COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES,

GEOLOGY AND GEOPHYSICS

RECORDS 1959, No. 19

AN EXPERIMENTAL SEISMIC SURVEY, HADDON DOWNS, SOUTH AUSTRALIA

by

E. R. SMITH and K. B. LODWICK

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DEPARTMENT OF NATIONAL DEVELOPMENT

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(J.M. RAYNER)
Director.

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ABSTRACT

An experimental seismic survey was conducted at Haddon Downs, South Australia, during October and November, 1957. The area lies within the Eromanga Sub-basin of the Great Artesian Basin, and at least 5,500 feet of Mesozoic section are known to exist there, part of which is of a marine facies. Preliminary reconnaissance work by geologists of Santos Ltd. which holds an Oil Prospecting Licence over the area, revealed some large anticlines on the surface.

The Company has already completed a limited amount of gravity work which gives promise of supplying useful information on both regional and detailed subsurface structure.

Two important refractors were recorded which may be useful for semi-regional mapping. A refractor of velocity 10,250 ft/sec. was recorded from a depth of about 2,700 feet, and this may represent the top of the marine Cretaceous section. The second refractor of velocity 17,000 ft/sec. and approximate depth 7,250 feet may be just below the base of the Mesozoic section.

Large multiple geophone arrays and pattern shots were needed to obtain good quality reflections over most of the area, except when shooting on the alluvial plains of the larger creeks.

The sedimentary section was shown to be at least 8,000 feet and possibly 16,000 feet thick. The base of the Mesozoic section is interpreted as being 7,250 feet deep on the refraction traverse and 8,600 feet at the south-east end of the reflection traverse. The rest of the section probably consists of Palaeozoic sediments. If so, the high velocity (17,000 ft/sec.) suggests that a dense elastic or crystalline limestone is probably present near the top of them.

The structure of the Mesozoic section is sub-horizontal, but there may be minor structures with dips less than 1° which correlate with the surface structures.

I. INTRODUCTION

From September 23rd to November 29th, 1957, the Seismic Group of the Bureau of Mineral Resources, Geology and Geophysics conducted an experimental seismic survey in the Haddon Downs area of the north-east of South Australia (see Plates 1 and 2). The survey was requested jointly by the South Australian Mines Department and Santos Ltd., the latter company holding an Oil Exploration Licence covering the area. The request followed an increasing interest in this area when a preliminary geological reconnaissance carried out by Santos revealed that anticlinal structures of considerable size existed there. It is known that the Mesozoic section is at least 5,500 feet thick, part of which consists of marine shales. The possibility of oil having accumulated in these structures warranted their further investigation.

Firstly, the work was of an experimental nature to assist Santos in determining what success might be expected from a subsequent large scale seismic survey to locate a suitable drilling target. Secondly, it was hoped to learn something of the subsurface geology of the area from the survey. The specific aims in order of importance were:-

(1) to determine whether the reflection method would be a suitable tool for studying the subsurface geological structure of the area and what techniques were best suited in the use of this method.

(2) to determine the thickness of the Mesozoic section and the likelihood of Palaeozoic sediments below the Mesozoic section.

(3) to determine the degree of correlation if any, between near surface and deep geological structures.

Considerable difficulty was experienced in recording reflections of reasonable quality, so that a large portion of the survey was spent in experimenting with multiple geophone and pattern hole techniques to improve reflections and provide a satisfactory answer to (1) above. Refraction shooting was also carried out as this method was more likely to give definite answers to (2). An answer to (3) would probably follow from the successful application of seismic reflection techniques.

2. CORDILLO DOWNS AREA

Cordillo Downs station is situated in the north-east corner of South Australia and now embraces what were originally three sheep stations - Cordillo Downs, Haddon Downs and Cadelga (Plate 2). The increasing menace of dingos forced the stations to change from sheep to cattle many years ago, and since then it has been found more economical to combine the three stations. Cadelga homestead is still used as an outcamp, but Haddon Downs is now in ruins.

Arrabury station lies to the east of Cordillo Downs, on the Queensland side of the border, Mount Leonard to the North, also in Queensland, and Innamincka to the south. The population of stations in this area is chiefly white with a few half-caste aboriginals, but no pure blood aboriginals are employed on the stations.

The nearest town to Cordillo Downs is Birdsville, which is approximately 180 miles by road. Only small quantities of petrol, foodstuffs, and other supplies are available in Birdsville. Bulk supplies can be obtained overland either from Broken Hill or from Marree (via Birdsville). There is no regular contractor on either of these routes with a through run to Cordillo Downs, but providing loading justified the trip, one could probably be found who would deliver to the area. The Stores and Transport Branch of the Department of Supply in Adelaide, transported petrol and explosive to the area for this survey via Broken Hill. Santos also assisted in transporting equipment from Broken Hill to the party during the survey. Emergency supplies, perishables, and small quantities of goods may be obtained from either Charleville or Broken Hill via T.A.A's Channel Service 'plane which calls at Cordillo Downs each fortnight. This 'plane service also delivers the mail.

The Cordillo Downs area is on the fringe of the south-western Queensland grazing areas. The country further west deteriorates into desert and semi-desert areas through which the Birdsville Track passes. The station, for the most part, consists of rough stony table-topped hills and table-lands dissected by broad stony valleys of the larger creeks. Haddon Creek floods out into sandhills to the north-east and has formed an alluvial flood plain (the Kachumba Plain) adjacent to the sand-hills. Similarly, Providence Creek has formed the Rainbow Plain between the table-lands and the sand-hills in the west.

The climate is warm to hot except during winter when the temperatures are milder. During the survey, maximum temperatures ranged from 80°F to 115°F and minimum temperatures from 42°F to 78°F. The average annual rainfall is only 5 inches and this is generally received during the summer months from December to February.

Vegetation consists chiefly of grasses which grow remarkably well between the stones. The small creeks are lined with stunted trees, and larger trees, including gums, grow on the banks of water holes and the major channels. The station relies on water holes in creeks, supplemented by sub-artesian bores and a few dams, for stock water. Even the larger water-holes however may not last from season to season. Although the area is within the Great Artesian Basin, the depth to the main aquifer (5,000 feet) makes it uneconomical to develop this source of water supply.

The station tracks are generally rough due to the stony nature of the ground and the many creeks flowing down from the hills. The trip from Cordillo Downs to Haddon Downs, a distance of 35 miles, takes approximately two hours of careful driving in a Land Rover. Cross-country driving is very slow and consequently much time was lost in travelling along traverses to and from the operating point. A light tractor fitted with a front end blade proved useful for improving creek crossings, but was not effective in grading the stony ground, as it turned up as many rocks from the ground as it cleared off the track.

3. GEOLOGY

General:

The Great Artesian Basin is a huge sediment filled depression which extends over large sections of Queensland, New South Wales, and South Australia and perhaps also the Northern

Territory, where the sands of the Simpson Desert conceal the geology. It has been extensively exploited especially in Western Queensland, for water supplies for towns, stations, and stock. Many reports of oil and gas showings have come from the thousands of bores drilled, and some of these have led to further exploration drilling to locate commercial quantities of oil. The most extensive search for oil has been in the Roma district of Queensland, and many of the bores drilled there have struck large quantities of petroliferous gas and have also produced a few hundred gallons of crude oil. Shows of oil and gas have also been reported from many holes drilled in the Longreach district of Queensland. A detailed report of authentic shows of oil and gas in the Queensland section of the Great Artesian Basin is given by Mott (1952). Reports have also been made of oil shows in bores near the western margin of the basin in South Australia (Sprigg, 1957).

A shallow basement ridge, running slightly east of north near meridian 147° east, called the Nebine Ridge, and a second basement ridge, running east-west to the north of the Richmond-Cloncurry railway, called the Euroka Shelf, divide the Great Artesian Basin into three sub-basins. These are named by Mott (1952, p.850) Carpentaria Basin for that section north of the Euroka Shelf, Surat Basin for the section east of the Nebine ridge, and Eromanga Basin for the central and western part.

The Cordillo Downs area lies within the Eromanga Basin and is probably close to the deepest section of the Great Artesian Basin. For this reason, the artesian water supplies of the Basin have not been developed in the area. The deepest hole drilled in the area is Patchawarra Bore, 50 miles south of Cordillo Downs homestead, which reached a depth of 5,458 feet without reaching the main artesian aquifer. Useful sub-artesian water supplies have been developed to some extent on Cordillo Downs station by bores up to 1,800 feet deep. Jack (1925) studied the logs of these bores in detail while investigating developments in shallow water areas in the north east of South Australia. By correlating the water bearing beds from their description in driller's logs and the analyses of the water they contained, he was able to draw subsurface sections through these bores. This was apparently the only detailed geological work carried out in the area prior to the investigation conducted by Geosurveys of Australia Ltd., on behalf of Santos, which was commenced early in 1957. This Company has had up to 4 geologists employed on detailed mapping of the area, and have also carried out geophysical investigations and shallow structure drilling. Santos Ltd. have recently merged its interests with a new Company, Delhi Australian Petroleum Ltd., and an extensive exploration program has been commenced.

