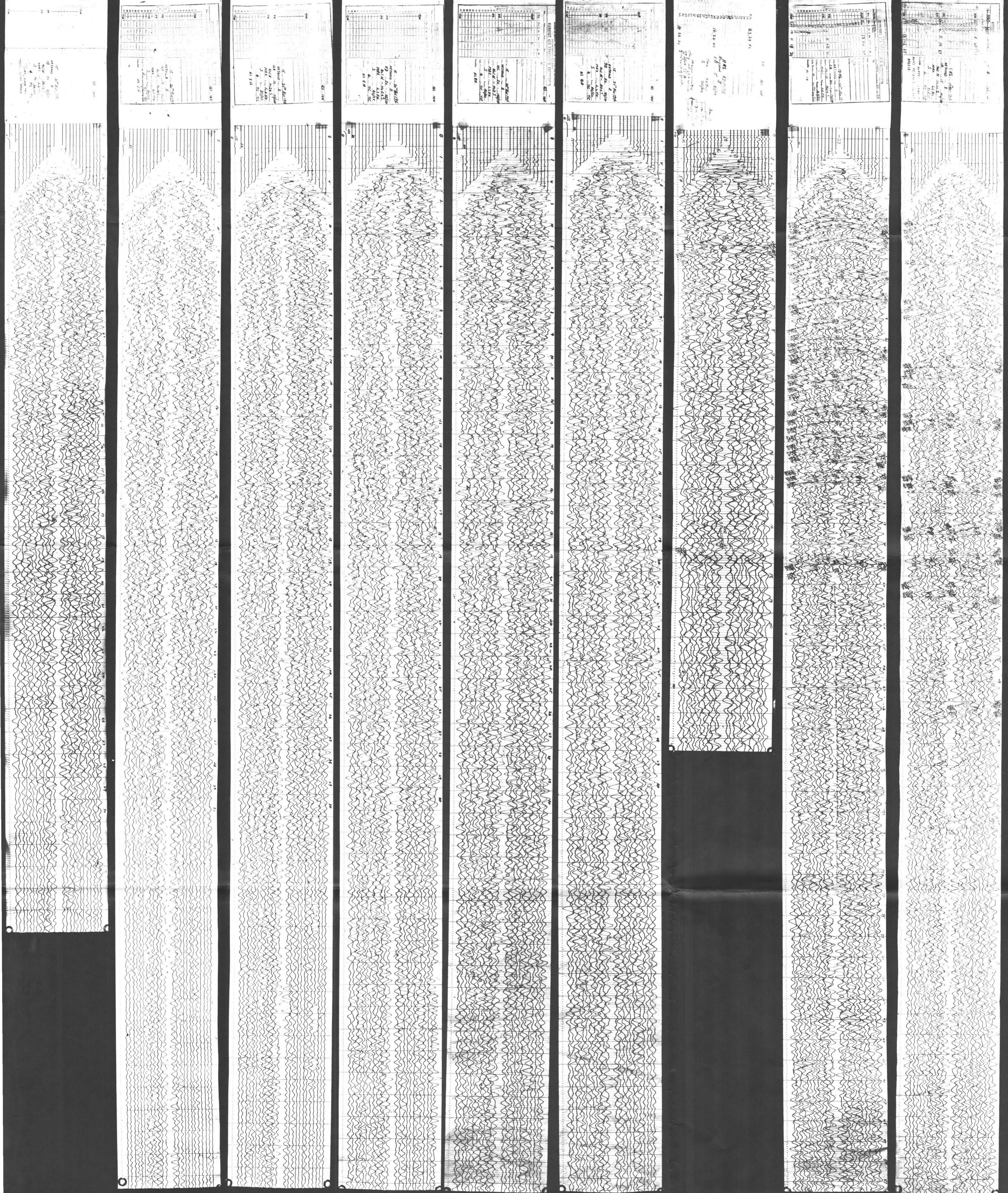


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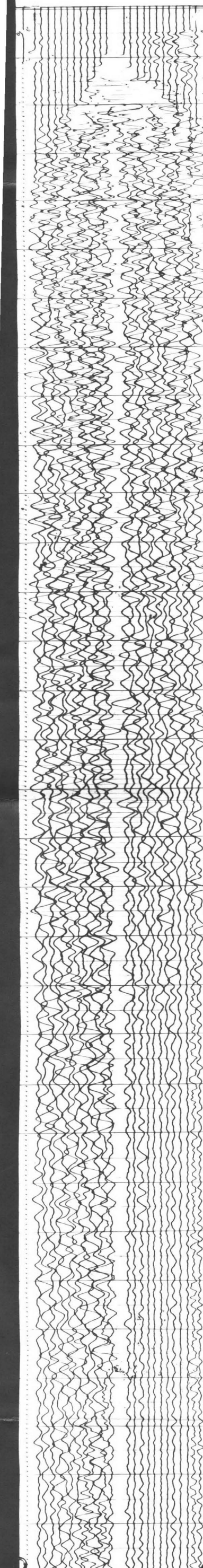
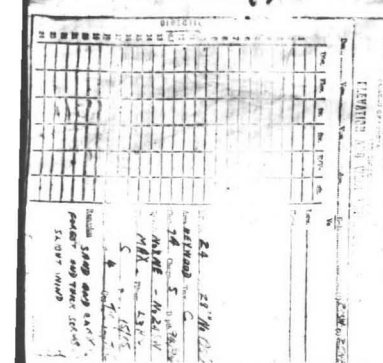


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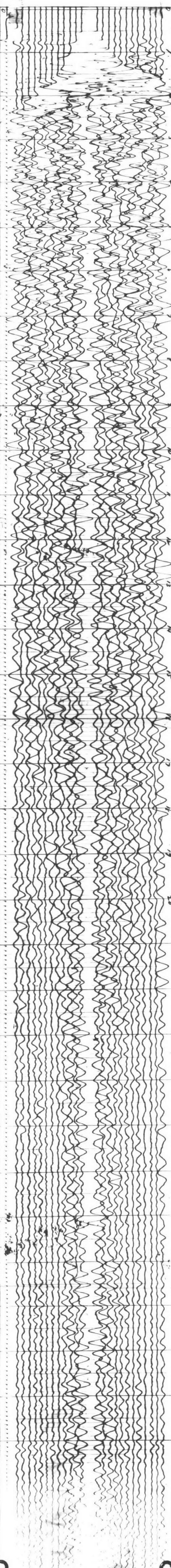
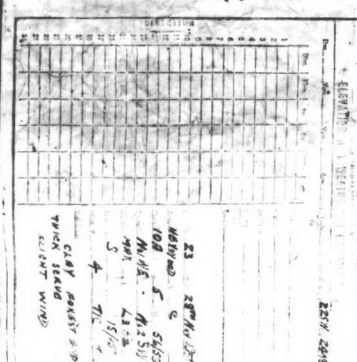


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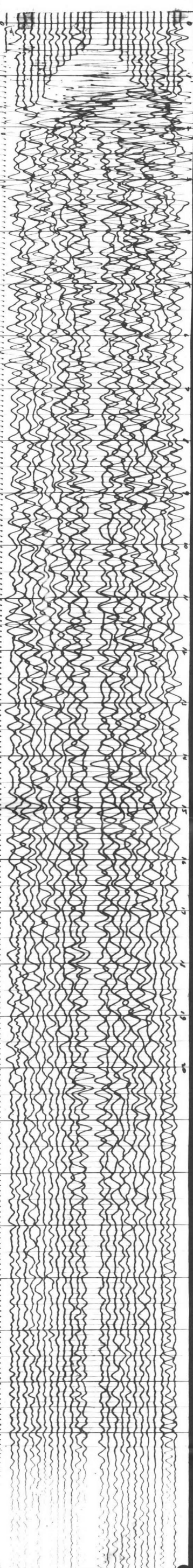
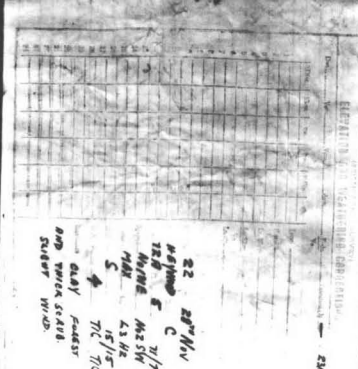


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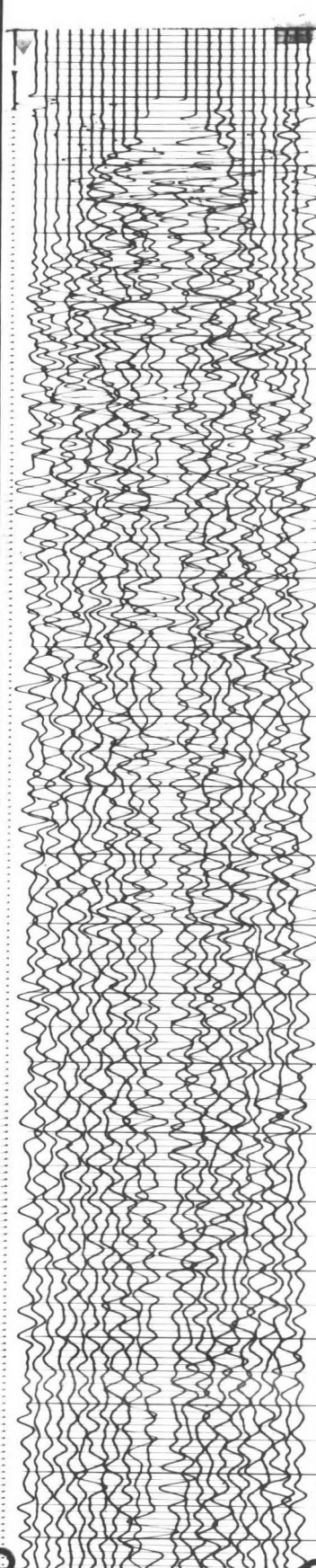
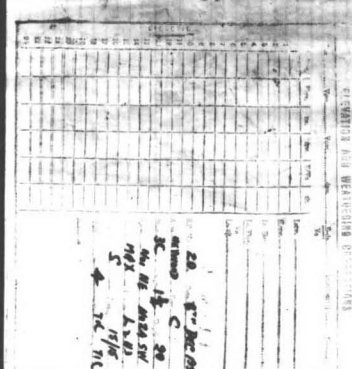


