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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 65-32

GEOPHYSICAL RECONNAISSANCE OF HUDSON BAY

Part I. Sea-Magnetometer Survey

Part II. Subbottom Depth Recorder Survey

(Report, 5 plates and 11 figures)

Peter Hood

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OF CANADA

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GEOPHYSICAL RECONNAISSANCE OF HUDSON BAY

Peter Hood

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

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ABSTRACT

A total of 6,500 nautical miles of sea-magnetometer data was obtained during the 1961 cruise of the M.V. Theta in Hudson Bay. The resultant total intensity values are presented in the form of profiles with the regional gradient removed but uncorrected for diurnal variation. A quantitative interpretation of the magnetic profiles shows that, in general, the depths to basement are least around the margins of the Bay, with the greatest calculated depths in excess of 10,000 feet occurring in the area to the northeast of Churchill. The depth determination values also reveal that an asymmetrical trough-like basement feature occurs in the area between Southampton, Nottingham, Mansel, Coats, and Digges Islands.

Ten continuous subbottom depth recorder profiles were also obtained in Hudson Bay covering some 225 nautical miles. Three of the profiles were in the Belcher Islands area and indicate that a minor anticline occurs along the central part of the southern end of Omarolluk Sound with tightly folded synclines on either side. Two profiles were in the central part of Hudson Bay, but the quality of the records was marred by the fact that they were obtained in heavy seas and only a few faint indications of subbottom reflections were obtained. The rest of the profiles were located immediately north of Churchill and indicate that gently north-dipping Palaeozoic sediments occur in that locality.

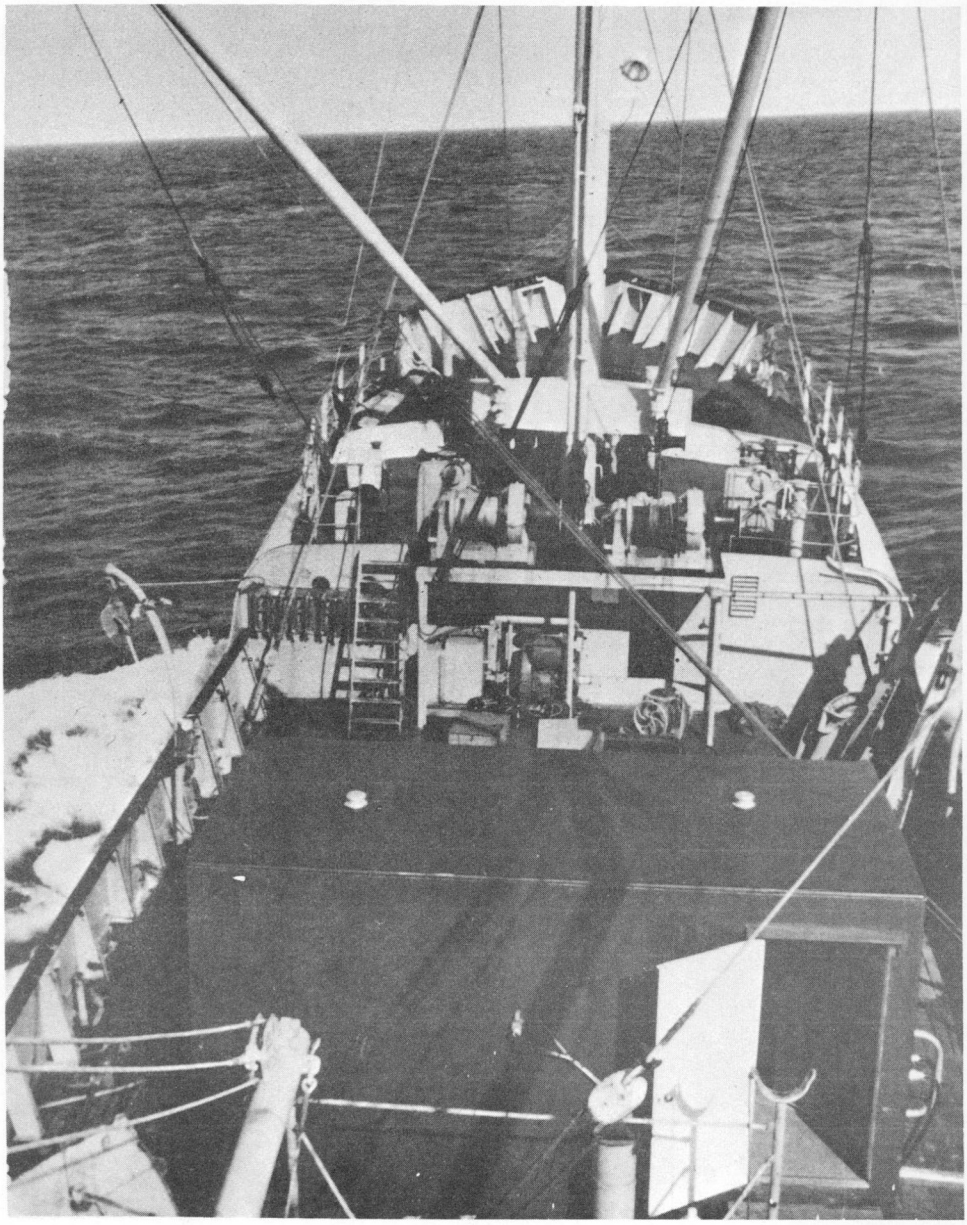

Plate I. View of front half of M.V. Theta in Hudson Bay showing special geophysical laboratory mounted on deck. 112206 B

GEOPHYSICAL RECONNAISSANCE OF HUDSON BAY

INTRODUCTION

During the 1961 field season a joint program of oceanographic observations was carried out in Hudson Bay by personnel from several Branches of the Department of Mines and Technical Surveys using the Motor Vessel Theta (see **Plate I**).

Figure 1 shows the track of the Theta in Hudson Bay. About 6,500 nautical miles of sea-magnetometer and 225 nautical miles of continuous seismic profiles were obtained, providing a fairly good reconnaissance magnetometer coverage for the Bay.

The geophysical instruments used on the cruise were the G.S.C. Model 60 proton precession magnetometer, a subbottom depth profiler of the spark discharge type, and a Lacoste - Romberg sea bottom gravimeter. The gravimeter was operated by personnel from the Dominion Observatory, and the results will not be discussed in this publication.

ACKNOWLEDGMENTS

The sea-magnetometer equipment was maintained and operated throughout the survey by W.J. Stauffer. Most of the initial reduction of the sea-magnetometer records was carried out by Miss M.E. Bower and D.A. Reveler; the latter also helped in the production of the final basement contour map. K.H. Owens aided greatly in the compilation of the magnetic profile map, and various members of the Geological Survey provided much helpful discussion in considering the geologic feasibility of the interpretation. M.J. Berry, a graduate student from the Geophysics Laboratory of the University of Toronto, helped the author of this publication in the installation and actual operation of the subbottom depth recorder.

Acknowledgment is also made: to Dr. W.M. Cameron, Director of the Marine Sciences Branch, for permitting the sea-magnetometer equipment to be installed on the M.V. Theta, which was under charter to the Division of Oceanographic Research; and to F.G. Barber, who was Chief Scientist on the cruise.

PART I

SEA-MAGNETOMETER SURVEY

SURVEY EQUIPMENT AND PROCEDURE

A Serson-type direct-reading proton precession magnetometer designed and built by the Geophysics Division of the Geological Survey of Canada (Collett and Sawatzky, in press) was used to obtain profiles along the ship's track.

This equipment measures the total intensity of the earth's magnetic field, which is around 60,000 gammas in Hudson Bay. The polarize-count time of the instrument is approximately 6 seconds, and an analogue readout records to the nearest 10 gammas.

The fish containing the magnetometer coils was towed on a cable about 500 feet behind the ship, that is, at a distance slightly more than twice the length of the Theta. This caused the magnetic field at the fish due to the ship itself to be negligible (Bullard and Mason, 1961).

A ship's log was towed behind the Theta, and this together with the ship's compass provided a dead-reckoning method of positioning. A 10 cm radar system was also used near the coast as an additional aid in fixing the ship's position. It is estimated that the positioning of the various profiles could be several miles in error, except when within radar range of the coast when the accuracy is usually within one mile.