Stratigraphy of the Eromanga Basin.

The geological formations of the Great Artesian Basin have been studied in great detail on the eastern margin in Queensland. The following summary of these formations has been compiled chiefly from reports by Mott (1952) and Whitehouse (1954). In Queensland, the section ranges from Permian, through Triassic, Jurassic, and Cretaceous, to Tertiary. However on the western margin of the Basin, the Cretaceous sediments overlap on to the Pre-Cambrian basement rocks, and so the extent of pre-Cretaceous sediments in the western part is not known except where bores may have penetrated the Cretaceous.

The Permian Formations may be well developed in the Surat Basin, but in the Eromanga Basin they are only known for certain as terrigenous deposits along the eastern margin, although it is suspected from drillers' logs that Permian sediments are present below the Mesozoic in the Longreach area.

It is doubtful if the older Triassic rocks - the Rewan Group, Clematis Sandstone and Moolayember Shales - extend into the Eromanga Basin, except along the eastern margin. They appear to be absent in bores drilled to basement in the Longreach district. However, the Upper Triassic Bundamba Group is much more widespread than the earlier Triassic formations on which it rests unconformably and it extends right across the northern part of the Eromanga Basin. It does not outcrop on the south and south-west margins, and so it is not known if it extends to the Cordillo Downs area of the Eromanga Basin. The formation consists of strongly current-bedded coarse sandstones with zones of shale or siltstone, and contains the most copious water supplies of any of the aquifers. The Walloon Coal Measures of Jurassic age are more limited in extent than the Bundamba Group. In the Eromanga Basin they thin westwards from 1,000 feet in outcrop on the eastern margin to a few hundred feet in the Longreach district. It is doubtful if they are present further west.

The Cretaceous sediments are by far the most extensive in the Great Artesian Basin and they set the practical limits of the Basin. They also contain the only known marine sediments deposited within the Basin since the Permian. The Blythesdale Sandstone, consisting of porous sandstones and conglomerates, is the earliest formation in the Cretaceous period and forms the most widespread aquifer of the Basin. This formation was the transition stage between non-marine and marine conditions and contains the first marine fossils. It was followed by two formations of marine shales, the Roma Formation and the Tambo Formation, of Lower Cretaceous age. These shales contain some calcareous sandstones and concretionary limestones. At the beginning of the Upper Cretaceous epoch, there was a return to lacustrine conditions, and the Winton Formation was laid down. This formation is very similar in lithology to the shales of the Roma and Tambo Formations, although it has more sandstone members and coal seams appear in it.

Over large areas of the Basin in the vicinity of the Queensland-South Australian border, the Cretaceous sediments have been covered by the Eyrian Formation, which rests on them uncomformably. This formation consists of arenaceous and argillaceous sediments of Lower Tertiary age.

Both the Eyrian Formation and the Winton Formation are capped by a superficial "duri-crust" which has been formed by the silicification of the sandstone and shales during a prolonged existence as a land mass, probably during the Miocene epoch. This capping makes it difficult sometimes to decide which of the formations is present at the surface and there is doubt therefore as to which of these formations is present along the seismic traverse. Geologists of Geosurveys Ltd. (Wopfner, 1957) believe that the Winton Formation is present near the surface along Traverse A from S.P. 1 to about S.P. 28 (Plate 3) but that south-east from here the near-surface rocks are probably the Eyrian Formation.

The likely section as known from the nearest bore information in the Cordillo Downs area is set out in Table 1.

The artesian bores in South Australia have nearly always been terminated when they have reached the main aquifer below the Marine shales, and consequently there is little information on this sandstone aquifer. In South Australian literature (Ward, 1946) the aquifer is generally referred to as the Jurassic Sands. However it may be the equivalent of the Blythesdale Sandstone.

TABLE 1.

Stratigraphic Section - Cordillo Downs Area, S.A.

Age.	Formation	Lithology	Thickness
Tertiary	Eyrian Formation	Sandstones and Shales	360' from bores on Cordillo Downs Stn (Jack, 1925)
Upper Cretaceous	Winton Equivalent	Lacustrine facies of blue shales containing sandstone members and coal seams.	3,695' in the Patchawarra bore, 50 miles south of Cordillo Downs Stn.
Lower Cretaceous	Tambo & Roma Equivalents	Marine facies of dark bluish-grey shales, containing thin beds of limestone.	2,433' in the Goyder's Lagoon bore 110 miles west of Cordillo Down Stn.
Lower Cretaceous or Jurassic	Blythesdale Equivalent	Porous Sandstone	Unknown.

Any attempt to predict what lies between the Cretaceous section, as outlined in Table I, and the Pre-Cambrian basement, in the Cordillo Downs area (if anything does) would be purely conjectural. However, it is informative to mention the possibilities. Of the other Mesozoic formations found in the Great Artesian Basin, the Walloon Coal Measures and the Bundamba Group may well have their counterparts in the Cordillo Downs area. The presence of Palaeozoic formations would be of greater significance however and these are known to crop out at many places around the margin of the Basin. Those which have greatest possibilities of extending to the Cordillo Downs area are:-

(i) The Cambrian and Ordovician sequences (largely limestones) of the Georgina Basin which crop out on the north-western margin of the Great Artesian Basin in the vicinity of the Georgina and Burke Rivers. In the Toko Range area these formations are deposited in a trough which appears to be plunging beneath the Cretaceous sediments in a south-easterly direction towards the Cordillo Downs area. In the Burke River area the main structural trend is north-south and these formations plunge to the south, also towards the Cordillo Downs area. (Casey, 1958).

(ii) The Permian formations, which are suspected to exist below the Cretaceous in the Longreach District and which may have a more favourable and greater development in the deeper parts of the Basin such as the Cordillo Downs area.

Structure of the Eromanga Basin.

From the correlation of bore logs in Western Queensland, Mott (1952) has drawn basement contours, which clearly show the Eromanga Basin deepening towards the corner of the South Australian border. Comparison of the Patchawarra bore with the deep bore Springleigh No. 3, 50 miles west of Blackall, shows the bottom of the Cretaceous is 3,400 feet below sea level at Springleigh 3 and has not been reached at 5,250 feet below sea level in the Patchawarra bore. This shows that thickening of the section (or at least the Cretaceous section) is continued to the South Australian border. On the western or South Australian side of the Basin the artesian bores show that the Cretaceous section is thickening towards the eastern border. It appears therefore that the Cordillo Downs area is in the vicinity of the deepest section of the Eromanga Basin.

The sections drawn by Jack (1925) from bore information on Cordillo Downs Station indicate a doming of both the Eyrian Formation and the fresh-water shales (Winton Equivalent) to the west of Haddon Downs. Initial air and ground reconnaissance surveys by geologists of Geosurveys Ltd. confirmed the existence of folding in this area, at least in the surface formations. Their work showed two major anticlinal axes - one trending north-north-east to south-south-west passing east of Betoota and the other trending north-east to south west passing west of Curalie (Wopfner, 1957). These apparently merge together in the Haddon Downs area and probably close off in a complex domal feature plunging south towards Cordillo Downs Homestead. This domal feature with structural relief of probably more than 1,000 feet in an east-west direction has a number of minor folds with structural relief of about 200 feet across the general crestal area. It may be described therefore as an anticlinorium.

4. GRAVITY INVESTIGATION

Geosurveys Ltd. commenced a gravity survey of the Cordillo Downs area during 1957 and have kindly supplied the Bureau with preliminary results of the work so far completed. Contours of the Bouguer anomaly are presented on Plate 2, which also shows the major anticlinal trends. The variation in the Bouguer values from minima to maxima are of the order of 20 milligals. If these anomalies are caused by structures within the Mesozoic section of similar magnitude to those mapped on the surface, then a density contrast of at least 0.8 would be required in the Mesozoic section. From what is known of this section, this is very unlikely. It seems more likely that they could be related to the structure at the base of or below the Mesozoic section. Assuming a density contrast of 0.5 to exist below the Mesozoic section, then these pre-Mesozoic structures would need to have vertical relief of the order of 3,000 feet. The areal coverage of the gravity survey is insufficient as yet to establish any definite correlation between the anomalies and the surface geological structures, which may be expected to exist if the pre-Mesozoic structure is reflected through the rest of the section. However, there are already indications that such a correlation may be possible. The positive anomaly to the north-west of

Haddon Downs correlates with the southern extension of the Betoota Anticline and it appears that its trend further to the north may be along that of this Anticline. The gravity trough to the north of Haddon Downs lies between the Betoota and Curalie Anticlines consistent with the position expected of a Syncline complementary to the Anticlines. In the vicinity of Haddon Downs and to the south-west, the gravity picture is more complex, but does show a north-east to south-west trending ridge in the general area of the complex domal feature. However, the gravity values continue to rise to the south beyond Cordillo Downs, although the Dome is known to plunge southwards.