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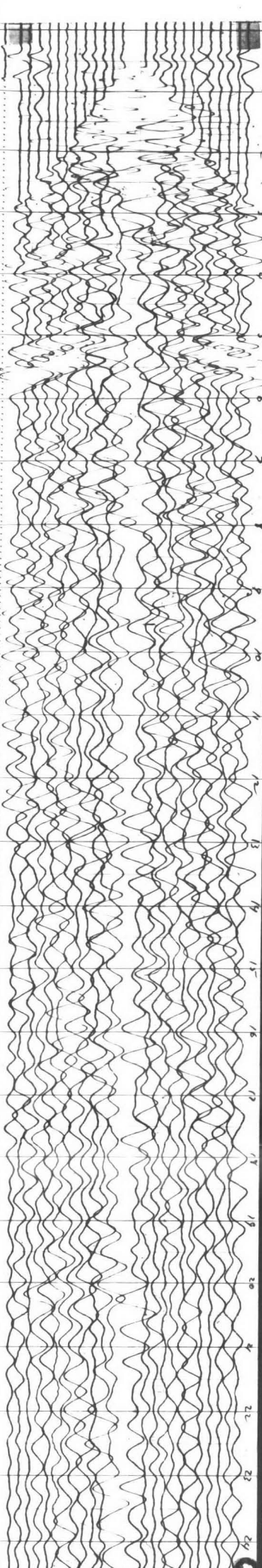
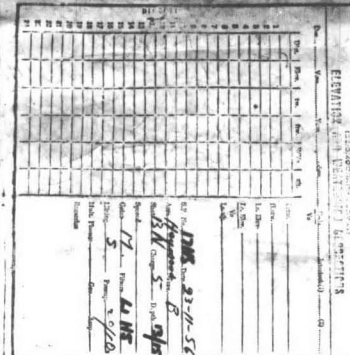


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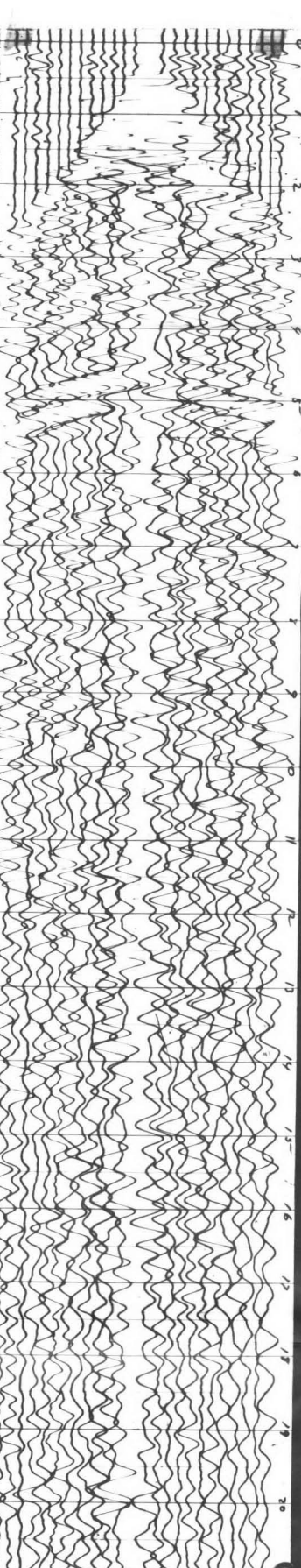
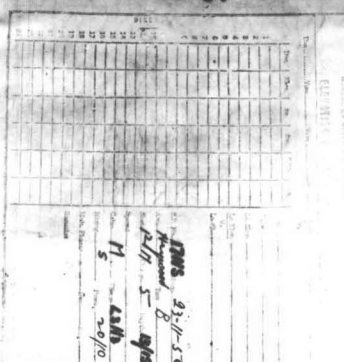


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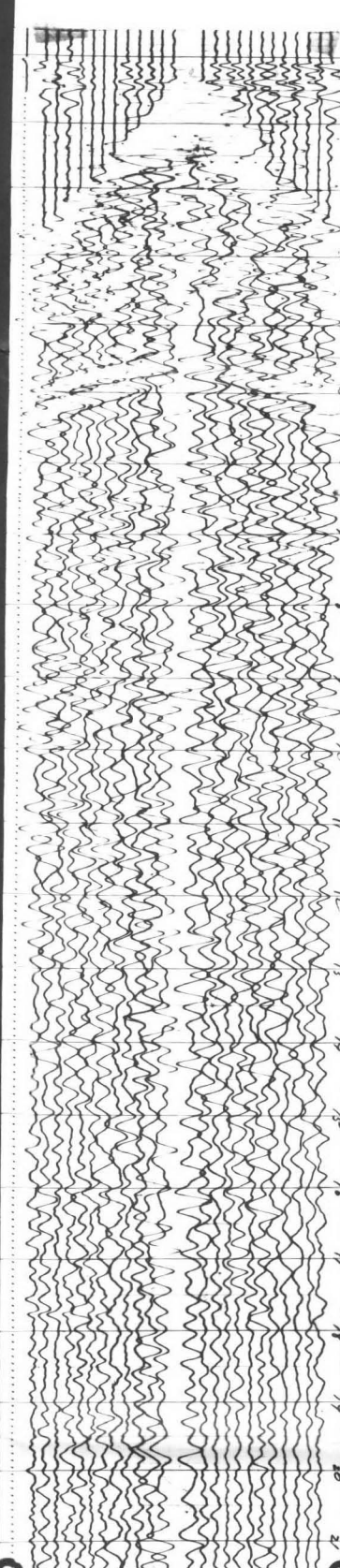
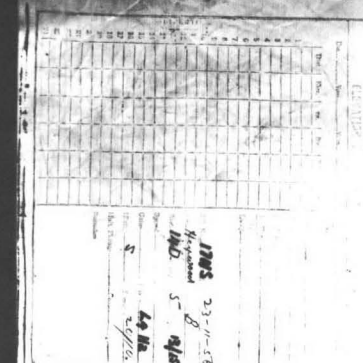