REDUCTION OF MAGNETIC DATA

A regional correction was made to the magnetic records using the values given in the inset on Figure 2. The regional contours (isodynes) of the total intensity of the earth's magnetic field essentially represent smoothed values of the data obtained in airborne geomagnetic surveys by the Dominion Observatory. No diurnal correction was made, however, although the Dominion Observatory magnetograms obtained with a Ruska magnetometer located at Churchill were inspected for the occurrence of large excursions and for magnetic storms. Surprisingly, many of the magnetic storms seen on the Churchill magnetograms did not appear or their effect was much reduced on the sea-magnetometer records, and this would indicate that there is a reduced effect for the area. Some correlation was, however, observed over short distances on the profiles.

Where the diurnal variation of the earth's magnetic field has appeared to noticeably affect the recorded values, a D has been put at the appropriate point adjacent to the profile on Figure 2. The letters MS indicate that a magnetic storm was recorded at Churchill during the time the profile was taken.

The original records were subsequently intercepted onto paper tapes. The values on the tapes were reduced, using gate dividers to a horizontal scale of 1 inch to 1 mile and then redrawn on cross-section paper

so that the vertical scale was 50 gammas to 1 inch. This meant that the ratio of the horizontal to vertical scales was 50 gammas to one statute mile, which is a typical ratio for the presentation of magnetic profile results. The resultant reconstituted profiles were then reduced photographically to the final presentation scale of 1:1,267,200.

INTERPRETATION OF MAGNETIC DATA

Discussion of Profiles and Individual Anomalies

Figure 2 shows the reduced magnetic profiles obtained in Hudson Bay. The dip of the earth's field ranges from 83° to 85° so that there would be very little displacement of the magnetic anomalies with respect to the causative body. The zero line of the profiles is also the ship's track, and the positive sign placed at frequent intervals along the profiles indicates the side on which the positive ordinate of the residual magnetic intensity occurs.

In general, near the margins of Hudson Bay the profiles are made up of short-wavelength, high amplitude anomalies, while those in the centre of the bay tend to be of longer wavelength, and of lower amplitude. This is a reflection of the depth to the crystalline basement.

In a few places an attempt was made to correlate in a qualitative way between adjacent profiles. Because the ship's tracks are so far apart, this type of interpretation is quite speculative and was only used in a few clearcut cases. The results of this correlation study are indicated on Figure 2 by two types of designation. The first is a dashed line, which denotes an inferred geologic boundary, and the second is a dotted line, which indicates a magnetic trend and, hopefully, would correspond to the strike of the underlying formations.

The profiles immediately south of the Ottawa Islands indicate that the strike of the Proterozoic rocks forming the islands extends in a south-southwesterly direction, whose extension would pass to the west of the Belcher Islands. The profile that passes between the Cape Smith - Wakeham Bay belt of gabbroic rocks (Kretz, 1960) supports the view that the belt extends into the Ottawa Islands. This interpretation (indicated by dashed lines on Figure 2) assumes that the volcanic belt consists of formations whose magnetic susceptibility is quite low, probably less than 250 x 10^{-6} cgs units. However, Kretz (1960) has found that a magnetite-bearing formation occurs at the base of the Cape Smith - Wakeham Bay belt, which is exposed along its south contact. This may be indicated on the profiles by the sharp anomaly that occurs immediately to the east of the dashed lines indicating the interpreted extension of the belt.

The highest amplitude anomaly (over 5,500 gammas) recorded during the survey occurred north of Station 131 in eastern Hudson Bay. It was not completely defined because the magnetometer coil in the towed fish forms part of a tuned circuit and the resultant audio frequency output from the anomaly was somewhat attenuated by detuning. It lies in the extension of the Manitounuk Group of basalt and sedimentary rocks (Low, 1900b; Kretz, 1960), which occur in the Hopewell Islands and which contain iron-formation.

From its character it seems probable that the causative body is magnetic iron-formation. An adjacent anomaly of 3,950 gammas may be part of the same formation.

Several other anomalies exceeding 2,500 gammas are to be found on the profiles. One of 5,100 gammas with an adjacent peak of 3,320 gammas occurs opposite Kovik Bay where the depth of water is about 350 feet. Since the depth to the causative body must obviously be in excess of this distance, the underlying formation must contain a much higher percentage of magnetite than is normally present in igneous rocks.

Other notable anomalies occur in the northwestern part of Hudson Bay. A 4,550 gamma peak occurs about 25 miles northeast of Marble Island, which is located at the entrance to Rankin Inlet. The anomaly happens to be located along the strike of the greenstones located on the north shore of Rankin Inlet (Lord, 1953). These rocks also contain magnetic iron-formation.

There is also an interesting group of magnetic highs north of Churchill Harbour. One of these has an amplitude of 2,760 gammas. Another group of anomalies occurring close by is located immediately to the east of the delta of Knife River, and is shown on GSC Aeromagnetic Map 638G. The tightly spaced set of short profiles (see inset on Fig. 2) in which the ship manoeuvred boustrophedon-fashion were obtained in an unsuccessful attempt to find the 5,760 gamma anomaly discovered on an aeromagnetic traverse from Coral Harbour to Churchill (Bower, 1959) by a Canso aircraft flying at 2,500 feet. The position of the maximum value was approximately 59°20'N, 93°16'W, being some 50 miles northeast of Churchill. The depth of water at this location is estimated from Canadian Hydrographic Chart No. 5400 to be approximately 170 feet. It would be expected that the amplitude of the anomaly at sea-level is probably in excess of 100,000 gammas. This conclusion is based on an empirical comparison with other high amplitude anomalies such as the one at Marmora (Bower, 1960). The Marmora anomaly was flown at a number of different elevations, the peak value at 2,000 feet being 950 gammas, and at 5,000 feet being only 170 gammas. A ground survey using a vertical force magnetometer yielded an anomaly of 30,000 gammas. The actual deposit at Marmora was buried by about 120 feet of Ordovician limestone.

It is concluded that the causative body of the anomaly northeast of Churchill is probably due to magnetic iron-formation. Such an anomaly would, of course, cause a ship's compass to be affected in its immediate vicinity. Actually on Canadian Hydrographic Chart No. 5000 a number of areas on the ship route from Churchill to Hudson Strait are designated as having "considerable magnetic disturbances". However, examination of the Magnetic Chart of the Canadian Arctic 1960.0 shows that the mean daily variation of the magnetic declination is from 1° to 5° with the designation "Magnetic Compass erratic". Thus it appears that the magnetic compass would not be so much affected in the vicinity of Churchill by the magnetic anomalies as by the proximity of the errant magnetic pole, which fortunately appears at the present time to be moving northward towards the geographic pole.

Several of the reduced profiles on Figure 2 have short lengths of negative anomalies where the recorded magnetic intensity fell below the regional value of the earth's magnetic field. Since the survey was carried out at a high magnetic latitude the associated low, which is normally found to the north of the positive peak at lower latitudes, will be very small. Therefore, where an area of pronounced lows is seen on the profiles, it must be caused by a negative polarization change in the underlying basement. These lows are generally located at the edges of Hudson Bay, but a negative area does occur in the northwestern quadrant of Figure 2 between Stations 177 and 178, and 183 and 184, and possibly extends to the south. It probably indicates a different rock type in the basement complex.

Other notable lows are to be found at the northwestern tip of Nottingham Island and in the area between Coats and Southampton Islands.

There are also two areas of lows near the Hopewell Islands on the eastern shore of Hudson Bay, and others that appear to be associated with the diabase traps of Long Island near Cape Jones at the entrance to James Bay, and which indicate the extension of these in a westerly direction. The presence of these lows along the concave shoreline of the southeastern quadrant of Hudson Bay would seem to be a feature of the Manitounuk Group of rocks, which extend from Cape Jones to the Portland Promontory. The lows are presumably associated with the basaltic cap rock, which consists of thick sills of porphyritic basalt overlain by thick basalt flows and thin beds of pyroclastic rocks (Woodcock, 1960), rather than with the Nastapoka Island rocks, which include some magnetite-bearing iron-formation.