The only detailed gravity work carried out so far in the area was along Traverse A of the seismic survey described in this report. Gravity readings were made at each of the shot points (i.e. at $\frac{1}{4}$ mile intervals). The Bouguer anomaly obtained is plotted on the Reflection Cross Section for Traverse A (Plate 6) together with the surface geological profile along the line. This traverse crossed the south-west end of the syncline on the north-west flank of the Curalie Anticlines, and then continued across the south-westerly extension of the latter anticline. In the locality of the traverse these structures are referred to as the Haddon Syncline and the Mount Howie Anticlinorium, the latter having two separate culminations. The Bouguer anomaly values decrease steadily from the north-west to the south east, falling by 9 milligals over the length of the traverse. This continual decrease in gravity in passing across the Mount Howie Anticlinorium suggests that the close proximity of the large dome near Haddon Downs has a controlling influence on the gravity values. In fact, in this region of convergence of the two major anticlinal axes, the structure at depth may be a large domal feature embracing both anticlines and with its crest near Haddon Downs where the gravity contours show a closed positive anomaly. Even at the surface, the structural relief between the Haddon Syncline and the Mount Howie Anticlinorium is only 300 feet along the traverse compared with possibly 1,000 feet further to the north-west.

There are second order variations in gravity along Traverse A and these have been extracted from the major gradient. These residuals are also plotted on Plate 6. These correlate very well with the surface structures, with a minimum in the Haddon Syncline and maxima at both of the culminations on the Mount Howie Anticlinorium. The Bouguer corrections for these values along the seismic traverse have been calculated using a density of 1.9 for the near surface formations. Neumann (1958) has deduced from a density profile carried out between shot points 2 and 5 on the traverse, that a density of 1.9 is correct for areas where shales and sandstones occur at the surface, but that a density of 2.4 should be used to remove the effect of the Duri-crust wherever it is at or near the surface and of significant thickness. The effect of this criterion on the relative gravity values should be investigated before interpreting the minor variations in gravity. The effect of correcting for a density of 2.4 on duri-crust areas is to reduce the Bouguer anomaly value over those areas by about $\frac{1}{2}$ milligal. Along Traverse A, duri-crust is near the surface from shot point 3 to 13 and from shot point 30 to 54. Reducing the values along these sections by $\frac{1}{2}$ mg. will make the minimum associated with the Haddon Syncline more pronounced and the values along the south-eastern flank of the Mount Howie Anticlinorium, including the eastern anticline, lower with respect to the western maximum. Both these changes will make the correlation with the surface geology appear better still.

From this discussion of the gravity data known at present, it is apparent that further regional and detailed work may prove very useful in elucidating the geological structure of both the Mesozoic and pre-Mesozoic formations. The conclusions arrived at concerning the sub-surface structure of the Basin will, of course, require verification by seismic work at critical places, before being held as correct interpretations.

5. FIELD WORK

The field crew consisted of 19 men, eight of whom were staff members of the Bureau of Mineral Resources, and 11 were casual hands. The Party Leader had the assistance of another geophysicist for computing and a clerk for camp management. The drilling team consisted of six men - a drilling foreman, two drillers, two drill helpers and a water-tanker driver. The recording team had a radio-technician as observer, a shooter, and four field hands. The crew was equipped with a mobile workshop which contained an arc welder, power greasing unit, battery charger and other equipment and tools necessary for maintaining vehicles and field equipment in good condition. A mechanic and an assistant carried out the maintenance work. The kitchen staff consisted of an experienced cook and a general hand as cook's offsider.

The laying out and levelling of traverses was carried out by a survey team supplied by Geosurveys Ltd. The open rolling country made surveying easy, little clearing being required. The chief drawback to progress was the slow-rate of travel necessary in vehicles over the very stony country.

The drilling crew had two "Failing 750" drilling rigs, mounted on Commer four-wheel drive trucks, and four 700 gallon water tankers on similar vehicles. The formations encountered in the area may be classified as follows:-

(a) Duri-crust or silicified shale: This is encountered only a few feet below the surface over a widespread area. At the top where the silicification process has been carried to its most advanced stage, the formation is very hard and presents really tough rock-bit drilling. Generally as the formation is penetrated the drilling becomes easier, and a Hawthorne bit can be substituted for the rock bit. Its thickness varied but averaged about 25'. Average drilling rate including changing rods was approximately 30 feet per hour.

(b) Soft clays and shales: These underlie the duri-crust and are at the surface in places where the duri-crust has been eroded. They present very good drilling, the drilling rate being of the order of 80 feet per hour.

(c) Alluvial clays and silts: On the Kachumba Plain, the flood plain of Haddon Creek, where the refraction traverse was situated, and on another flood plain at the south-east end of traverse A, the formations mentioned above have been covered by alluvial clays and silts which provide excellent drilling conditions with the rate up to 100 feet per hour.

Water for drilling purposes was always a problem as water holes and bores are rare. Water tankers were hauling water for distances up to 10 miles over very rough stony country, sometimes taking up to 3 hours for a round trip.

The recording instruments including geophones, were manufactured by the Technical Instrument Company. They have 24 amplifier channels with provision for selecting one or two stage filter networks on both the high and low cut sides to give broad or sharp cut-offs. The response curves for the amplifiers in the various filter settings are shown on Plate 10. The camera has 50 channels with provision for 24 straight and 24 mixed traces. Either unilateral or bilateral mixing may be selected. These instruments are fitted in a dark room cab which is mounted on a Land Rover chassis. Transceivers, manufactured by South-western Industrial Electronics, and fitted to transmit time break and uphole times, are used for communication between observer and shooter when this is necessary in refraction shooting. The party possessed about 400 geophones.

Portable geophone cables were used and were laid by hand from breast reels. These were carried in another Land Rover together with the geophones and cables for multiple geophone hook-ups. The shooting truck was another four wheel drive Commer carrying a 700 gallon water tank.

6. REFRACTION TRAVERSE

The refraction work was conducted along a 10 mile line, called traverse B, running approximately north-south on the alluvium of the Kachumba Plain about 12 miles to the north-east of Haddon Downs (see Plate 3). It was approximately along the axis of the Haddon Syncline, and it could be expected that duricrust would underlie the alluvium.

The geophone spread consisted of 24 geophone stations spaced at 220' intervals, except for the middle interval which was 440'. Thus the spread covered one mile. Distances between shot points and the geophone spread ranged from zero to seven miles and for each distance, profiles were shot in opposite directions. The positions of shot points and their corresponding geophone spreads were selected so that, as near as could be estimated in advance, waves from all refractors recorded came from below the centre portion of the traverse (S.P.98 to S.P.102), irrespective of the direction of shooting. This is illustrated at the bottom of the time-distance curves on Plate 5. With this set-up, the two groups of refracted waves for a particular refractor from each direction of shooting come from approximately the same subsurface section of the refractor (viz. that section below S.P. 98 to S.P. 102) and thus give accurate measurements from which the velocity of the refractor can be calculated.

Charges of 200 lbs. were sufficient to give good first arrivals for shot point geophone distances up to 5 miles, but for larger distances bigger charges are needed. The party did not have sufficient explosive to use charges in excess of 200 lbs. for these distances.

Results:

One mile of reflection shooting along the centre portion of the refraction traverse, and a mile at right angles to this, was completed and Plate 4 shows the cross-section obtained from this shooting. Many reflections of poor to fair quality were recorded to depths of 9,000 feet but only a few very poor quality ones from below this depth. (Note that this section has been plotted on a linear time scale. The depth scale has now been added to the section, this being obtained from a t- Δt analysis). The cross-section shows that the beds are sub-horizontal beneath the centre of the refraction traverse. Thus inaccuracies in the calculation of velocities caused by the dip of the refractors should be small.

The time-distance curves from the refraction shots are plotted on Plate 5. The seismic velocities and depths calculated for the refractors recorded are listed below in Table II.

TABLE II

Velocity	Depth	Probable Formation
V_1 : 5650 ft/s.	Sub-weathering	
V_{2A}: 6860 ft/s.	350'	
V_{2B}: 6800 ft/s.	800'	
V_3 :10250 ft/s.	2670'	Marine Cretaceous
V_4 :17000 ft/s.	7250'	Limestone near top of Palaeozoic.

It will be noted that two velocities of almost equal value are listed at different depths. V_{2B} appears to be a separate refraction to V_{2A} and has a much greater amplitude than the latter. It is recorded from both directions of shooting commencing at shot to geophone distances of about 3,000 feet and its first breaks can be recognized arriving about 70 milli-seconds later than those of V_{2A}. The refractor V_{2A} is probably a thin layer of velocity 6,860 ft/s. in which the energy is attenuated very quickly, and which lies about 400 feet above the main refractor of this velocity.