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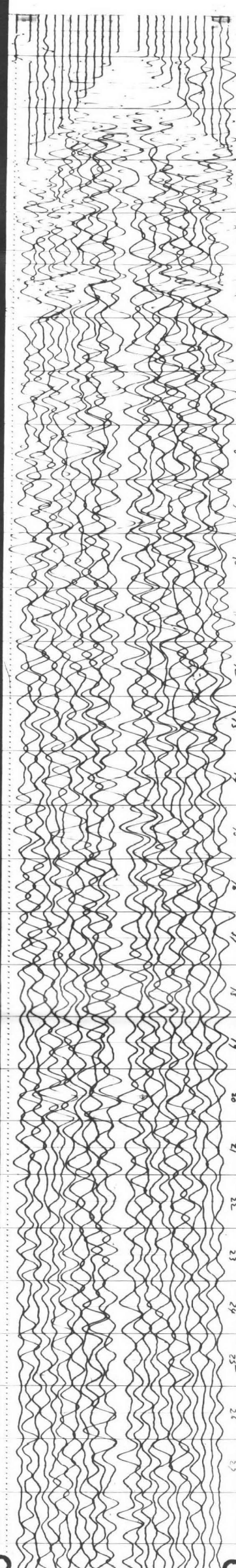
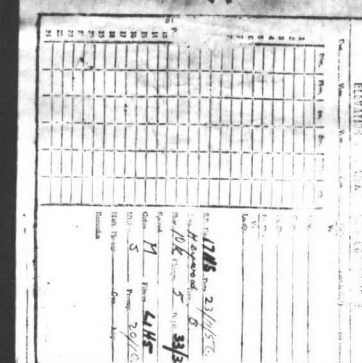
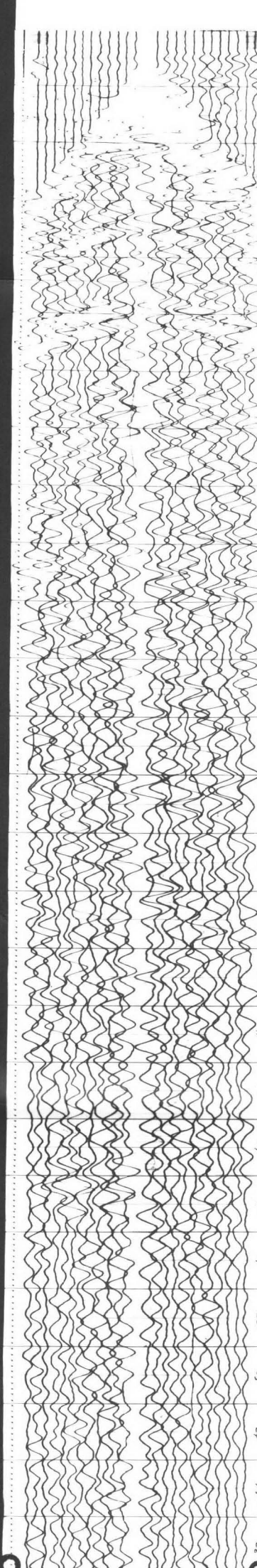
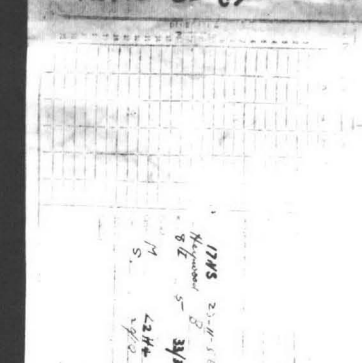
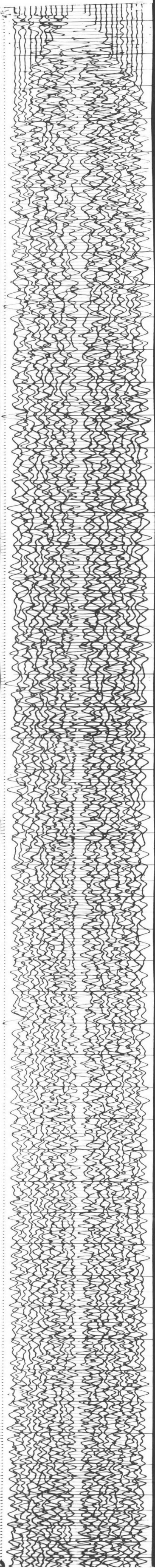
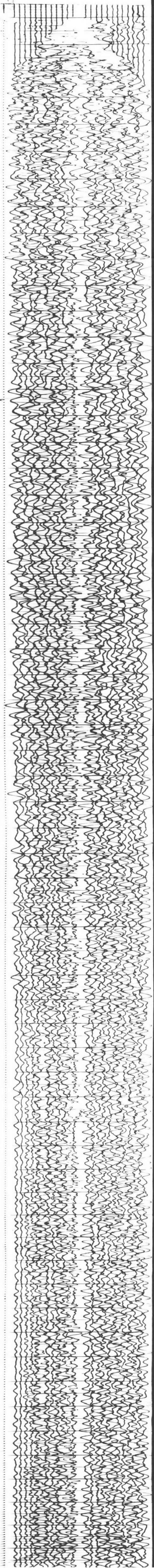
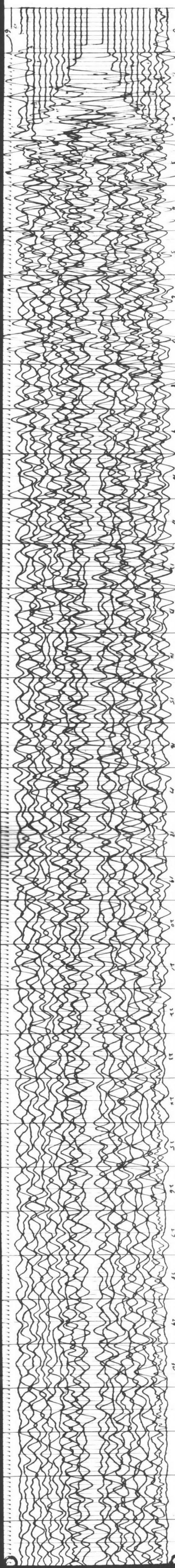


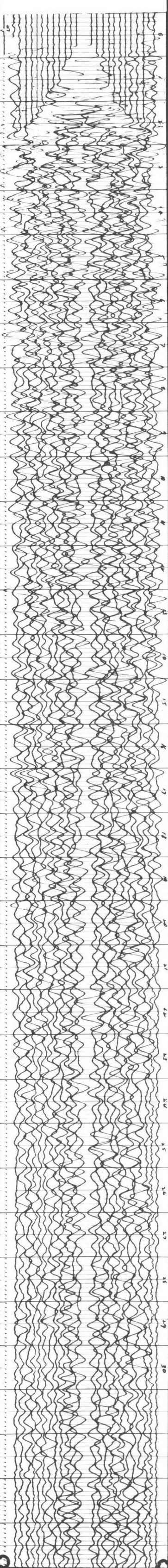
PLATE 3E (1)



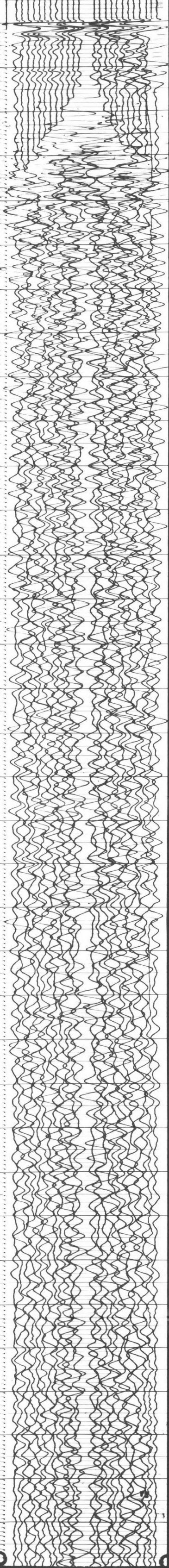
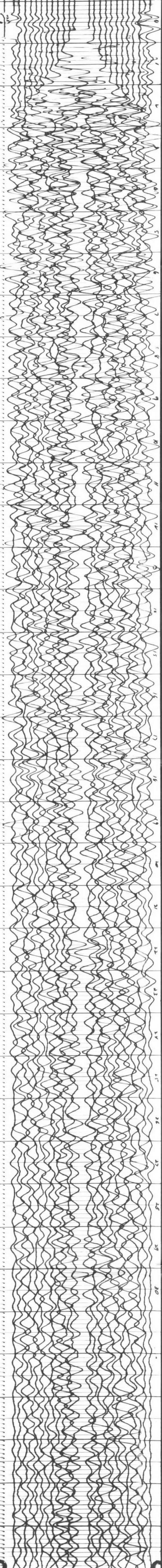
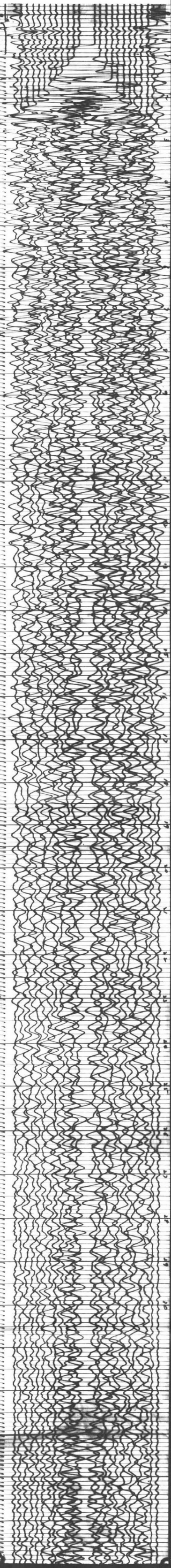
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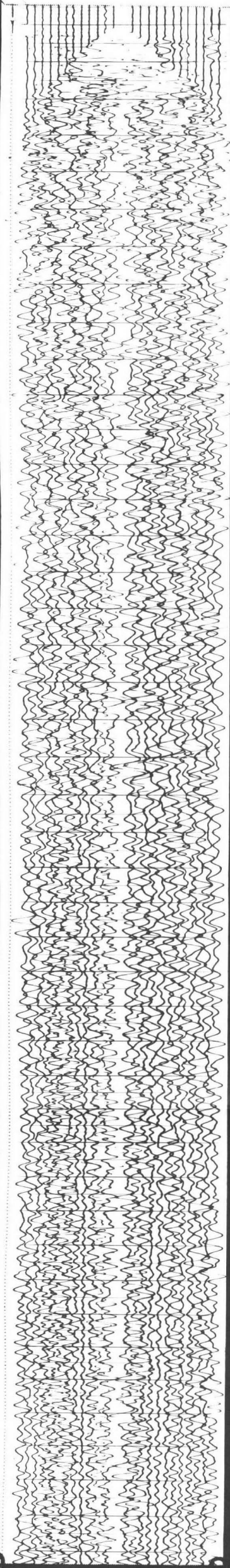
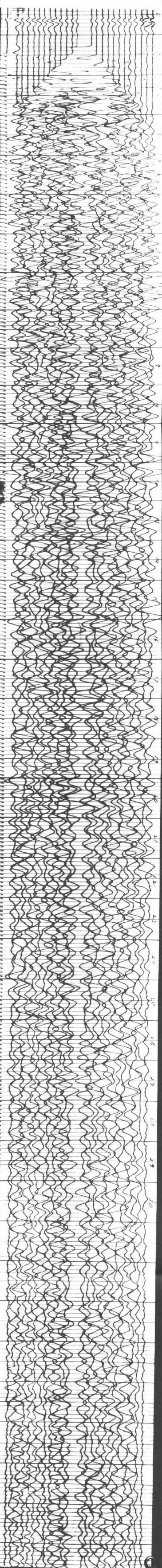
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PLATE 3G(7)