Quantitative Interpretation

Basis of Quantitative Interpretation

Approximately 500 depth-determinations were carried out on the original sea-magnetometer records using two graphical methods. The positions of these depth determinations are indicated on Figure 3; a depth determination carried out on one side only of a magnetic anomaly is indicated by a solid dot, whereas a depth determination obtained by averaging the values obtained from both sides is indicated by a dot inside a circle. None of the depth determinations was carried out on anomalies whose amplitude was less than 100 gammas. The methods used were: (1) the half-slope method of Peters (1949), which was used in the majority of determinations of the sub-sea depth to the basement, and (2) the so-called 'straight-slope' method (Agocs, 1958; Nettleton, 1962).

The term 'basement' here denotes the crystalline igneous and/or metamorphic rock complex, which usually has much more pronounced magnetic properties, i.e. intensity of magnetization due to susceptibility and remanent magnetism, than the overlying sedimentary strata, which have very much weaker magnetic properties. The explanation for this difference in magnetic properties is that igneous and metamorphic rocks generally contain a higher percentage of the magnetic mineral magnetite than is found in sedimentary rocks.

Where the sedimentary strata are intruded by igneous bodies the calculations will yield depths to the intrusive rocks, thus giving an erroneous idea of the thickness of the sedimentary cover.

Both depth determination methods used are based on the following simplifying assumptions:

1. the magnetic trends are at right angles to the direction of the profile and are elongated transverse to this direction;
2. the anomalies are caused by sharp discontinuities in the magnetite content of the underlying rocks; and
3. the sides of the causative body are vertical and of great vertical extent, being at least three times the depth to the top of the body.

Peters' (1949) half-slope method actually applies to the symmetrical dipping dyke curve. In high magnetic latitudes such as Hudson Bay, this means in practice that the causative body is assumed to be dipping vertically. The horizontal distance between the half-slope points was taken to be 1.6h where h is the depth of burial as Peters suggested, and this is approximately the case where the depth of burial is half the width of the dyke.

The 'straight slope' method is based on the empirical relationship between the depth to the causative body and the horizontal extent of that part of the anomaly that has a uniform slope. Estimation of this distance from the sea-magnetometer records is complicated by the fact that the data are not recorded in a purely analogue form. Actually the values of the total intensity are recorded in digital form and then converted to an analogue trace. The magnetic signature therefore appears as a series of steps on the sea-magnetometer record.

These simple graphical methods have been used because the more refined methods are not warranted in obtaining depth calculations from the profiles. The more elegant quantitative methods are normally used when the anomaly has been completely defined by a series of parallel profiles across it, thus enabling a magnetic contour map to be constructed. It will be expected that many of the calculated depths will have large errors, which would tend to be greater rather than smaller than the true depth. However, in view of the large number of depth determinations carried out and the averaging effect obtained by contouring the data, it is felt that the structural picture presented must at least correspond to the true one in a general way even if the absolute depths may not be completely accurate.

It should be emphasized that potential field data do not admit of a unique solution, for their interpretations to some extent are subjective. The accuracy of the final picture depends on the skill and experience of the interpreter, and should therefore be tied as closely as possible to the known geology of the area under study.

Basement Contour Map

Figure 3 shows the resultant contours of the Precambrian crystalline basement surface of Hudson Bay as inferred from the magnetic data. The calculated depths were contoured using the following contour intervals—1,000, 2,500, 5,000, 7,500 and 10,000 feet. No drilling results

were incorporated into the results. Actually, very little drilling appears to have been carried out around the margins of Hudson Bay, although such drilling could contribute greatly to the accuracy of the picture.

Naturally it would not be expected that the basement underlying Hudson Bay is the same rock type throughout, because there is an obvious difference between the rock types on the east and west coasts (see Fig. 2). Moreover, the contact between rocks of Hudsonian and Kenoran ages must pass under the bay.

The most striking feature on Figure 3 is the elongated trough in the centre of the bay, which trends in a northeast direction and which would indicate that the thickness of sediments exceeds 10,000 feet. There may be some tectonic significance in the fact that it is in line with the Nelson River gravity feature (Innes, 1960; Wilson and Brisbin, 1961, and 1962), which divides the Churchill and Superior geologic provinces, although more control to establish this trend would be desirable. The gravity anomaly in the Nelson River area consists of a strong gravity high on the Bouguer anomaly map (Innes, 1960; Wilson and Brisbin, 1961, and 1962) bounded on either side by gravity lows. In the vicinity of Bird in the lower reaches of the Nelson River the anomaly becomes less definite and appears to branch into two arms; one arm strikes in the general direction of Churchill and the second trends in an easterly direction. Confirmation of its possible extension into Hudson Bay awaits further gravity measurements.

On Figure 3 a small 'high' occurs southeast of the main elongated trough; southeast of this is a second depression in the basement topography. The 5,000-foot contour parallels the southwest shore of Hudson Bay from Fort Severn to Cape Churchill. The nearest reported drill-hole in the area (Davies et al., 1962, p. 148) is about 35 miles west of York Factory at an elevation of about 220 feet. It intersected 533 feet of Palaeozoic sediments under 320 feet of overburden before reaching the Precambrian basement. These data, coupled with holes farther to the east close to the Churchill railway, indicate that the basement slopes to the northeast at approximately 12 1/2 feet per mile. If the depths reported in the hole are representative of the area and this average slope were maintained it would not be sufficient to account for the calculated depths indicated on Figure 3. It would be necessary therefore for the slopes to increase towards the centre of Hudson Bay, or for an additional structural effect such as a fault to be present, for mutual consistency between the interpreted basement map and the onshore drilling results.

Another interesting feature is found in the extreme northeastern corner of Hudson Bay at the outlet to Foxe Channel and Hudson Strait. The contouring of the depth determination values reveals an asymmetrical trough-like basement feature, which is bounded by Southampton, Nottingham, Mansel, Coats, and Digges Islands. From its general shape it is possible that this is a basement graben formed by faults that strike northwest. One fault cuts the Bell Peninsula on Southampton Island and a second one passes immediately to the north of Coats and Mansel Islands. There is also some topographic evidence to support this graben hypothesis, namely that the depth of water is greater over much of the area than it is in the rest of Hudson Bay (Fig. 1). Actually the water immediately north and west of Digges Island is more than 1,600 feet deep, within 1 1/2 miles from shore.

Canadian Hydrographic Chart 5412 shows that the slope on the north side of Digges Island, is steep and elevations of 935 feet occur on the island, which consists of gneisses and migmatites of Churchill age (Kretz, 1960). The steepness and the linearity of the north side of the island and the bathymetric contours to the west, which all line up with that part of New Quebec immediately to the west of Cape Wolstenholme, would appear to support the interpretation of a fault scarp occurring there. The description by Low (1900a) of the topography and geology near Cape Wolstenholme would also seem to support this view.

Examination of Map No. 5 in the Gravity Series of the Dominion Observatory shows that the Bouguer contours are parallel to, and the gravity values decrease in a northerly direction in this area, which is also consistent with this thesis. Moreover the north end of Coats Island is parallel to the north coast of Digges Island and is straight. The Geologic Map of Canada (1045A) shows that a small area of Palaeozoic sediments occurs on the northern tip at Cape Pembroke and there are Precambrian hills rising to some 500 feet immediately to the south, although most of Coats Island is covered by Palaeozoic sediments. The bottom of Hudson Bay slopes off rapidly north of Coats Island and depths in excess of 600 feet are recorded within a mile of the shore.

The northeastern side of the postulated 'graben' would appear to be bounded by the extremely linear southwestern side of Nottingham Island, which consists of Proterozoic granite and the fault-line scarps that strike northwest on Bell Peninsula and elsewhere on Southampton Island (Bird, 1953; Manning, 1936) and mark the Palaeozoic-Precambrian contact. These topographic features on Southampton Island range from 50 to 800 feet in height, and are up to 70 miles long, in marked contrast to the generally flat-lying areas in the western part of the island covered by Palaeozoic limestone.

Consideration of the interpreted basement contour map (Fig. 3) shows that the 'graben' is deepest to the southeast; the contours have been left open at that end because of lack of information farther to the east, and because the feature may well extend into the Hudson Strait as far as Deception Bay. If this is the case, Charles Island would appear to form the north side of the 'graben' in this area. Thus the 'graben' in Hudson Bay appears to be at least 175 miles long, and at least 300 miles long if it extends as far as Deception Bay in Hudson Strait.