The refractor V_3 (10,250 ft/sec.) was recorded as a first arrival at distances from 2 to 3½ miles, and V_4 (17,000 ft/s.) from 3½ to 5 miles. The shots for distances over 5 miles did not give good first breaks. In attempting to pick later phases close to the first breaks on these records, it was difficult to follow the same phase across the whole spread. The character of the phase changes was similar to that which generally occurs when two separate refractions are recorded simultaneously at the geophone spread. The times for phases which could be followed with reasonable certainty across the records are plotted on Plate 5. The apparent velocities of these phases from S.P's 80 and 120 are 18,300 ft/sec. and 19,290 ft/sec., both of which are in excess of 17,000 ft/sec. This may mean that another refractor with a velocity greater than 17,000 ft/sec. exists below V_4. It remains doubtful however because of ambiguities in picking the correct phases and because these apparent velocities are close enough to 17,000 ft/s. to be updip values of that velocity.

Interpretation:

The refractor, V_3, of velocity 10,250 ft/sec. at a depth of 2,670 feet is represented by such a strong event and the velocity contrast with the formations above it is so marked, that it seems likely that it represents a major change in the lithology of the section. The transition from the lacustrine shales of the Winton equivalent to the marine shales of the Tambo and Roma equivalents is expected at a depth of this order, but the lithology of these formations in general is so similar that a marked velocity contrast would not be expected. However, the marine shales have limestone beds present within them which could account for the velocity of 10,250 ft/sec. The refractor, V_3, is tentatively assigned as being at or near the top of the marine shales.

The refractor, V_4, recorded from a depth of 7,250 feet is also represented by a strong event and its velocity 17,000 feet per second is considerably higher than that of V_3. Such a high velocity is not likely to be recorded from a sandstone or a shale. It is however what might be expected from a dense clastic or crystalline limestone or an igneous or a metamorphic rock. As none of these rocks are likely to occur in the Mesozoic section, the refractor, V_4, is interpreted as a pre-Mesozoic formation.

The reflection cross-sections in the middle of the refraction traverse (Plate 4) indicate a sedimentary section of 9,000 feet which is probably conformable with surface geology. As the refraction work suggests that the Mesozoic section is not deeper than 7,250 feet, it is a reasonable assumption that the rocks in the remaining 1,750 feet of the sedimentary section are Palaeozoic. If the presence of another refractor below V_4 and with a higher velocity is confirmed, it would be additional evidence of Palaeozoic sediments between the Mesozoic and basement. A band of reflections at about 7,500 feet on the cross-sections (Plate 4) may, perhaps, correlate with the V_4 refractor. No unconformity is apparent on the cross-sections at the approximate depth of V_4.

7. RECORDING TECHNIQUES IN REFLECTION SHOOTING.

Multiple Techniques:

The recording of reflections is difficult in many areas because the level of noise generated by the shot is so high relative to the reflected energy that the latter cannot be recognized through the noise. The filter circuits of the amplifiers reduce the noise considerably, but they cannot filter out noise whose frequency falls in the pass band required to record reflections. It has become common practice in areas of poor reflection quality to reduce the noise level in the pass band of the amplifiers by the use of multiple geophones, connected in series-parallel arrangements, to provide the inputs for the amplifier channels, and to generate the initial signal at the shot point from a number of charges exploded simultaneously in separate holes. Both these methods tend to improve the signal to noise ratio. The reflected energy travels near vertical paths from shot to geophone and consequently the horizontal displacements between geophones or charges produce relatively small phase differences causing little attenuation of the reflected energy when compounded. The noise energy however travels horizontally, and the phase differences determined by the positions of the geophones and charges are sufficient to attenuate the noise appreciably.

The attenuation of the noise is dependent on the spacing of the units (whether geophones or charges) along the direction of travel of the energy. Units placed in line along the traverse will only attenuate noise whose direction of travel has a substantial component along this line. However, the noise radiates in all horizontal directions from the shots, and may be reflected or diffracted from discontinuities off to the side of the traverse so that it can arrive back at the traverse from any horizontal direction. The units are therefore often laid out in areal patterns so that noise arriving from any horizontal direction is attenuated.

The signal to noise ratio of the reflections will improve with the number of units used in a group. This number, however, is usually limited by practical considerations, viz., the number of geophones available for use and the speed at which holes can be drilled. Practical reasons also commonly determine whether areal patterns or in-line arrays are used. Holes are generally drilled in patterns unless the line is along roads in populated areas or through thick scrub, where it is impractical to move off line. The multiple geophones are most often laid out in line, for as well as the disadvantages of patterns mentioned above, the laying out of the hook-up wiring for an areal array of geophones becomes complicated and tedious. The frequencies to be attenuated are usually known (the pass band of the amplifier) and if the velocity of the noise along the spread can be determined, then the optimum spacing of the units can be calculated. However, the final decision of the best spacing to use is commonly arrived at by trial and error in the field.

Record Quality and Its Improvement in the Haddon Downs Area:

The quality of reflection records obtained by the simpler methods of shooting, i.e. by single holes and the use of groups of four geophones at 5' intervals (this was the common arrangement of geophones that the party had previously used in good reflecting areas) was generally poor in the Haddon Downs area. One of the reasons for the poor quality records was certainly the bad surface conditions for planting geophones. Probably about 90% of the area is strewn with large and small gibbers which are remnants of eroded duri-crust. These gibbers are also distributed through the soil and make a good firm geophone plant almost impossible, even after clearing away the gibbers on the surface. The only fair quality records obtained in the area using simple techniques were those shot on alluvium where the gibbers were sparsely distributed and geophones could be firmly planted, and this latter fact probably accounts for a lot of the improvement. The use of a large number of geophones per trace is therefore desirable in the Haddon Downs area even if only to improve the overall "plant" of a geophone group. For the noise created by a bad plant will be random and the reduction in this noise level should on the average be proportional to the square root of the number of geophones used.

The results of the reflection shooting in terms of the quality of the records and the means of improving them other than the above consideration can best be discussed under the headings of the three types of formations on which shooting was carried out.

(a) Alluvial Clays and Silts:

The reflection shooting at the centre of the refraction traverse and the two miles at the south-east end of Traverse A was shot on formations of alluvial clays and silts, which have been deposited over the duri-crust by the flooding of the larger creeks.

Groups of six geophones per trace in line at 22' intervals in conjunction with single shot holes with the charge at an average depth of 60 feet were used in this shooting. In general, records were of fair quality with one or two fair to good reflections and quite a few poor ones. A very strong reflection was recorded at 1.8 seconds on records from S.P.55 to S.P.62, at the south-east end of Traverse A.

As these records were considered to be good enough for the purposes of the present survey, pattern shots or different multiple geophone set-ups were not tried.

(b) Duri-crust and Silicified Shale:

Duri-crust or silicified shale were present within a few feet of the surface along about half of Traverse A, from S.P.3 to S.P.13 and S.P.30 to S.P.54.

The section from S.P.3 to S.P.13 was shot initially using single holes, with optimum charge depth varying erratically between 70' and 130', and two types of geophone arrays - 4 per trace at 5' intervals and 6 per trace at 10' intervals, the latter being slightly the better geophone set-up (see records A and B on Plate 8). At S.Ps. 37 and 38, a comparison of 6 geophones per trace at 10' and 22' intervals was made and the longer interval was found better. The technique of using units of variable effectiveness, described by Parr and Mayne (1955), was also tried. Six geophones were laid out as four units at 22' intervals, with 2 geophones at each middle unit and 1 geophone at the two end units. (See Record G on Plate 7). No improvement was noticeable however. The section from S.P.37 to S.P.44 was then shot with 22' spacing of the six geophones. These records were all of very poor quality, although one or two definite reflections could generally be recognized on them. Plate 7 presents a typical set of these records in which the variations of multiple geophones described above were used. A pattern shot fired at S.P. 38 is also included for comparison.

A set of experiments was then carried out at S.P.9 using various patterns and multiple geophone groups. The records from this shooting are displayed on Plate 8. The party had enough geophones to use 16 per trace and these were all used on some shots. The array of geophones then consisted of 10 in line at 22' intervals and 6 at right angles to line at 22' intervals. A pattern of 25 holes drilled to 30 feet was used to shoot 9 point, 16 point and 25 point patterns at varying depths and with different sized charges. All the pattern shots produced a marked improvement in the quality of reflections compared with the single hole records. And of these the 25 hole pattern shot (record C) was the best, giving a record with two good quality reflections and many poor to fair quality ones. The increase in the number of geophones also seemed desirable (compare records E and F on Plate 8). The conclusion arrived at was that the more units used in the pattern shot and in the geophone group, the better the quality of the record obtained. Two nine hole patterns that were shot respectively at depths of 29' and 12' (records F and G on Plate 8) gave records of similar standard. This is important as the drilling in the duri-crust is very slow and if the depth of the holes can be cut down, then a great saving is made in drilling time. It is probably satisfactory if the charges are placed a few feet into the solid duri-crust.