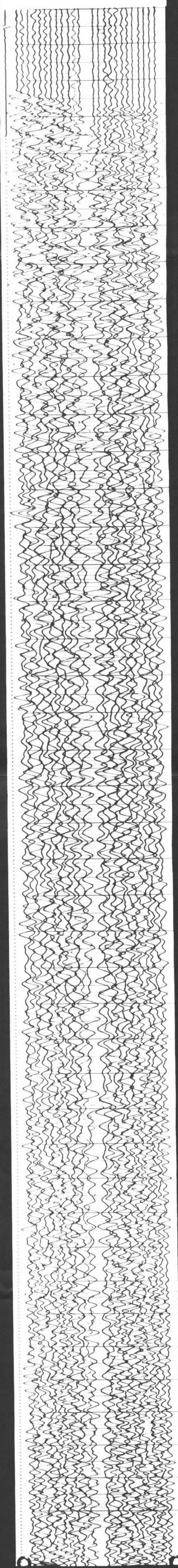
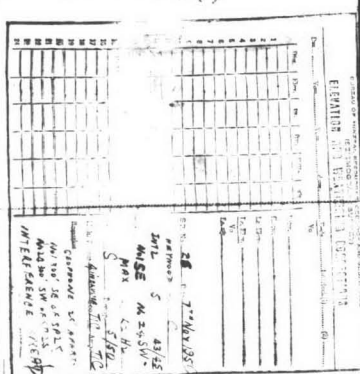


PLATE 3G(6)

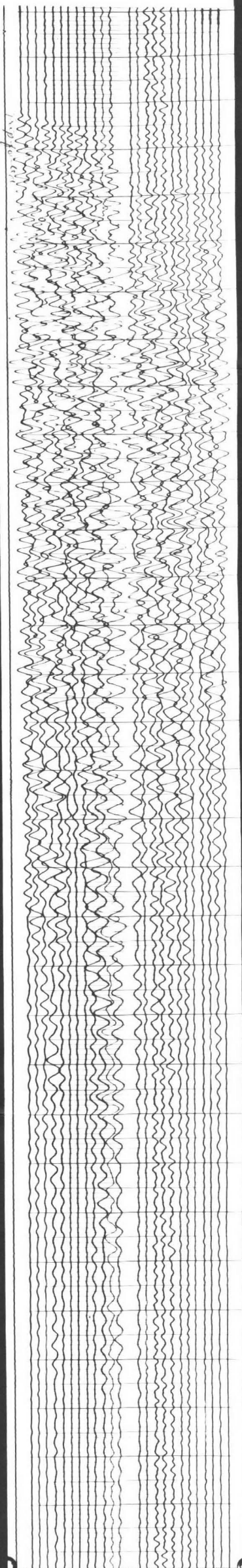
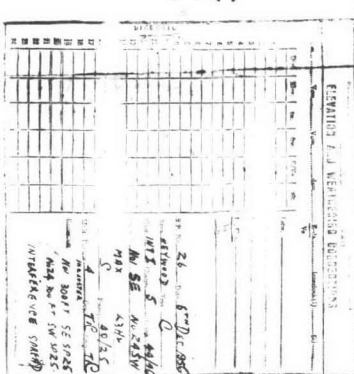


PLATE 3G(5)

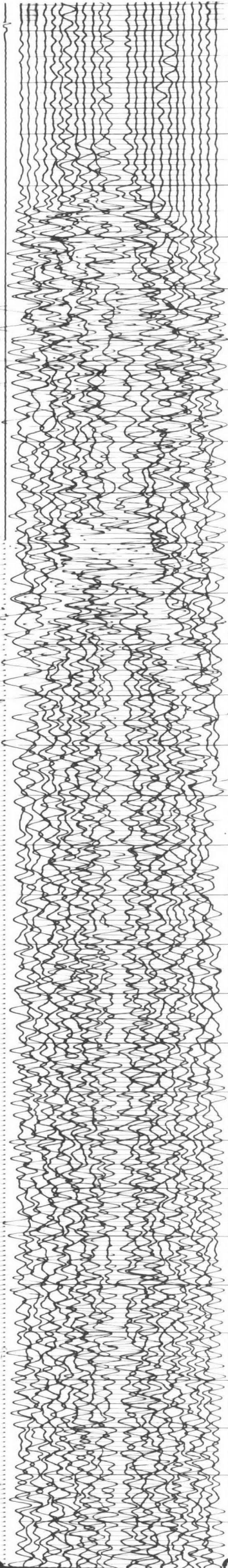
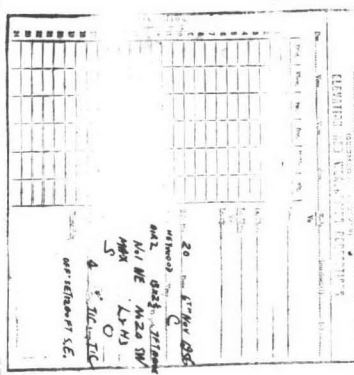


PLATE 3G(4)

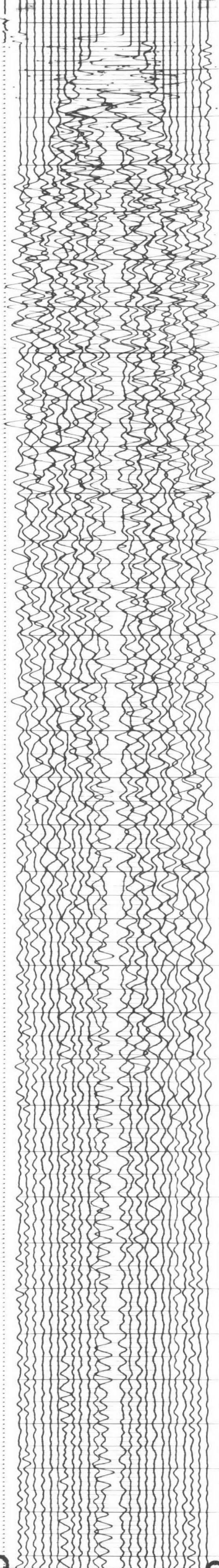
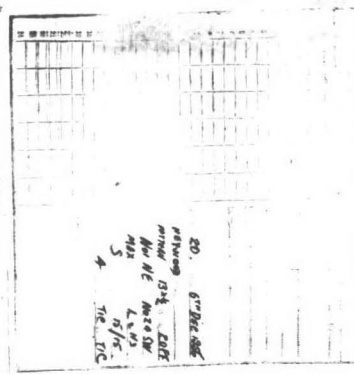


PLATE 3G(3)

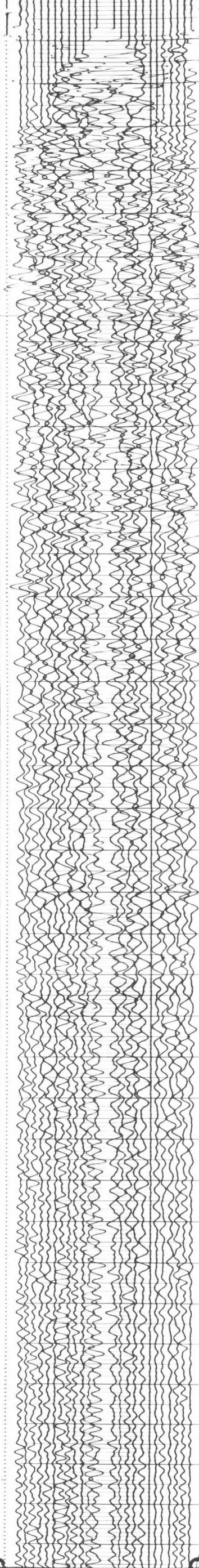
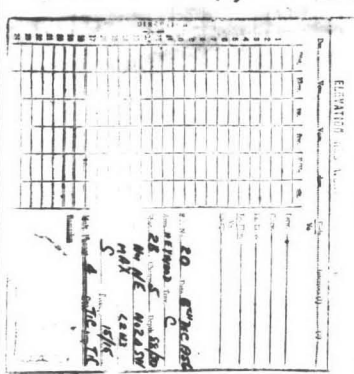


PLATE 3G(2)

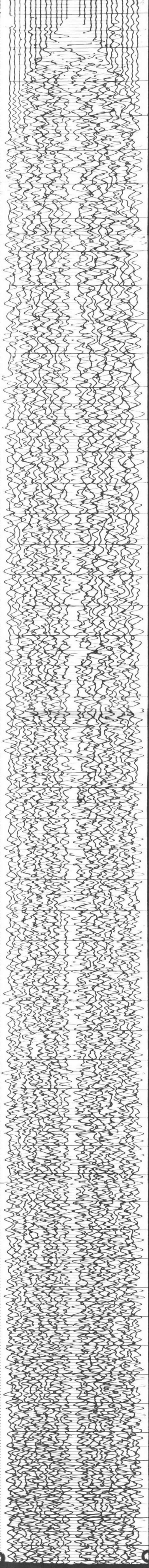
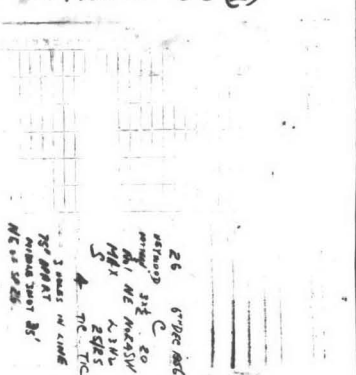


PLATE 3G(1)