No drilling appears to have been carried out in the area, but the greatest thickness of Palaeozoic limestone reported in the literature (Bird, 1953) is at Cape Donovan halfway along the northeast coast of Southampton Island, where about a thousand feet of sediments occur as a vertical cliff.

A single traverse made between the Belcher Islands and Long Island has suggested the presence of a layer of sediments some 5,000 feet thick in this area. This interpretation may be erroneous in view of the paucity of data, especially since granite rocks, which could be completely non-magnetic, occur to the south in the Cape Jones area (Eade et al., 1957). There must, however, be a geologic boundary in the area, because structural trends in that part of Quebec are close to being east-west, whereas those in the Belcher Islands are north-northeast and the degree of folding is

much more intense. The rocks are also a more basic variety (Jackson, 1960) than those in the vicinity of Cape Jones. The medium-grained basic igneous rocks of the Manitounuk Group that occur on Long Island are similar to the diabase sills that intrude the Palaeozoic sediments at Sutton Lake (Hawley, 1925) in northern Ontario, and with those occurring in the Richmond Gulf area. All three intrusive rock types appear to curve in the same manner as the southeast coast of Hudson Bay and are possibly contemporaneous.

CONCLUSIONS

Perhaps the most interesting aspect of this survey, at least to the petroleum industry, is that it has indicated that the sediments in Hudson Bay are much thicker than had hitherto been supposed. The sediments were formerly thought to form a thin skin over the underlying basement, but the present study has indicated that this view is erroneous. However, the sediments may also be in part Proterozoic, as there is a substantial thickness of Proterozoic sediments exposed on the Belcher Islands and elsewhere in the eastern part of the Bay (Jackson, 1960). Possibly some of the section is Cambrian.

More definitive methods, such as marine seismic exploration, will have to be carried out in Hudson Bay in order to substantiate this interpretation.

The thickest part of the sedimentary section occurs where the water is deepest, in the centre of the bay. However, the thickest sedimentary cover on shore occurs on the southwestern tip of Coats Island where a depth in excess of 2,500 feet is indicated by contour lines.

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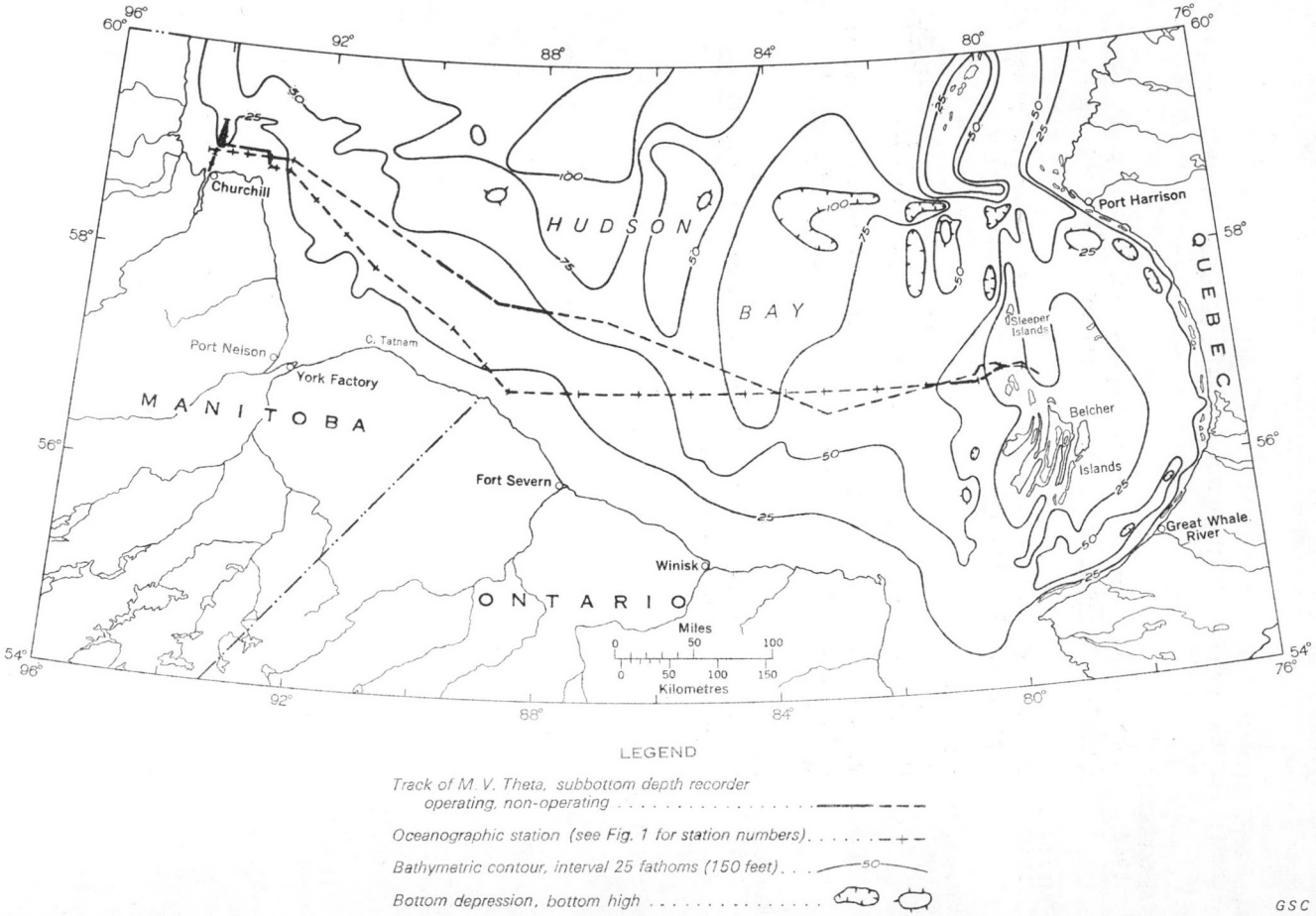

Figure 4. Track of M. V. Theta in Hudson Bay seismic survey traverse from Churchill to the Belcher Islands

PART II

SUBBOTTOM DEPTH RECORDER SURVEY

INTRODUCTION

The subbottom depth recorder equipment was installed on the M.V. Theta on the 8th and 9th of September 1961, and the cruise, which was actually phase 3 of the oceanographic program, began on the 10th of September. The ship sailed eastwards from Churchill to the Omarolluk Sound in the Belcher Islands, and thence back to Churchill. The profiles obtained during the cruise, are indicated by the solid lines in Figure 4. The depth recorder equipment was removed from the ship on the 23rd of September and returned to Ottawa.

A total of ten continuous seismic profiles was obtained in Hudson Bay covering some 225 nautical miles. Three of these profiles were in the Belcher Islands; two traverses were made in the central part of Hudson Bay, and the rest were made immediately north of Churchill. On the best day of traversing, 48.6 nautical miles of profiles were obtained in about 8 hours.

SURVEY EQUIPMENT

Previous Spark Discharge Instruments

An intense electric spark discharge confined to a very small volume of water will vaporize the water and produce high-pressure bubbles whose expansion and contraction radiate acoustic energy. This phenomenon was first used by Anderson (1953) at the Marine Physical Laboratory of the Scripp's Institute of Oceanography. However, its practical use as an acoustic source appears to have been first appreciated by J.B. Hersey and S.T. Knott (1956), who carried out initial development work at Woods Hole Oceanographic Institution. The Lamont Geological Laboratory of Columbia University began research into the spark discharge method in 1957. Further development work has been carried out by W.C. Beckmann and others (1959), who developed a commercial instrument, which has been licensed to several companies in North America. Some of the more interesting surveys in which this instrument has been used are: down the Mackenzie River in the District of Mackenzie (Pallister, 1960; Meador, 1961), in Lake Erie (Paterson and Gregotski, 1961), in Cape Cod Bay (Hoskins & Knott, 1961) and the Gulf of Mexico (Moore and Curray, 1963), for the English Channel tunnel project (Beckmann, 1960), for the exploration of underseas coalfields in Northern England (Maries and Beckmann, 1961; Clarke et al., 1961), in the Persian Gulf (Officer and Weber, 1959), and off the coast of Japan.