As the drilling time available to the party was 16 hours per day (i.e. an eight hour shift on each drill), it was impracticable to embark on a program of drilling 25 holes at each shot point. Nine hole patterns were chosen as those most likely to give a reasonable balance between reliable results and reasonable progress. As the recording crew could easily keep up with the rate of progress of the drills on 9 hole patterns, the geophone array was maintained at 16 per trace placed as described above. The sections of Traverse A from S.P.3 to 13 and S.P.30 to 44 were shot using these techniques.

Although some improvement over single hole records was noted in most cases, the amount of this improvement was generally disappointing (see Record H on Plate 7) and only in the section from S.P.6 to S.P.10 did it approach that attained at S.P.9. This section of the traverse is in the bottom of the Haddon Syncline whereas most of the rest of this shooting was done on the top of the Mount Howie Anticlinorium. It appears then that the structural conditions are also affecting the quality of the reflections.

(c) Soft Clays and Shales:

In places where the duri-crust has been eroded, the shooting was conducted in the soft clays and shales which underlie it. This occurred along sections 1 to 3 and 13 to 30 of Traverse A.

The initial shooting on the shale at shot points 1 and 2 and from S.P.14 to 23 using single holes and both multiple 4 geophones at 5' and multiple 6 geophones at 10' was similar to that on the duri-crust, the records being very poor although one or two reflections could generally be recognized. Various patterns were then tried at S.P's 14, 17 and 18, ranging from 25 holes at 50' to 9 holes at 100', together with various geophone arrays using up to 16 geophones. These records are presented on Plate 9. The improvement over the single hole records was only very slight. At S.P.20 a single hole was shot as deep as 276 feet without any improvement. The rest of the section on the shale from S.P.25 to S.P.30 was shot using single holes and 16 geophones per trace at 22' intervals in the form of a cross described above.

The section shot on these clays and shales is adjacent to the section shot on duri-crust where little improvement was obtained by the use of patterns, and is also placed structurally on top of the Mount Howie Anticlinorium. The structural conditions may again be the controlling factor causing the poor quality reflections.

8. RESULTS OF REFLECTION TRAVERSE A.

Traverse A was commenced in the western limb of the Haddon Syncline, about 5 miles to the north-east of Haddon Downs. It extended to the south-east for 15½ miles, crossing the Haddon Syncline and the Mount Howie Anticlinorium at approximately a right angle to their axes, and finishing well down the south-east flank of the anticlinal structure. The axis of the syncline crossed the traverse at about S.P.8 and the two culminations on the Mount Howie Anticlinorium were at S.P's 20 and 43.

The reflection cross-section along the traverse, Plate 6, was plotted using the best record which was obtained at each shot point, irrespective of whether they were single holes or pattern shots. The section of the traverse from S.P.44 to

S.P.54 was not shot. A linear time scale was used for the plotting. The scale to convert to depths has now been drawn on the section, the velocity information for this being obtained from a t - Δt analysis.

Reflections were recorded from depths down to 8,000 feet over the whole traverse. At the south-east end of the traverse, from S.P.57 to S.P.62, the reflections persisted to a depth of 16,000 feet. This increase in the reflection section is probably due to the better surface shooting conditions at this end compared with the rest of the traverse. No evidence has been found to suggest that these deeper reflections are multiples.

From S.P.21 to S.P.30 the reflections are not as plentiful and are of very poor quality. This section coincides approximately with the section where single holes only were used, the crestal area of the Mount Howie Anticlinorium, and the rough terrain encountered crossing the ridges near Mount Howie. It is probable that these three criteria all contribute towards the poor reflection quality.

The dips of the reflections are mostly small - of the order of 100 feet per mile - and are generally less than the dips measured on the surface. In fact they are of the same order as the possible errors involved in the weathering corrections applied. Under these conditions, it is necessary to be able to correlate a reflection for at least one mile (4 shot points), and preferably more, before the dip can be considered confirmed. The only reliable dip information for this section then is:-

(i) Approximately 100 feet per mile to the north-west between S.P.7 and S.P.11, which is similar to the dips on the surface for this section of the north-west flank of the Mount Howie Anticlinorium.

(ii) Zero dip from S.P.18 to S.P.21, below the surface axis of the Western Anticline of the Mount Howie Anticlinorium.

(iii) Zero dip from S.P.55 to S.P.60 at a depth of 7,000 feet. This section was considered to be on the south-east flank of the structure, but it is possible that it is off the flank.

(iv) South-east dip of 100 feet per mile from S.P.54 to S.P.62 at a depth of 8,600 feet. This information is supplied by an excellent reflection that correlates over the two miles.

Although, as pointed out above, other dips indicated by less continuous reflections must be regarded as doubtful, they do in some places conform approximately with the surface structure. For example there is an indication of a synclinal reversal below S.P.39 between the Western and Eastern Anticlines. There are also two reflections which indicate steeper dips of about 15° to the S.E. at 5,500 feet below S.P.3, where on the surface dips of 25° to the south-east have been measured.

<u>Interpretation</u>:

The reflection cross-section suggests that a conformable section of 8,000 feet exists below traverse A, and it is likely that this represents the Mesozoic section in this area. The strata of this section are relatively horizontally bedded, although there are possibly minor structures with dips of the order of 100 feet per mile (1°) which may correlate with the surface structures.

At the south-east end of the traverse the probable thickness of the sedimentary section is 16,000 feet with a slight angular unconformity existing at 8,000 feet. This extra section could consist of Palaeozoic sediments, and they would probably extend to the north-west as well, although no reflections were recorded from them along that part of the traverse. The component of dip of these deeper sediments along the traverse is well confirmed as 100 feet per mile or 1° to the south-east.

9. CONCLUSIONS

The following conclusions have been arrived at from the seismic work conducted in the Haddon Downs area.

(1) Although insufficient work has been carried out so far to arrive at a definite conclusion, the gravity investigation gives promise of providing useful preliminary information on both large scale and detailed subsurface structure.

(2) Refraction work could be a useful tool in mapping subsurface geological structure on a semi-regional scale. Two good refractors (V_3 and V_4) are recorded which may correlate over large distances in the area. If so, then the refractor V_3 could be used to map the Mesozoic structure at an approximate depth of 2,670 feet, and the refractor V_4 could be used to map the pre-Mesozoic structure.

(3) The seismic reflection method will provide subsurface structural information, but the production of good quality data will require the use of large multiple geophone arrays and pattern shots, particularly where the information is required on the crestal areas of the anticlines. A reflection survey, intended to map a structure in detail to select a drill site, will be costly, and, unless the party is equipped with several drills, would also be very tedious.

(4) It is fairly certain that the sedimentary section is at least 8,000 feet deep in the Haddon Downs area, and it may be as deep as 16,000 feet.

(5) The refractor of velocity 10,250 ft/sec. at a depth of about 2,700 feet may be near the top of the marine Cretaceous section. As the depth to this formation in the Patchawarra bore, 90 miles to the south, is 4,040 feet, a considerable thinning of the formations above must take place towards the north, or else they have been substantially eroded in the Haddon Downs area.

(6) The refractor of velocity 17,000 ft/sec. at a depth of 7,250 feet is interpreted as being at or a little below the base of the Mesozoic section. It is probably either a limestone or an igneous or metamorphic rock. It is not likely to be a shale or sandstone. In attempting to correlate this refractor with an event on the reflection cross-section along Traverse A, the strong reflection recorded at 8,600 feet at the south-east end of Traverse A is the most

likely choice. If this interpretation is correct the Mesozoic section has increased by 1,350 feet in the 18 miles between the refraction traverse and the south-east end of the reflection traverse. This reflection also indicates that a slight angular unconformity exists between the Mesozoic section and the pre-Mesozoic.

(7) The possible existence of Palaeozoic sediments below the Mesozoic section is suggested by:-

(a) the reflections recorded from below the high velocity refractor (i e. from below 7,250 feet) on the refraction traverse,

(b) an indication that a further higher velocity refractor may exist below 7,250 feet,

(c) reflections recorded to 16,000 feet on the south-east end of the reflection traverse.

If this evidence is assumed conclusive, a dense clastic or crystalline limestone may be expected near the top of the Palaeozoic section, as it is the most likely sedimentary formation with a high enough velocity to represent V_4 (17,000ft/sec.). The suggestion that limestone may exist in the probable Palaeozoic sediments at depth at Haddon Downs is a reasonable one as Ordovician and Cambrian limestones are known in the Georgina Basin to the north (Casey 1958).

(8) The Mesozoic section is relatively flat-bedded and along Traverse A shows no definite structural correlation with the surface geology. However the minor variations in dip, which are generally less than 1°, seem to bear some relation to the surface structures although they are of smaller relief.

10. RECOMMENDATIONS.

The geophysical investigation of the subsurface structure of the Eromanga Basin in the vicinity of the Queensland-South Australian border, should commence with a gravity survey covering the area. In view of the high cost likely for an extensive seismic reflection survey, it is recommended that refraction shooting should be used to confirm any structural highs suggested by surface geology or the gravity survey. By this means, the amount of reflection work necessary could be reduced to the final detailed investigation of the crestal area of the prospective anticline.