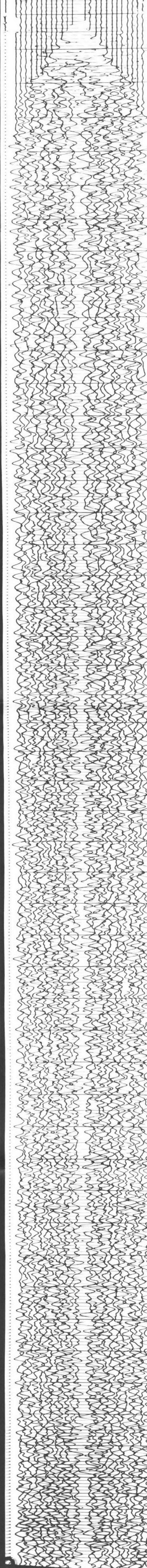
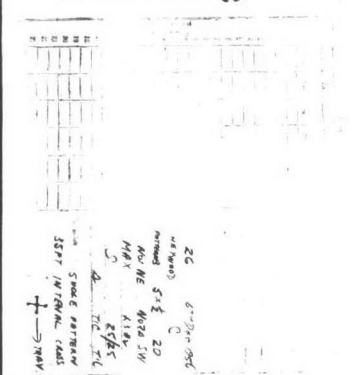


PLATE 3H(7)

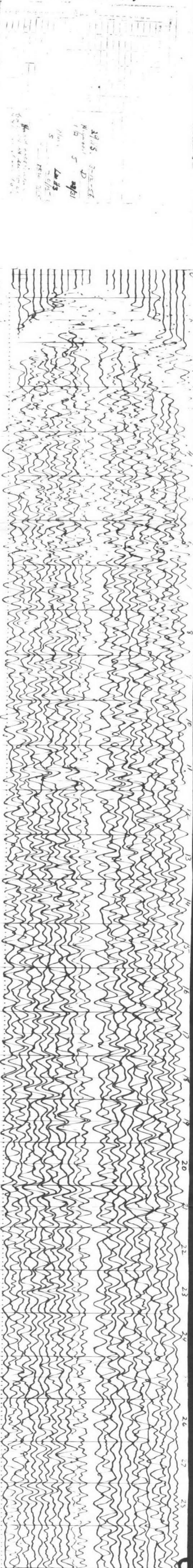


PLATE 3H(6)



PLATE 3H(5)

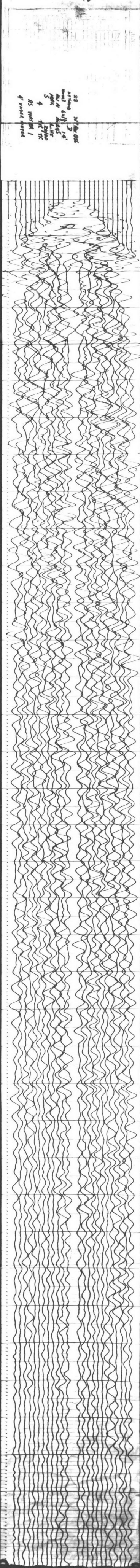


PLATE 3H(4)

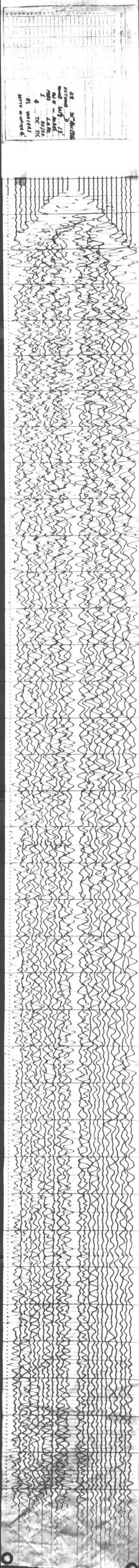


PLATE 3H(3)

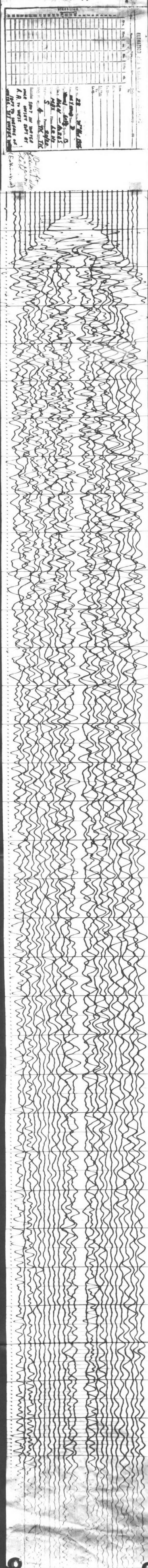


PLATE 3H(2)

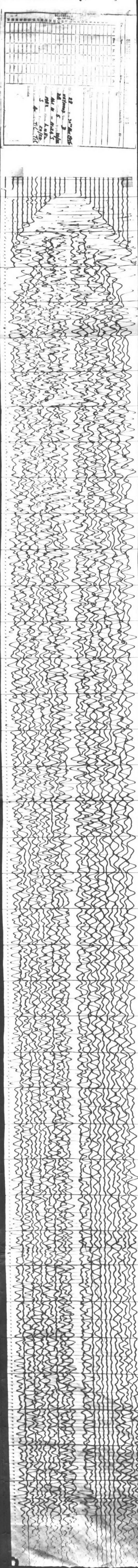
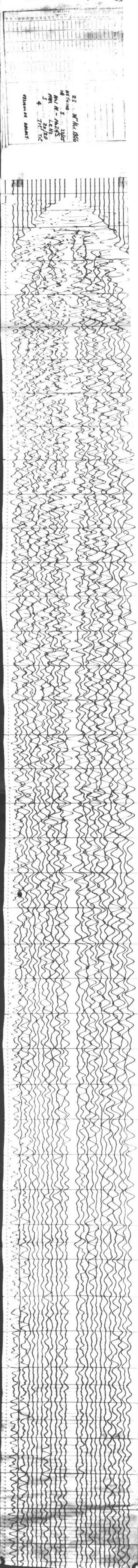
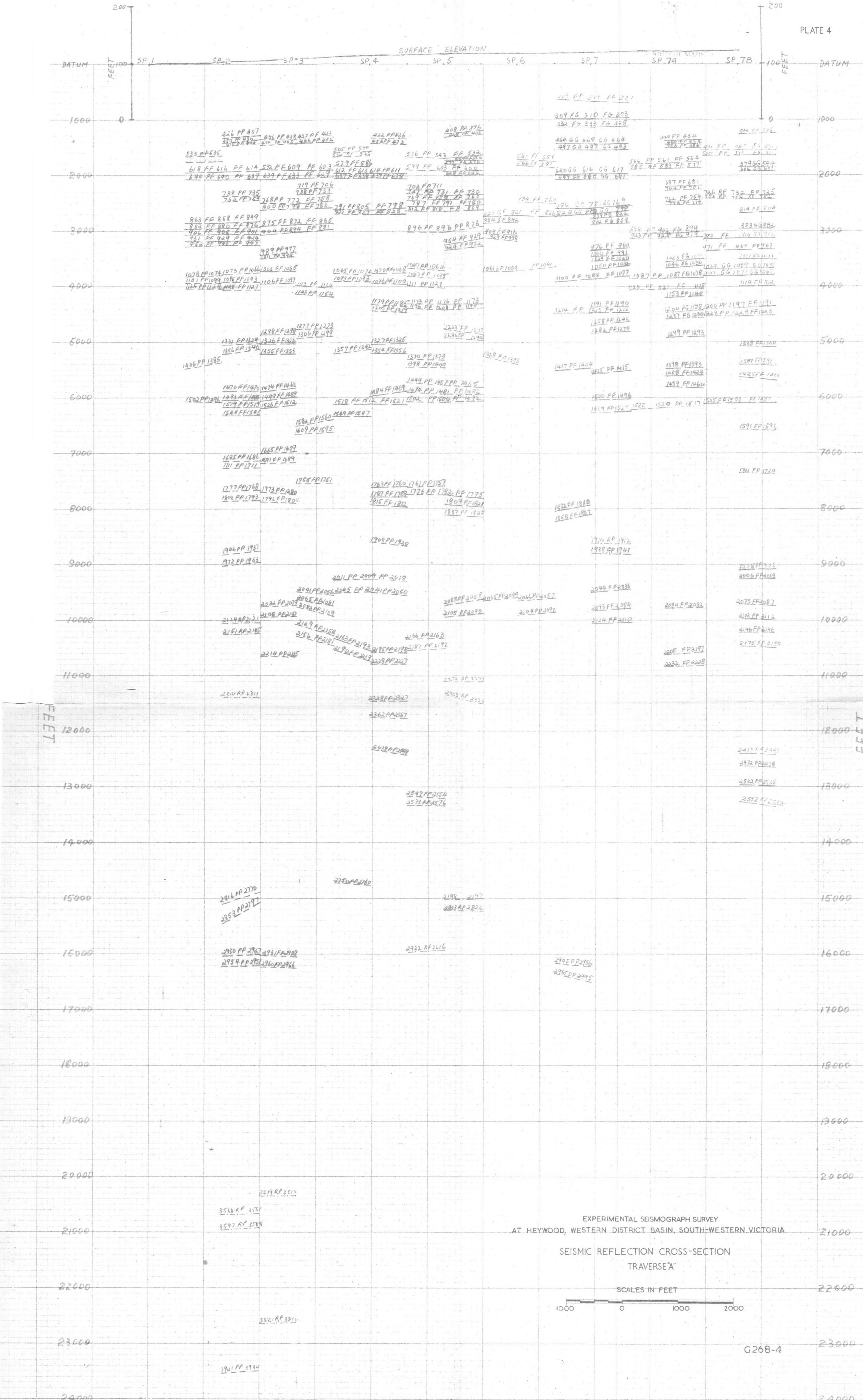
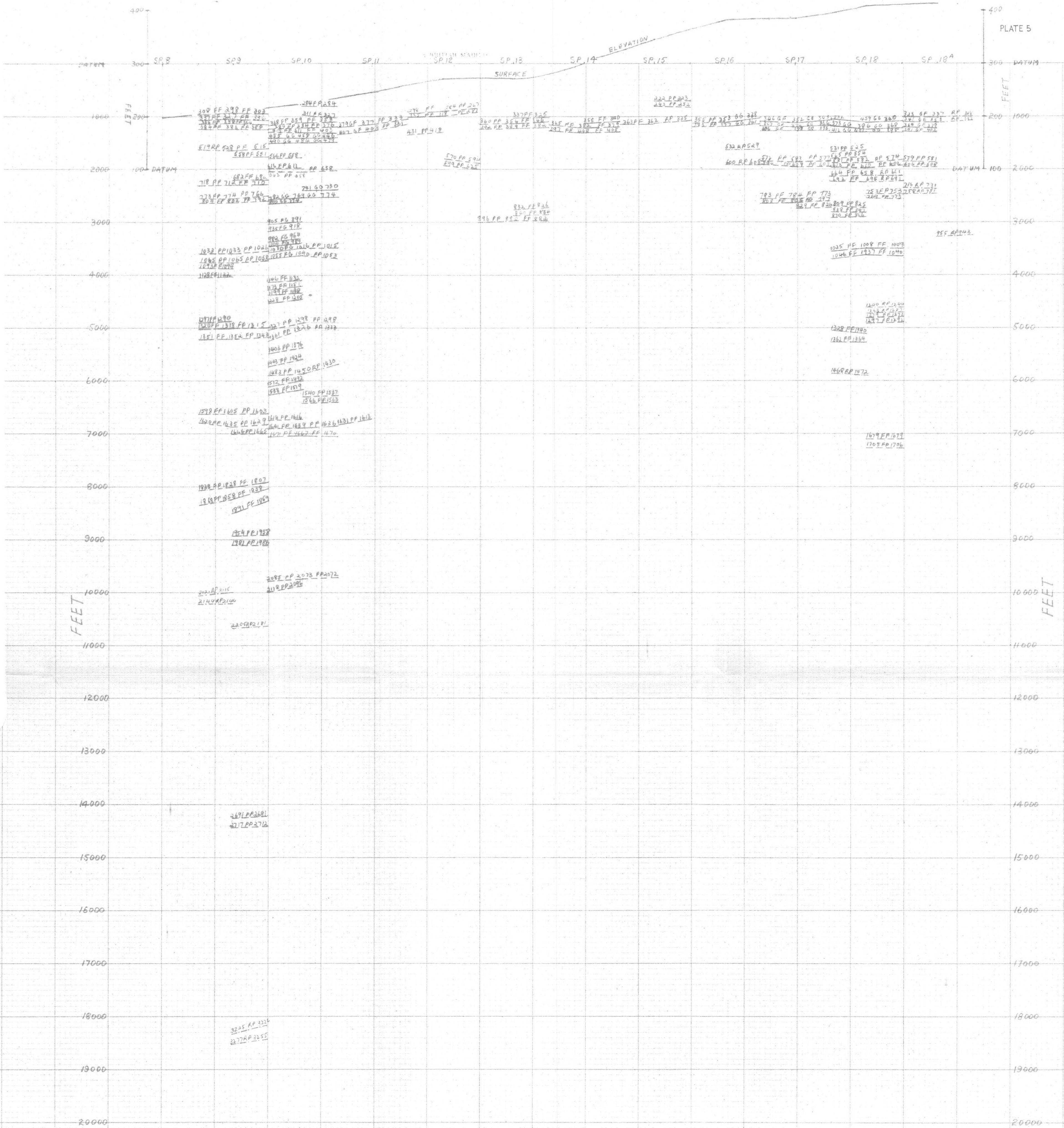