The maximum penetration that has been claimed is 1,600 feet in 60 feet of water (Maries and Beckmann, 1961); however, a more typical value would be around 500 feet, but this, of course, would vary with the depth of water, and with bottom and subbottom geologic conditions.

History of Development of the Canadian Subbottom Depth Recorder

The equipment was designed and built jointly by the Geophysics Laboratory of the University of Toronto and Hunting Survey Corporation Limited of Toronto, using money provided by the Geological Survey of Canada and the National Research Council. The first test of the instrument was in July 1961, when the M.V. Porte Dauphine carried out a series of traverses on Lake Erie. The Hudson Bay project was the first salt-water test of the subbottom depth recorder.

Description of Survey Equipment

The major units of the subbottom depth recorder used on the survey (Fig. 5) are as follows:

1. High-voltage unit
2. Amplifier unit
3. Control and Recorder unit
4. Cable system

High-voltage Unit

The high-voltage unit is basically a D.C. power supply, which charges two 1 microfarad condensers to 12,000 volts. These are discharged by a thyratron through the spark-electrode system, which is towed behind the ship. The thyratron is triggered by a pulse coming from the control unit. Approximately 150 joules of energy are discharged into the spark-electrode system and are thus converted into acoustic energy with some loss in efficiency. A current-control device is provided in the unit to even out the load on the ship's generator. A safety device is incorporated into the unit, which shorts out the condensers when the lid of the unit is removed.

The energy in the spark is about the same as that obtained from the explosion of a small detonator (Maries and Beckmann, 1961). This is rather small compared with the energy contained, for instance, in a single half-pound stick of seismic explosive, which releases nearly 70,000 joules of energy on detonation (Davidson et al., 1954). However, there is a gain in recorded information by reason of the fact that the reflections are composited i.e., the individual traces are displayed side by side.

Recently spark-discharge equipment has been developed (Shor et al., 1963) that can provide an output energy of 24,000 joules to the spark-electrode system. This energy is thus comparable to that which can be obtained from explosive, but the installation is bulky since a number of large high-voltage condensers are required and this factor together with the not inconsiderable power requirements necessitates the use of a well-regulated medium-sized generator. This would make the complete installation on the ship a semipermanent one since the equipment and its ancillaries would not be readily portable.

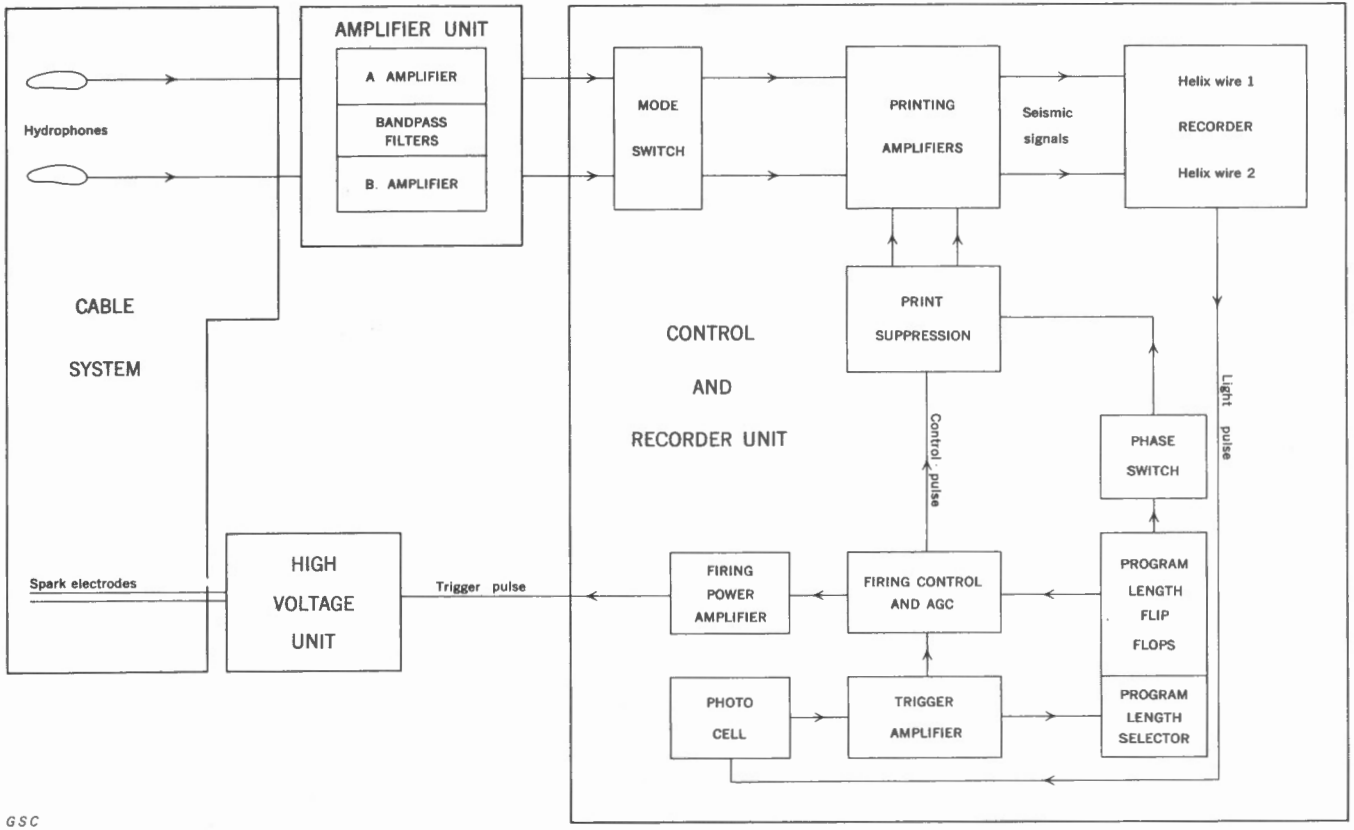

Figure 5. Block diagram of Canadian subbottom depth recorder.

Amplifier Unit

The amplifier unit is a straightforward transistorized amplifier, which incorporates a variable bandpass filter network. The filters are a commerical unit made by Allison (Model 420R), and are variable from 20 cps (low-cut) to 20,000 cps (high-cut).

Control and Recorder Unit

The recorder uses a modified Alden unit, which utilizes the helix-wire method of printing on an electro-sensitive paper. This recording paper has a fast response and sensitivity, and is thus able to give tonal shades.

The power distribution panel and a control unit, by which the recording parameters can be varied, are located on the recorder chassis. A phase switch controls the time covered by each of the two channels. For position 1, reflections received from 0 to 0.2 second (200 milliseconds) after the spark occurs are printed on the recorder chart. A mode switch determines which amplifier (A or B) shall be relayed to the helix wires 1 or 2. A program-length switch alters the spark-recurrence frequency in steps of 0.2 second from 0.2 second to 1.8 seconds. A rectification switch permits either the full signal, or the positive, or the negative halves of the signal to be printed. The appearance of the record is considerably changed by the use of this switch. The half-wave record has a 'salt and pepper' appearance and is probably best used when the reflections are strong and clear, since they are then sharply defined. The character of the full-wave record is smudgy and the reflections are less sharply defined. It is probably best used when the reflections are weak. The recorder unit was subsequently modified by the University of Toronto and the control unit was separated from the recorder chassis.

In addition, a fiducial button is provided on the control unit, which causes a mark to appear in the space provided in the centre of the record. It may thus be used to record a time fiducial by writing in the time afterwards against the mark with a pen or pencil. Greenwich Mean Time was used throughout the survey, and this was taken from the ship's clock.

Cable System

This consisted of two hydrophones and the electrode system, which were towed about 200 feet behind the ship. One hydrophone went open circuit early in the survey, so that subsequently only one hydrophone was used. The hydrophones were the Harris transducer (velocity) type, Model MP-35. The electrode system consisted of two Canada Wire and Cable Company RG-8/U coaxial cables. The copper wire at the end of the coaxial cables actually formed the electrodes between which the spark occurred. A nylon cylinder, through which the copper conductors passed, kept the conductors about half an inch apart. It was necessary to trim the insulation surrounding the wire about once every four hours because one of the electrodes, the cathode, was eroded away by about one half inch during this period of time. The polarity of the electrodes was usually reversed at that time also by changing over the spark-electrode cable at the terminals of the high-voltage unit. This balanced out the differential wear of the copper wire.