Any seismic party preparing to carry out reflection work in the area should be equipped with a large quantity of geophones to enable multiple geophone arrays of at least 12 per trace to be used. It should also have plenty of drilling potential to enable the use of 25 or 36 point patterns to be drilled without seriously affecting the rate of progress of the recording crew. This may require 3 or 4 drills and, on occasions, each working 2 shifts per day. As water is a serious problem in the area, it is recommended that the drills should have provision for air drilling. This technique should be admirably suited to drilling shallow holes (up to 50 feet) in quick time in the duri-crust.

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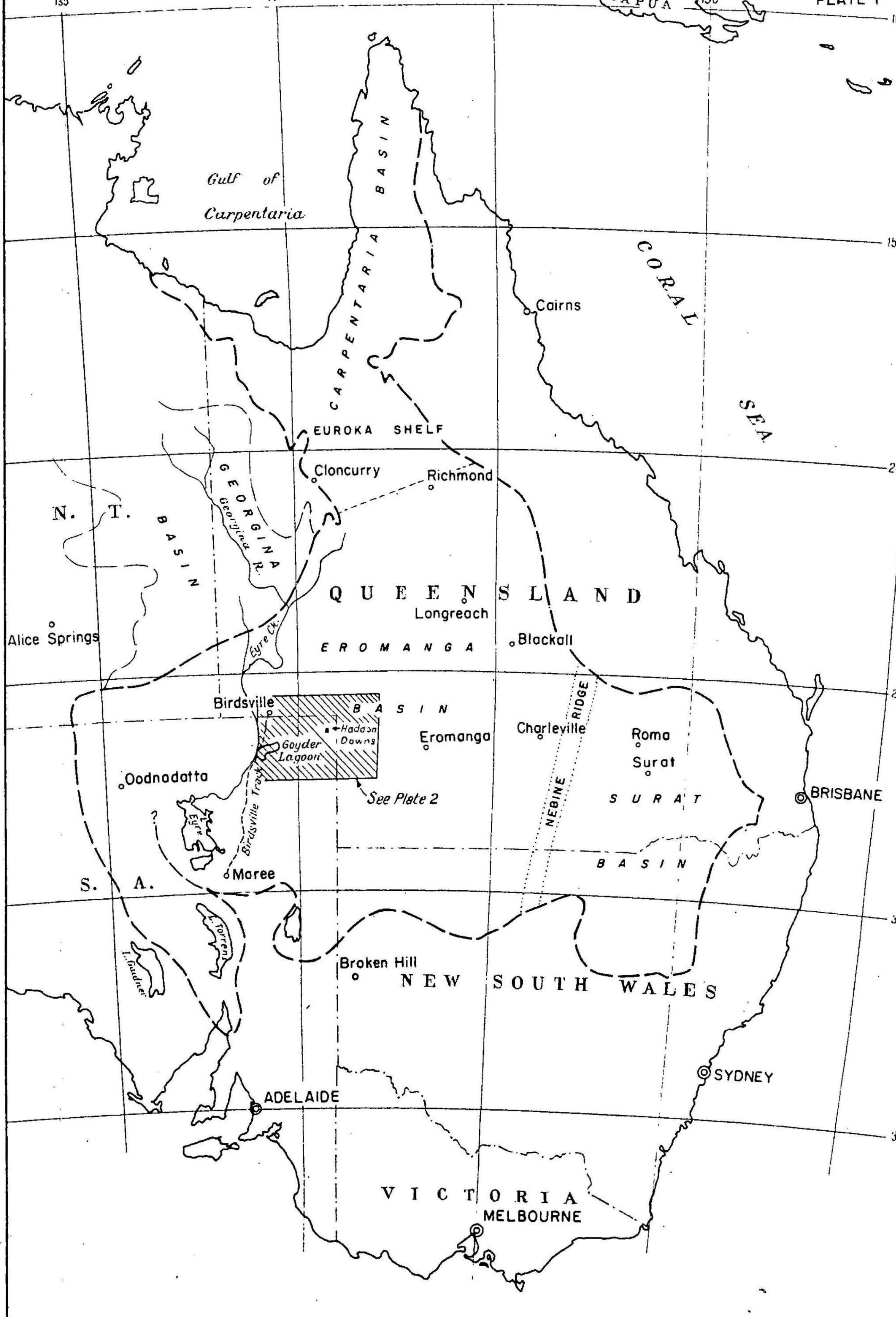
PLATE I



EXPERIMENTAL SEISMIC SURVEY AT HADDON DOWNS,

SOUTH AUSTRALIA

LOCALITY MAP

LEGEND
Boundary of Great Artesian Basin

SCALE IN MILES
100 0 100 200 300

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics. G 296-2

To accompany Records 1959, Nº 19

PLATE 2

LEGEND

Track

Station

Bouguer Anomaly contours

Anticline

Syncline

EXPERIMENTAL SEISMIC SURVEY AT HADDON DOWNS, S.A

CORDILLO DOWNS REGION

GEOLOGICAL AND GRAVITY DATA
FROM GEOSURVEYS' PLANS SAN 167 AND SAN 206

SCALE IN MILES

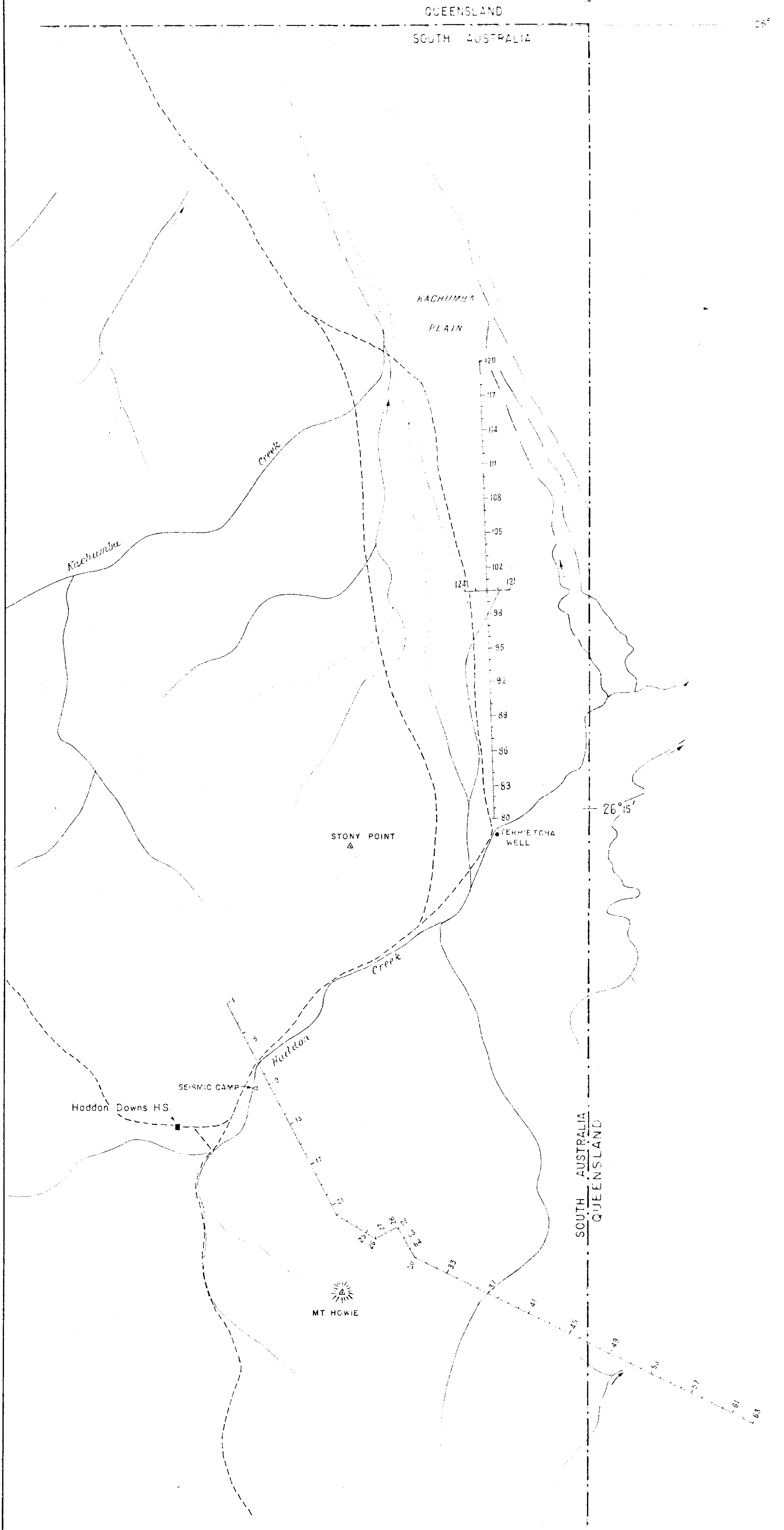
8 0 8 16 24

CONTOUR INTERVAL 1 MILLIGAL

Geological Section, Bureau of Mineral Resources, Geology and Geophysics. G 296-3

To accompany Records 1959, Nº 19

PLATE 3



EXPERIMENTAL SEISMIC SURVEY AT HADDON DOWNS,

SOUTH AUSTRALIA

SEISMIC TRAVERSES

SCALE IN MILES

2 0 2 4

G 296 - 4

To accompany Records 1959, Nº 19

EXPERIMENTAL SEISMIC SURVEY, HADDON DOWNS, SA.