PLATE 3H(1)







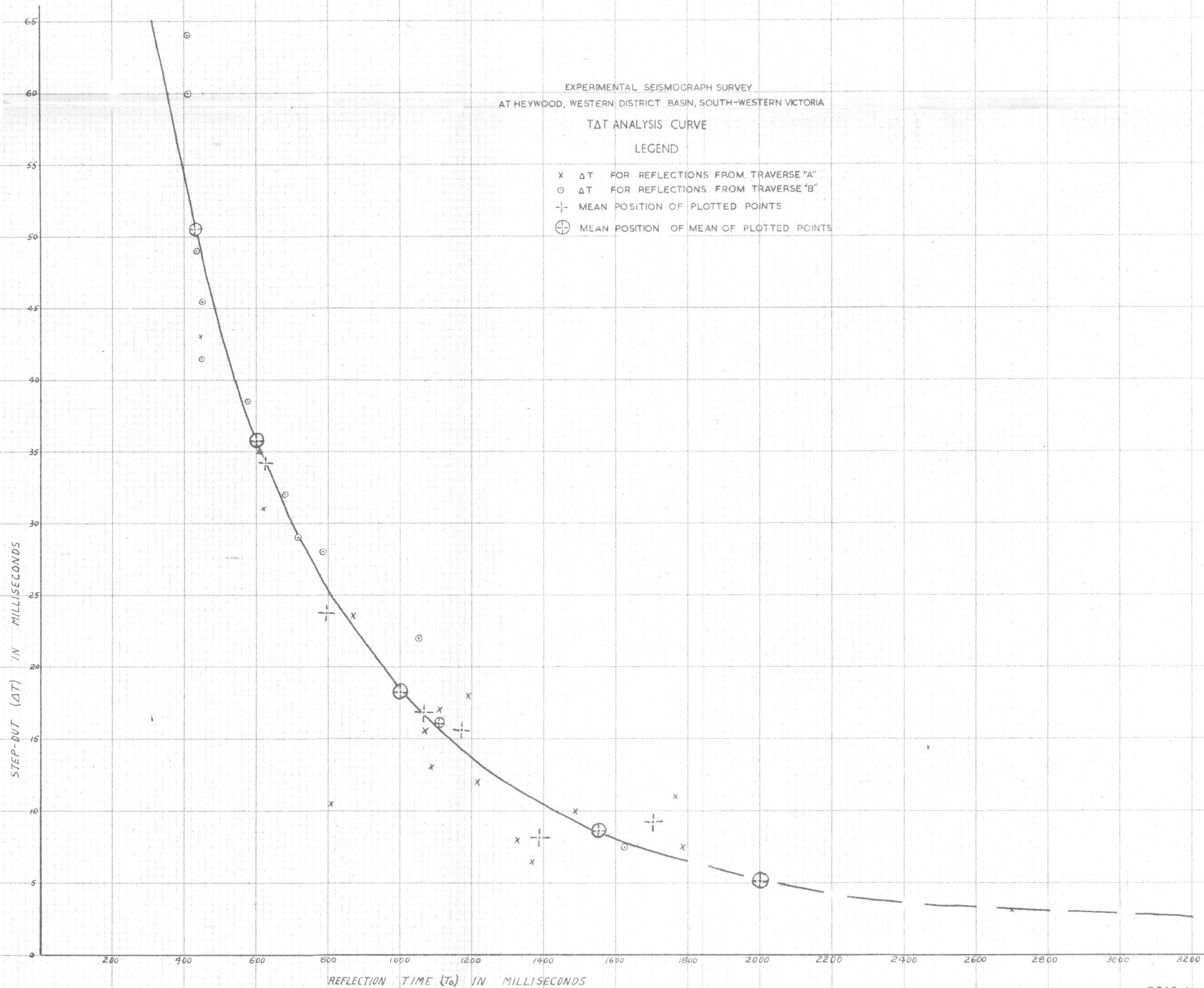
EXPERIMENTAL SEISMOGRAPH SURVEY
AT HEYWOOD, WESTERN DISTRICT BASIN, SOUTH-WESTERN VICTORIA
SEISMIC REFLECTION CROSS SECTION
TRAVERSE "B"
SCALES IN FEET
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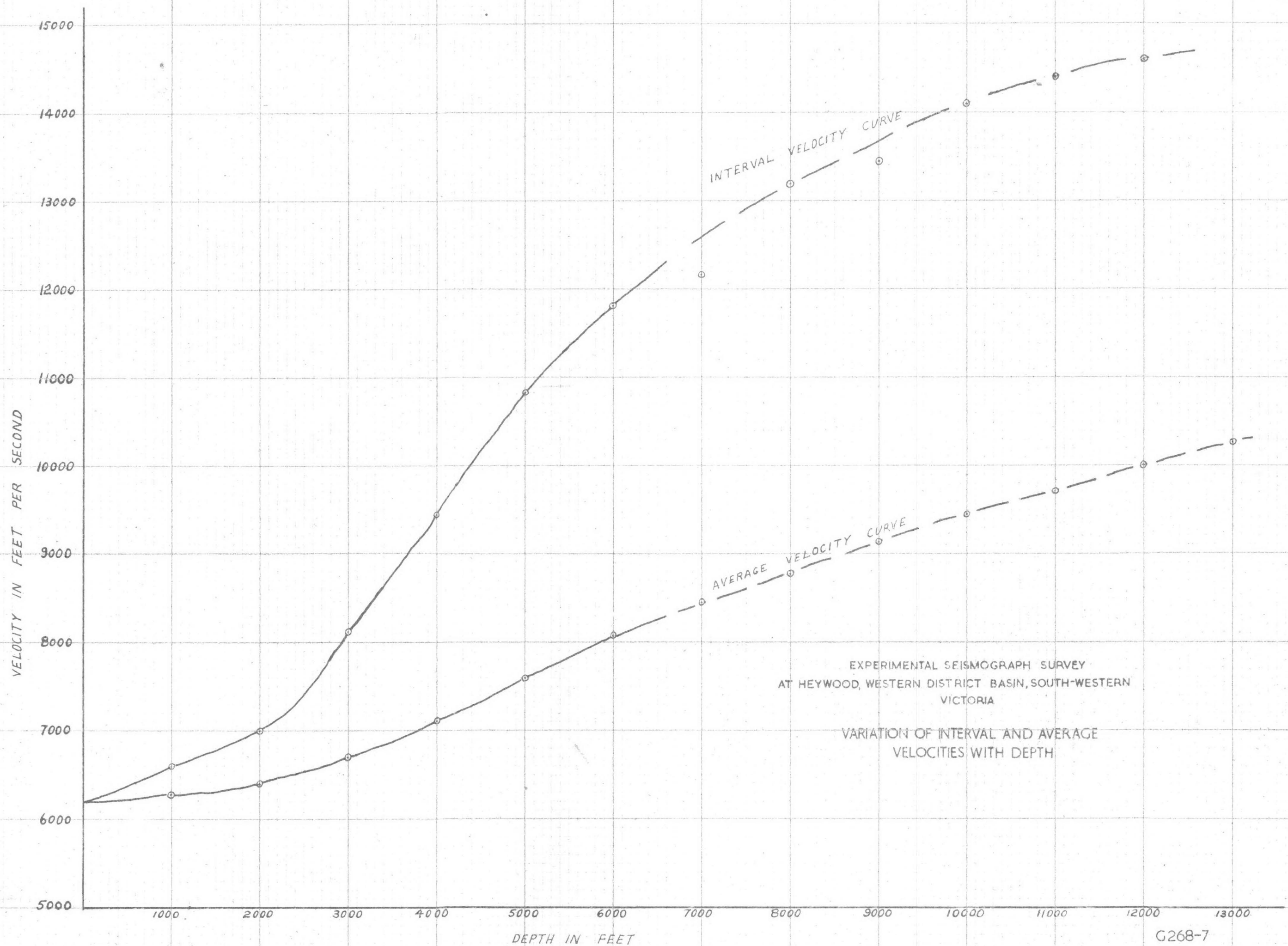
EXPERIMENTAL SEISMOGRAPH SURVEY
AT HEYWOOD, WESTERN DISTRICT BASIN, SOUTH-WESTERN VICTORIA