Some intrusion of sea water was noted along the braid of the coaxial cable, although this did not appear to affect the performance of the system.

Field Techniques

The high-voltage unit was installed on the deck of the M.V. Theta and was protected from the elements by a wooden cabinet, which was constructed by the ship's carpenter. White styrofoam floats were attached about every 20 feet along the hydrophone and electrode cables in order that the cables would float, and so that the hydrophone and spark-discharge electrode system would remain fairly close to the surface. It was found that about 200 feet of cable were necessary in order to reduce the ship's noise recorded by the hydrophones to a reasonable level.

The recorder and amplifier units were installed in a portable laboratory (Plate II) situated amidships on the main deck. Two cables threaded along the gunnels of the ship connected the hydrophone to the amplifier unit, and relayed the trigger pulse from the control unit to the high-voltage unit. Considerable experimentation was carried out with the settings on the control unit in order to obtain the best possible record.

P.H. 1-7-61

Plate II. Subbottom depth recorder installation on the M.V. Theta.

For the greatest penetration, it appeared that a bandpass filter setting of 20 to 700 cps was desirable, while a typical frequency setting for best definition was 150 to 2,000 cps. The spark recurrence frequency was set at 0.6 second, and the paper speed of the recorder was set at 1.4 inches per minute. The rectification switch was commonly set at the negative half-wave position.

The speed of the ship was generally around 6 knots, and fiducial marks were made every 5 to 10 minutes, so that these would be spaced at one half to one nautical mile apart.

SURVEY RESULTS

Description of Record

The chart from the subbottom depth recorder is essentially a variable-density time cross-section, with the reflections being unmigrated. It is therefore directly analogous to a geologic cross-section, although a somewhat distorted one since the vertical scale is not constant. On the seismic record (see Plates III, IV, and V) can be seen the origin at which the spark occurs, the direct wave trace which is caused by acoustic energy travelling directly between the spark electrode and the hydrophone, the bottom reflection which is usually the strongest reflection seen on the record, subbottom reflections, and multiples of the bottom and subbottom reflections. It will be noted that the direct-wave trace and all reflections have a double pulse character, which is probably due to the expansion and contraction of the explosive bubble formed at the spark electrode. The travel time is about 200 milliseconds across half of the record as indicated by the scale on the right-hand side.

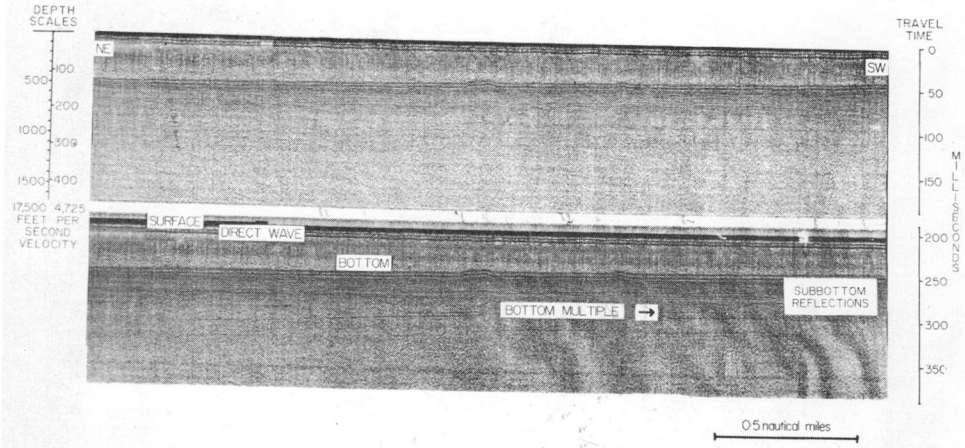

Plate III. Subbottom depth recorder profile north of Churchill, Manitoba.

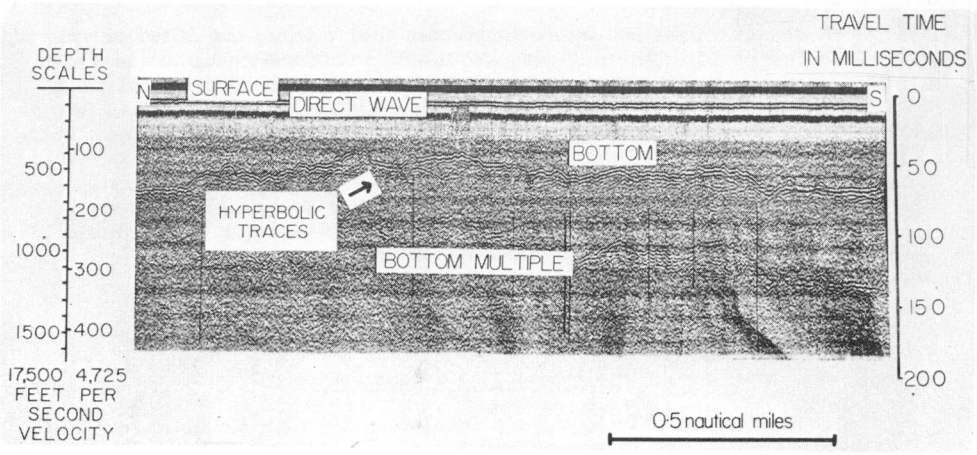

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Plate IV. Section of Record taken in the Belcher Islands, showing hyperbolic traces.

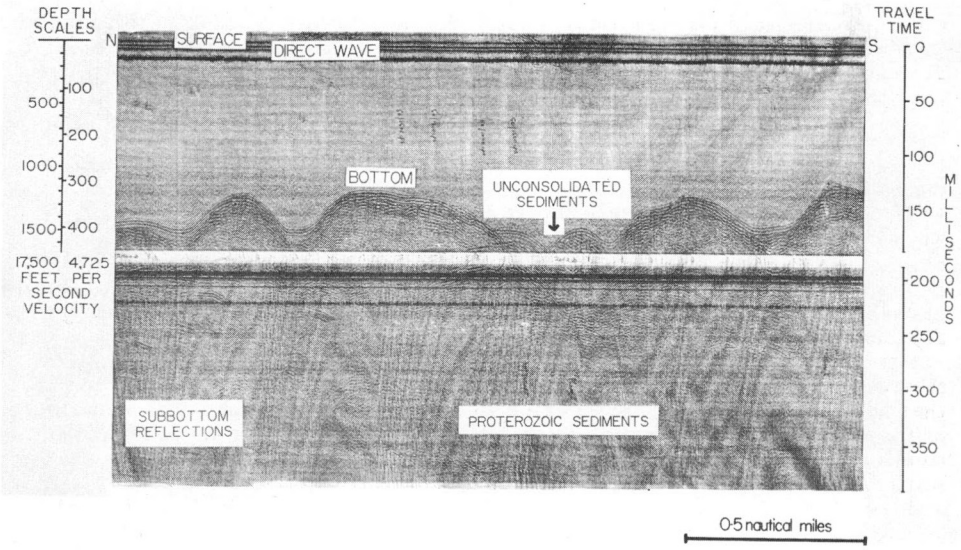

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Plate V. Subbottom depth recorder profile in Omarolluk Sound, Belcher Islands.

From observations made during the survey, the average salinity of the sea water in Hudson Bay was around 32 parts per thousand and the average temperature for Hudson Bay was about -1.6°C. Using Wilson's (1960) formula the velocity of sound in water during the survey was approximately 4,725 feet per second. Velocities in the recent sediments, Palaeozoic sediments, and the Precambrian basement were taken to be 5,000 feet per second, 15,000 feet per second, and 20,000 feet per second respectively. These values are based on figures given in the standard textbooks on geophysics and on determinations from seismic refraction surveys in southwestern Ontario (Hobson, 1960). The depth scales on the left hand side of Plates III, IV, and V are therefore drawn for the water velocity, and for that through the Precambrian.