REFRACTION TRAVERSE

TIME DISTANCE CURVES

(INCLUDING SKETCH OF RAY PATHS)

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics G 296-6

To accompany Records 1959, Nº 19

PLATE 6


BOUGUER GRAVITY ANOMALY
RESIDUAL GRAVITY ANOMALY
WESTERN ANTICLINE
MT HOWIE ANTICLINORIUM
EASTERN ANTICLINE
NOT SHOT
SURFACE ELEVATION
BASE OF WEATHERED LAYER
LEGEND
Reflection quality:
Good
Fair
Poor
Uncertain reflection
Depth of Shot
Reflection time converted to datum
2041
PP
2051
Reflection quality grade
EXPERIMENTAL SEISMIC SURVEY, HADDON DAWNS SA.
TRAVERSE A
REFLECTION CROSS-SECTIONS
INCLUDING SURFACE GEOLOGICAL SECTION, BOUGUER
& RESIDUAL GRAVITY ANOMALIES ALONG TRAVERSE
HORIZONTAL SCALE IN FEET
1000
500
0
1000
2000

PLATE 7


Plate 7 (a)
Plate 7 (b)
Plate 7 (c)
Plate 7 (d)
Plate 7 (e)
Plate 7 (f)
Plate 7 (g)
Plate 7 (h)

PLATE 8

Plate 8 (a)

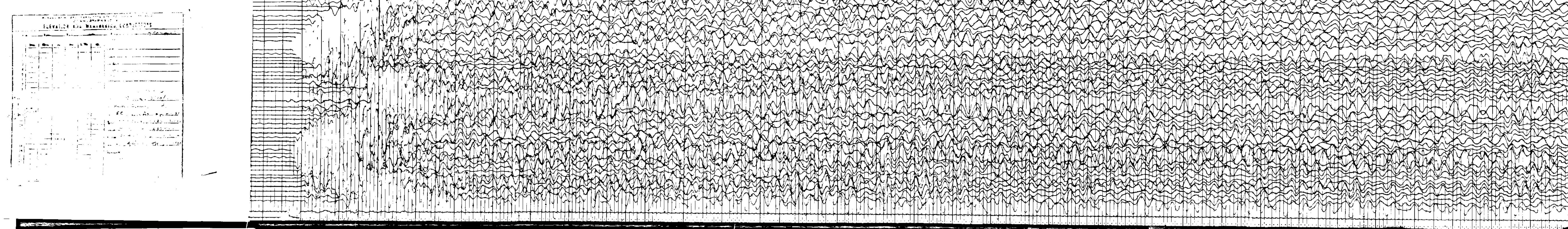


Plate 8 (b)

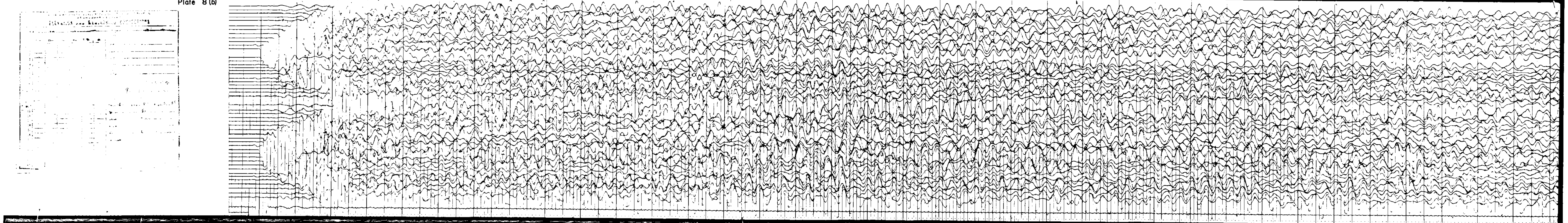


Plate 8 (c)

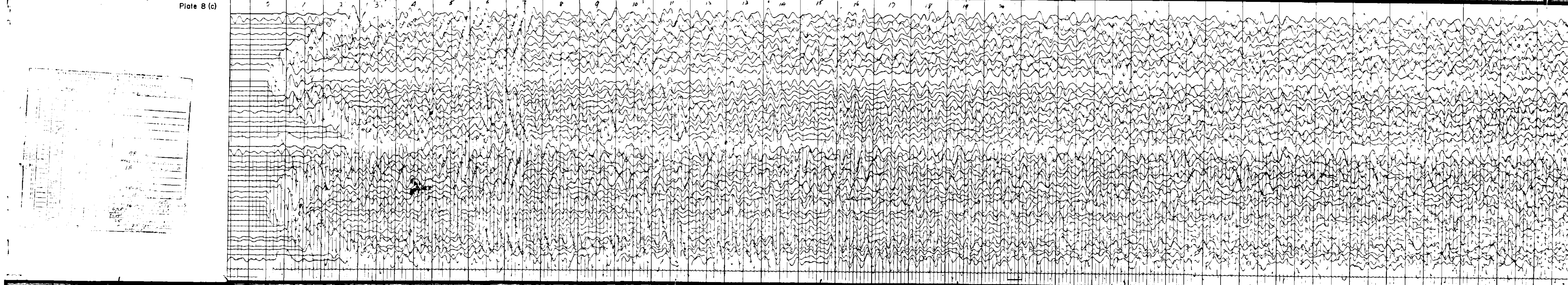


Plate 8 (d)

Plate 8 (e)

Plate 8 (f)

Plate 8 (g)

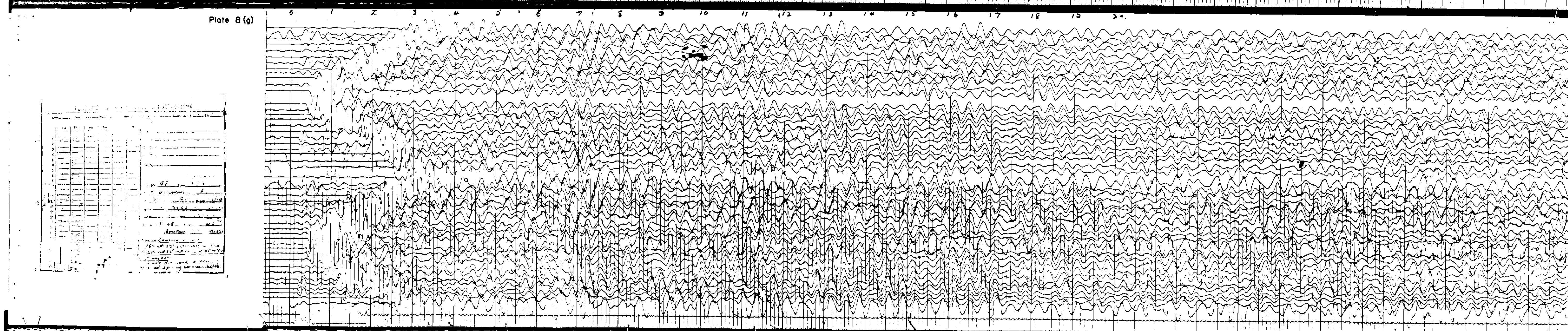


Plate 8 (h)

PLATE 9

Plate 9(a)

Plate 9(b)

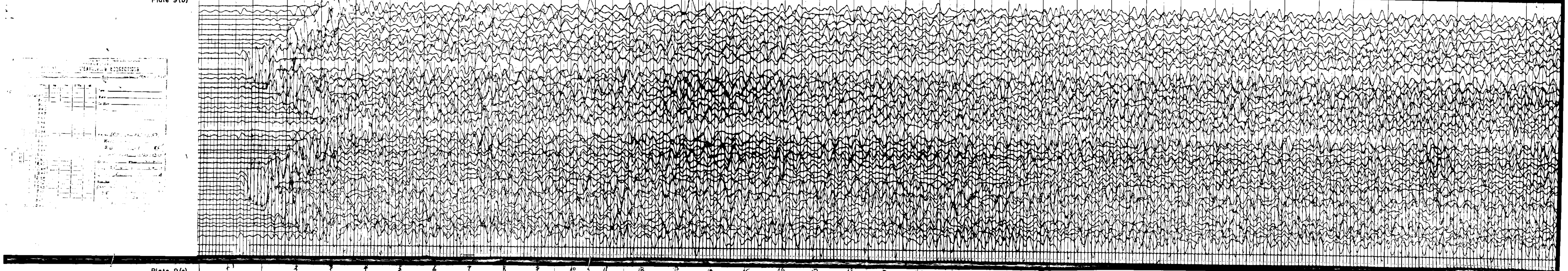


Plate 9(c)