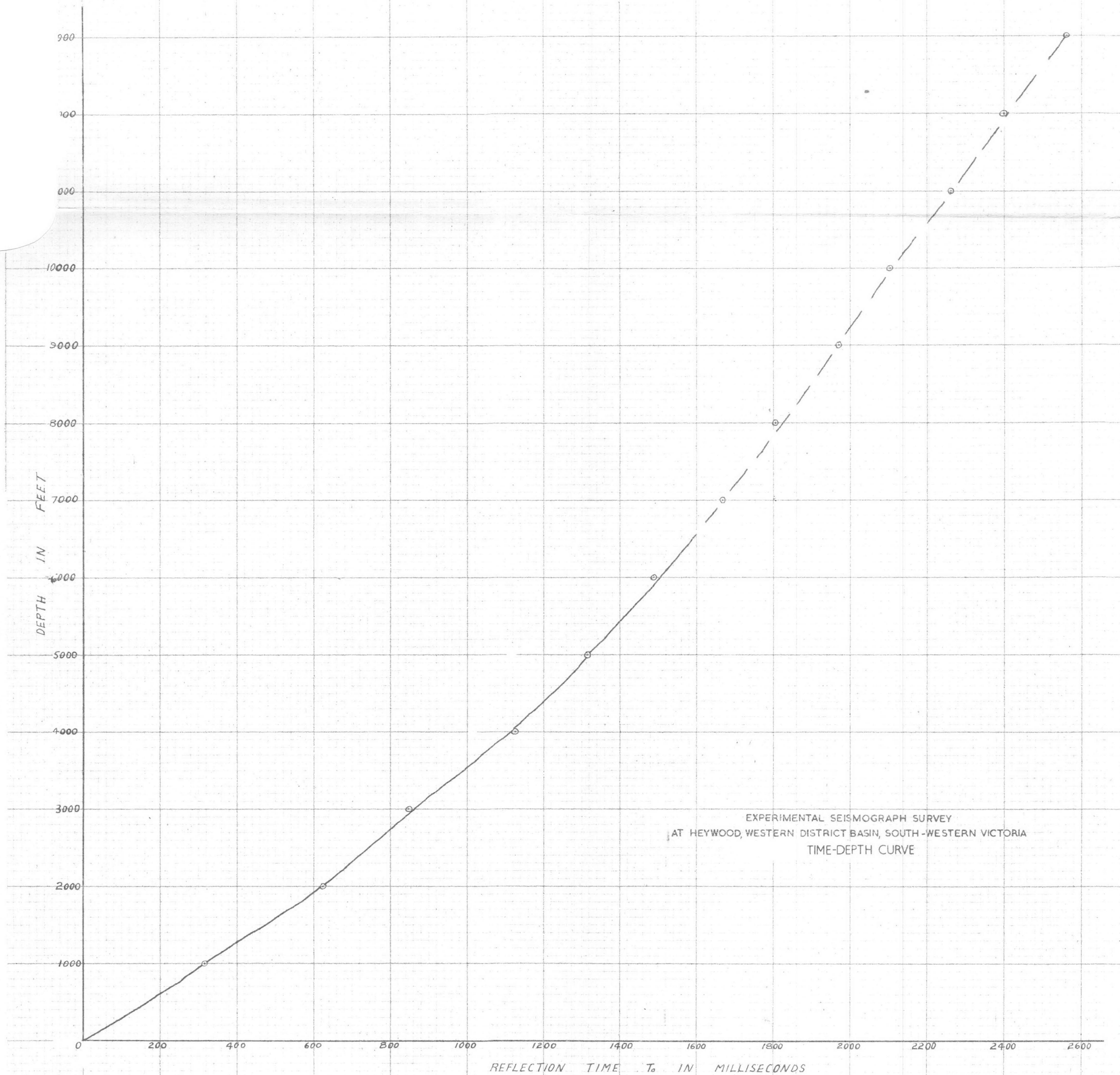
TΔT ANALYSIS CURVE

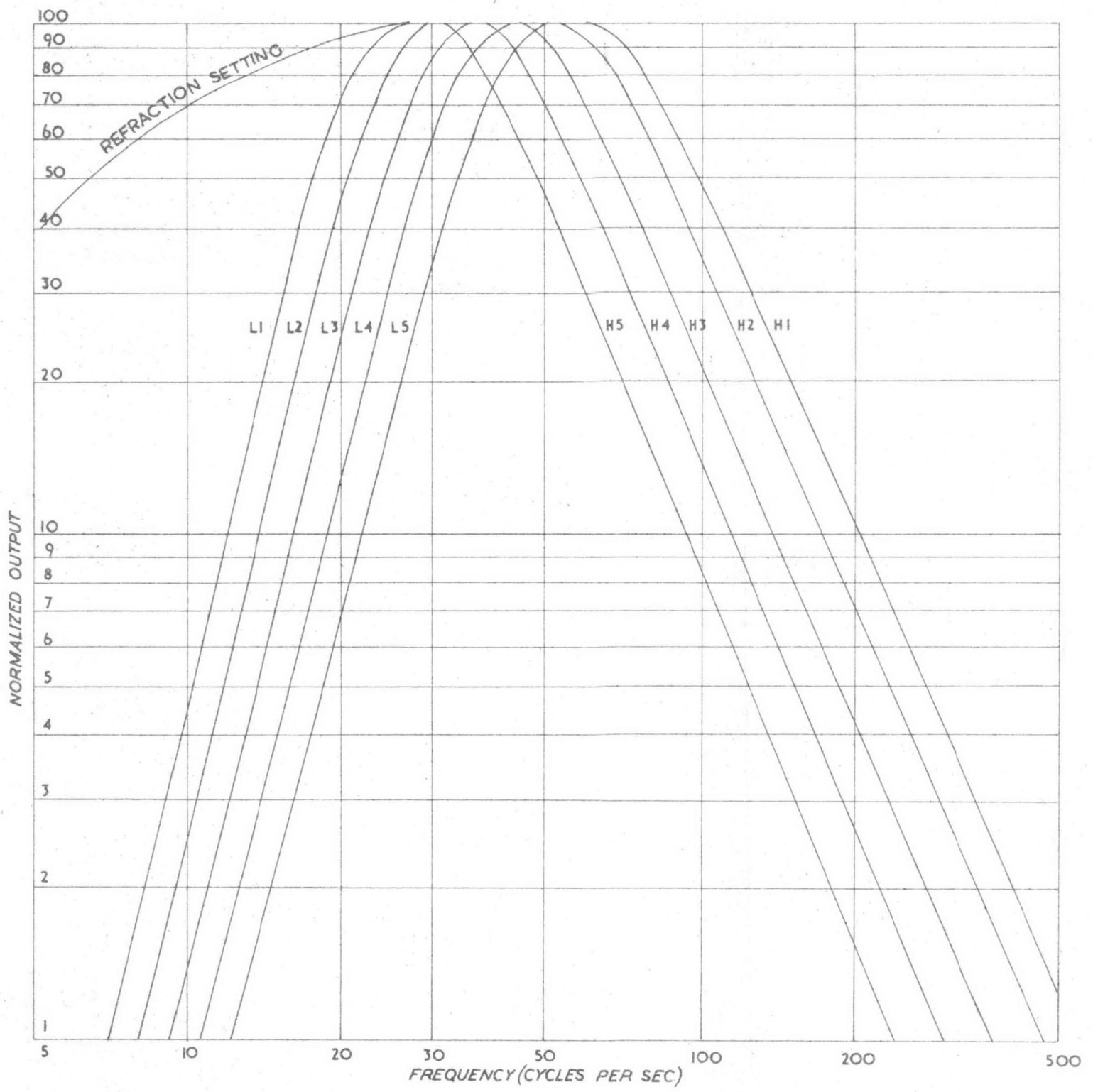
LEGEND

- x ΔT FOR REFLECTIONS FROM TRAVERSE "A"
- ΔT FOR REFLECTIONS FROM TRAVERSE "B"
- + MEAN POSITION OF PLOTTED POINTS
- ⊕ MEAN POSITION OF MEAN OF PLOTTED POINTS