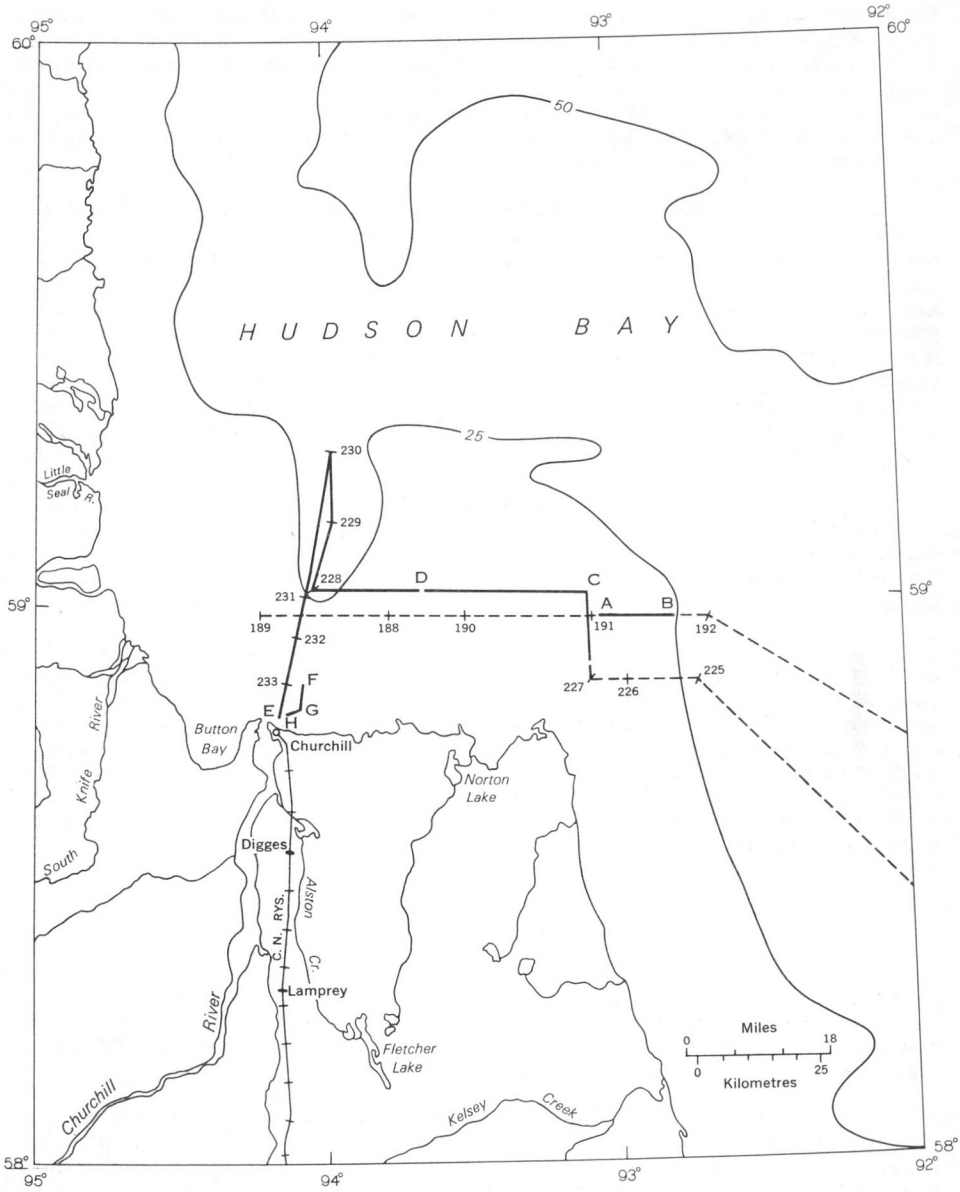
The average depth of penetration in the sediments using this equipment was about 400 feet which is a relatively thin skin of material in comparison with the probable total thickness of sediments in the Bay. In a few places a somewhat greater depth of penetration was obtained.

The vertical exaggeration of the record with the ship's speed at 6 knots is about 4 to 1.

Profiles North of Churchill

Figure 6 shows the track for the profiles obtained in the area north of Churchill; the reduced profiles are presented in the Appendix. In general, the records were somewhat disappointing, no subbottom reflections being recorded on Sections AB and FGH. On the other profiles obtained there is generally a persistent reflection about 30 feet below the bottom, and in some profiles there are at least two subbottom reflections. This lack of penetration may be due to the high attenuation of the acoustic energy through the silt layer deposited from the sediment carried down by the Churchill River.

The character of the subbottom reflection changes from undulating in the most northerly profiles near Station 230, where the relief is of the order of 40 feet, to relatively flat in those profiles closer to Churchill. It is, of course, possible that this is not the same horizon. To ascertain the composition of the various strata it is desirable to extrapolate to known geology. The area in the immediate vicinity of Churchill consists of quartzite probably of late Proterozoic age, which the Geological Survey of Canada aeromagnetic maps (Nos. 634G, 639G, 640G, and 645G) indicate have a relatively low susceptibility. M.Y. Williams (1948) examined a sample of the rock and found that it contained about 70 per cent quartz; he also noted that no feldspar and ferromagnesian minerals were present. The remainder of the sample was composed of sericite. If this sample is at all representative there is little doubt that the Churchill quartzite does have a low susceptibility. It could also be expected to have a fairly high velocity probably in excess of 15,000 feet per second. Williams also confirmed J.B. Tyrrell's (1896) observations that dips west of the Churchill River were southeasterly and that the dip of the Churchill quartzite east of the river was invariably 70° to 80° in a southwesterly direction. His conclusion was that the lagoon and harbour represented a southward-plunging syncline.



LEGEND

Track of M. V. Theta, subbottom depth recorder operating, non-operating ..... A B

Oceanographic station number 230

Bathymetric contour, interval 25 fathoms (150 feet) 25

GSC

Figure 6. Track of M. V. Theta north of Churchill, Manitoba

The aeromagnetic maps also indicate the possible presence of a fault running east-west along the coast, as indeed does the topography. Magnetically the strongest evidence for a fault comes from the line of highs running in a northeasterly direction through Button Bay. With the above possible structural complications it becomes somewhat tenuous to extrapolate the geology out into Hudson Bay. However, it is clear from other evidence, specifically the sea-magnetometer results, that the crystalline Precambrian basement is at no great depth i.e. less than 1,000 feet in the area immediately north of Churchill Harbour.

A number of interesting isolated features occur on the profiles north of Churchill. Immediately to the north of Station 228 is a sharp expression in the bottom topography (45 feet high, and 500 feet at the base) whose southerly side is extremely steep, while to the north it is more gently sloping. The south side of the feature is probably the 'curve of maximum convexity' (see Appendix, and also Northrop et al., 1959; Hagedoorn, 1954). Another possible explanation is that it is a shipwreck and silt has accumulated in the lee of the obstruction by deposition from the relatively strong currents emerging from the mouth of the Churchill River. However, there would appear to be some subbottom reflections beneath the feature, which suggest a geological origin, perhaps a sand wave.