Plate 9(d)

Plate 9(e)

Plate 9(f)

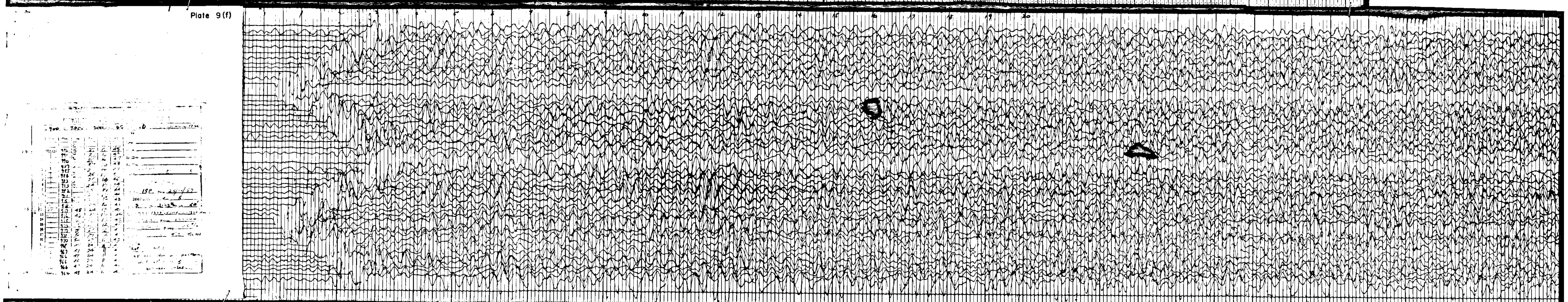


Plate 9(g)

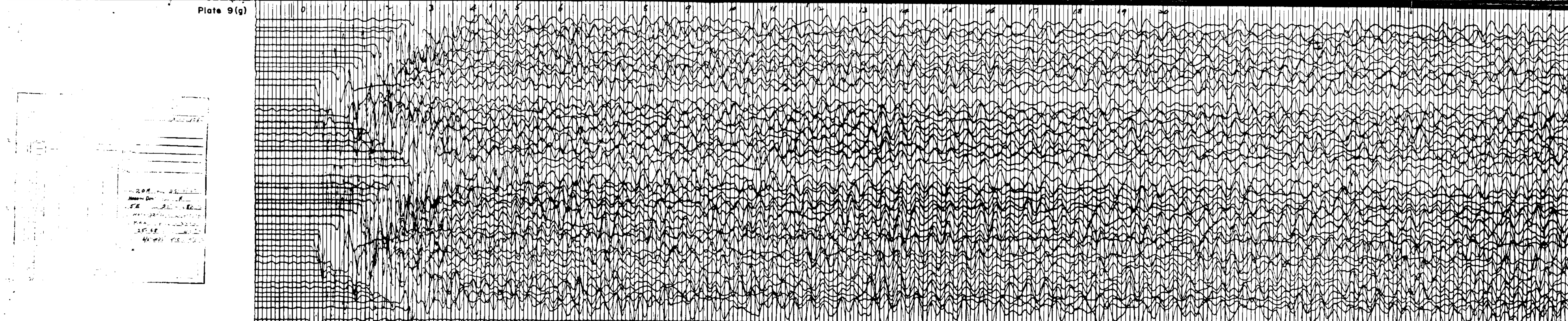
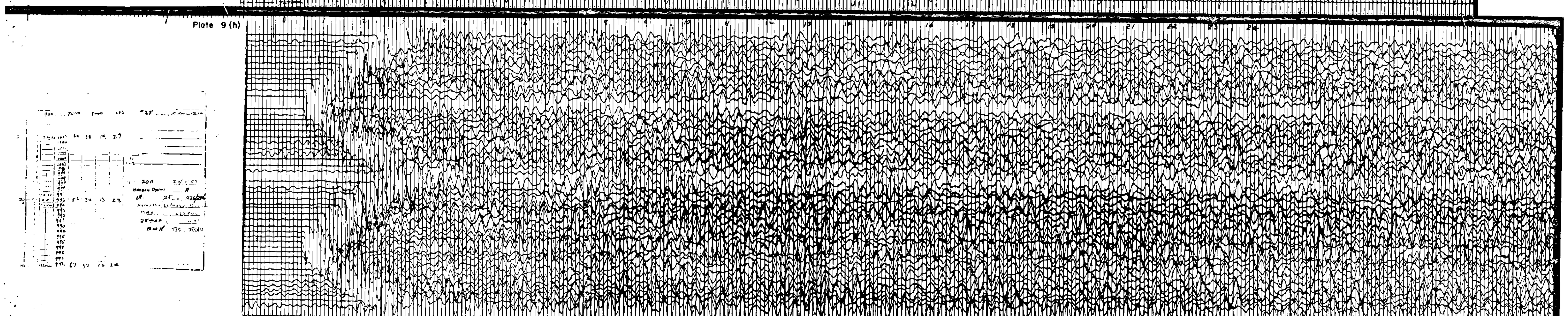
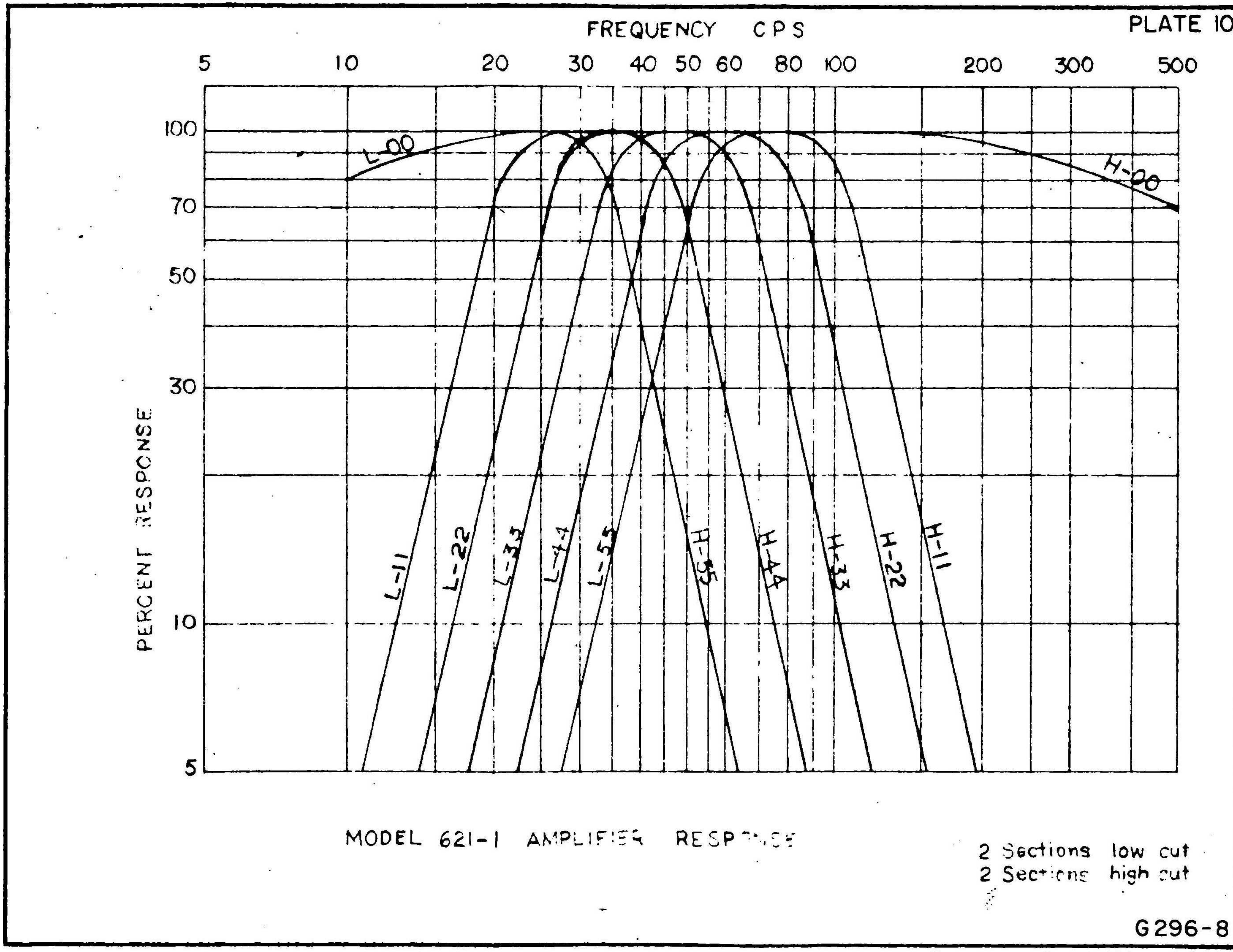


Plate 9(h)





To Accompany Records 1959, N°19