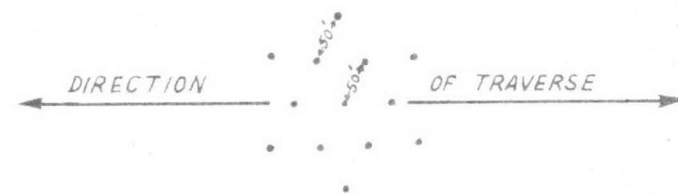






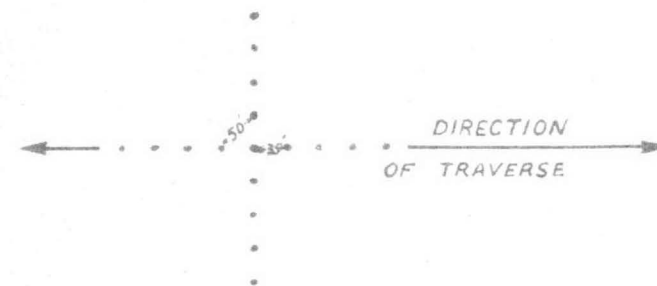


FILTER CURVES
T.I.C. AMPLIFIER BAND PASS TYPE 521



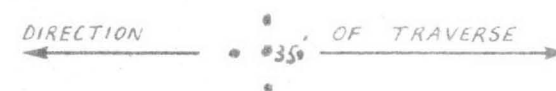
13 POINT STAR PATTERN

USED FOR HOLE SHOOTING AND AIR SHOOTING AT SHOT POINTS 7, 18, 20 AND 28.



17 HOLE CROSS PATTERN

USED AT SHOT POINT 26.



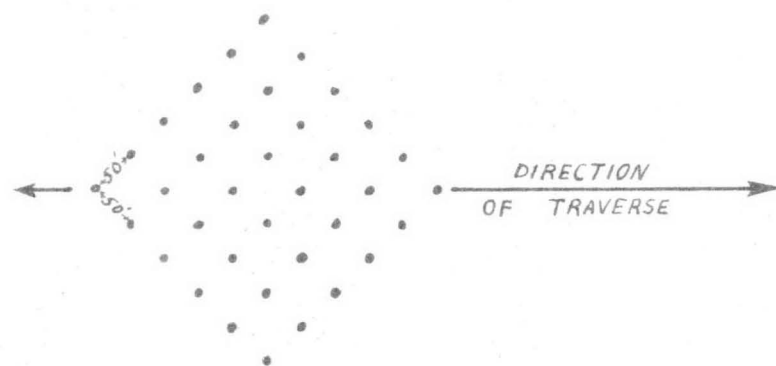
5 HOLE CROSS PATTERN

USED AT SHOT POINT 26



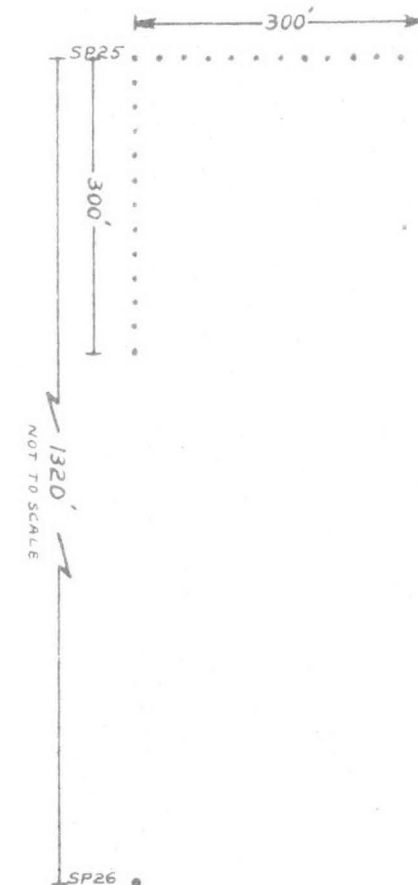
3 HOLE IN-LINE PATTERN

USED AT SHOT POINT 26



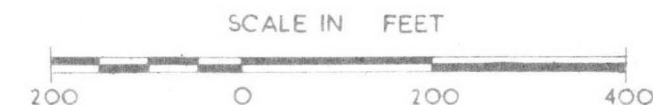
36 HOLE DIAMOND PATTERN

USED AT SHOT POINT 26

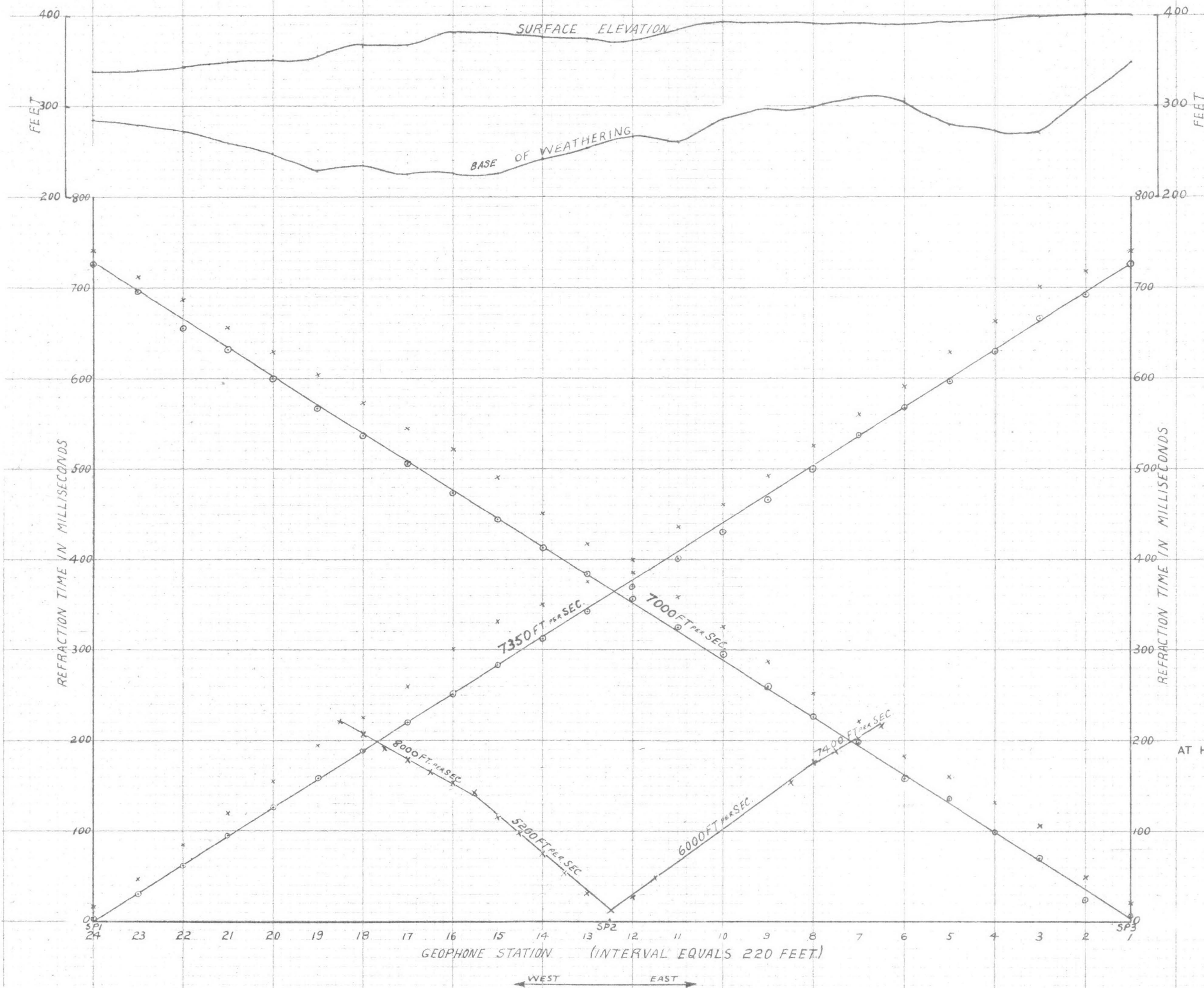


GEOPHONE PATTERN FOR ANALYSING NOISE FREQUENCY

SHOT FIRED AT SHOT POINT 26



EXPERIMENTAL SEISMOGRAPH SURVEY
AT HEYWOOD, WESTERN DISTRICT BASIN, SOUTH WESTERN VICTORIA
LAYOUT OF PATTERN SHOTS



EXPERIMENTAL SEISMOGRAPH SURVEY
 AT HEYWOOD, WESTERN DISTRICT BASIN, SOUTH - WESTERN VICTORIA
 REFRACTION PROFILE
 JURASSIC ROCKS NEAR DIGBY

LEGEND
 x UNCORRECTED TIME
 o TIME CORRECTED FOR WEATHERING
 (ASSUMING THAT ONE VELOCITY WAS RECORDED)