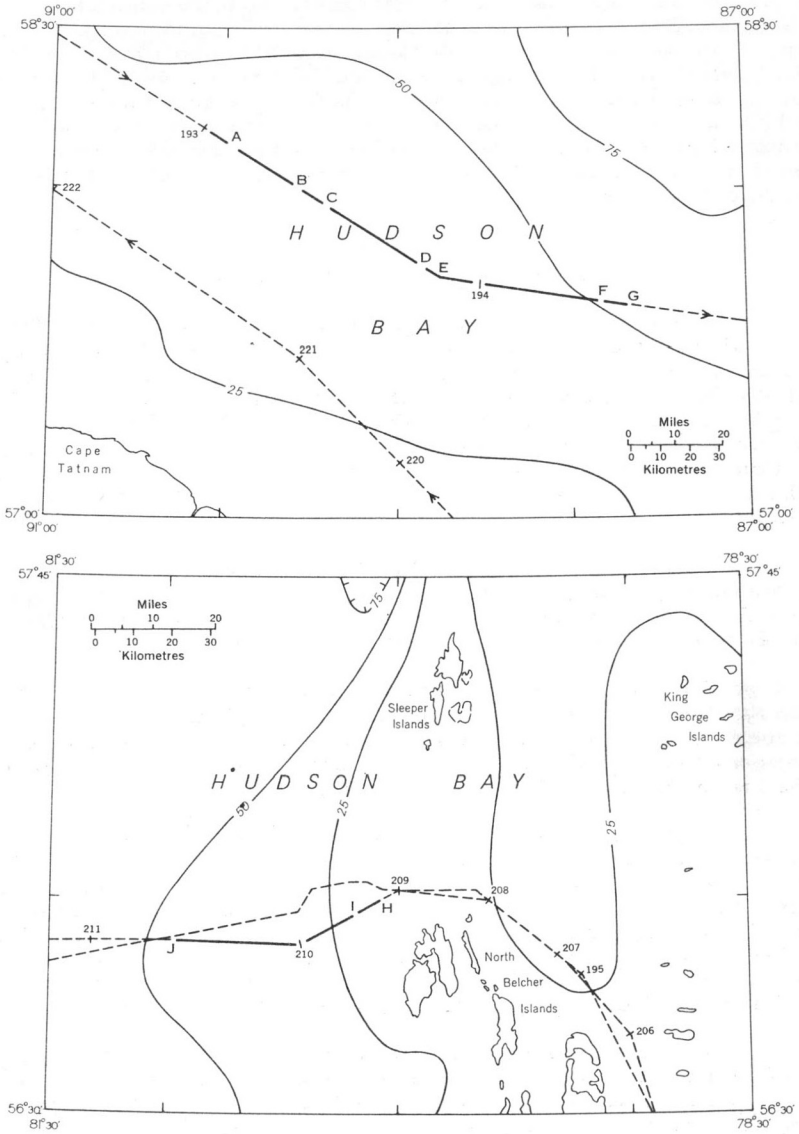
Immediately south of Station 230 and nearly opposite the mouth of the Little Seal River is a depression in the subbottom reflector. This depression is about 3,000 feet wide and is some 50 feet deep. It is inferred that this feature marks the former course of a river, possibly the Little Seal.

One of the better quality profiles occurs between Stations 232 and 233 the original record of which is shown on Plate III. Two subbottom reflections have been interpreted on the section; the remaining reflections appearing on the original record are multiple reflections from the bottom and the second subbottom reflector. Because of the flatness of the deeper subbottom reflector it is interpreted as the top of the Ordovician (?) strata, or possibly an intermediate horizon therein. This interface dips to the north at about 12 feet per mile and would appear to be covered by about 50 feet of recent sediments.

Profiles in the Central Part of Hudson Bay

The track for the traverses is given in Figure 7, and the reduced profiles are presented in the Appendix. Unfortunately only the bottom reflection was usually recorded; this was mainly due to the fact that the equipment was operated during heavy seas when the background noise was high, causing the signal-to-noise ratio to be poor.

However, the records are not completely without interest. The bottom reflection shows several depressions, which might be ancient river courses. One occurs about 1 1/2 miles east of point D and is about 30 feet deep and 600 feet wide. Another occurs about 3 miles west of Station 210. There are also a number of esker-like features occurring on Section H-I-Station 210-J. These are flat-topped, range in width from 800 to 1,700 feet wide, and are up to 60 feet high. These are indicated on the reduced profile



LEGEND

Track of M. V. Theta, subbottom depth recorder operating, non-operating ..... F G

Oceanographic station number 220

Bathymetric contour, interval 25 fathoms (150 feet) 25

GSC

Figure 7. Track of M. V. Theta in central part of Hudson Bay

in the Appendix by the letter e. It would seem from the position of this profile in Hudson Bay that the Palaeozoic/Proterozoic contact might occur along its length. However, it is difficult to decide a likely position from the records, which are almost devoid of subsurface reflections. In any case it is unlikely that the contact would be well defined because there would probably be a number of Palaeozoic outliers. Nevertheless, the character of the bottom features, which are 'blocky' rather than rounded, indicates that the contact would occur to the east of I and that the subbottom material is Palaeozoic limestone.

Profiles in the Belcher Islands

Figure 8 (in pocket) shows the track of M.V. Theta in the Belcher Islands, the reduced profiles obtained are presented in the Appendix. The profiles were all located either in the approach to Omarolluk Sound or actually within the sound. Sections AB and CD are located between the Bakers Dozen Islands and Wiegand Island. The subbottom relief in the initial part of Section AB is quite variable, with changes of relief up to 70 feet. Comparison of the relief between Wiegand and Loaf Islands suggests that the subbottom strata is probably Jackson's (1960) Unit 15 rather than Unit 13 in the Belcher Group.

Jackson described Unit 13 as consisting mainly of dark green-grey, aphanitic to fine-grained, amygdaloidal, massive, and pillowed basalt. Unit 15 was described as being mainly of dark green to dark grey, laminated to thick-bedded greywacke with interbedded argillite.

The bottom relief of Section CD is somewhat similar to that of Section AB. A gully occurs on the northwest end of the profile and is about 1,500 feet wide and some 70 feet deep. A few feet of unconsolidated sediments cover the bedrock on the southeast end of the profile, as indicated by the shallow subbottom reflection.

Section EFG is located immediately north of Gushie Point on the northeast corner of Flaherty Island. Up to 40 feet of silt lies on the bedrock and contains a number of boulders. The position of some of these boulders, as indicated by short hyperbolic signatures on the original record (Plate IV) is given in the Appendix. Some of the boulders appear to be rather large — up to 20 feet high. A well-defined bottom multiple is also to be found on the original record, which is due to the bottom being a high-contrast reflector. The subbottom reflections generally dip to the northwest.

The bottom reflection on Section HIJ, which is located just south of Gilmour Peninsula in the Omarolluk Sound, is much smoother than on the previous sections discussed. Dips of the reflections are generally to the south. Subbottom overburden seems to be thicker for this section with typical values of 60 feet in the centre of the profile. A fault labelled f_1 in Figure 8 has been interpreted from the subbottom depth recorder charts and from the bathymetric information given on the hydrographic maps. Fault f_1 (strike N70°) passes to the south of Bradbury Island and intersects a copper occurrence given on Map 8-1960 (Jackson, 1960). It dips to the south and has a surface expression as indicated by the airphotos of the area. There appears to have been some transcurrent movement of the fault in a right-handed manner.

A pronounced underwater topographic feature occurs on the north end of Section KL, which also appears on Canadian Hydrographic Chart 5470, and shows that it is an isolated peak. It gives rise to a very strong bottom multiple, which indicates that there is very little silt on its sides.

Two faults, f_2 and f_3, have been interpreted from this profile and from the hydrographic data. Fault f_2 strikes N 80° and cuts La Duke Island on the east side of the Sound, while sinistral fault f_3 strikes N 60° and passes through the southern tip of La Duke Island. Both these faults appear to strike in the general direction of copper and sulphide occurrences (Jackson, 1960). An additional fault may occur immediately to the south of fault f_2. Subbottom dips on the southern slope of the underwater mount are to the south while those in the southern part of the profile are to the north. The area between the faults is higher than that on either side so that the fault would appear to be normal; transcurrent movement of fault f_3 would appear to be sinistral, as indicated by the bathymetric data and the air-photos.

The next set of profiles to be discussed are located in the southern part of Omarolluk Sound, which is very much deeper than the northern end. Two narrow troughs extend for many miles parallel and relatively close to Mukpollo Peninsula, French, O'Leary, and Innetalling Islands, which enclose the southern part of the Sound. The deepest parts of the troughs lie in the extreme southern half of the sound off French and O'Leary Islands and the 80-fathom (480 feet) subsea closed contour runs for about 14 and 12 miles respectively parallel to the shore.

Actually the depth of water in the troughs is comparable to that found in the deepest parts of Hudson Bay except for the northeast corner at the outlet to Hudson Strait. It is reasonable to suppose that the troughs are related to the general structure of the Belcher Islands. Depths in the central part of the southern end of Omarolluk Sound are much shallower, being less than 150 feet in places.

The profiles consist of a closed traverse from Station 200 north along the east side of the sound. The track passes between Walton and Camp Islands to a point designated Q in Figure 8 midway up Walton Island. The ship then proceeded south parallel to Mukpollo Peninsula on the western side of Omarolluk Sound to the extreme southern part of the Sound (Point T). An abrupt change of course was made to bring the ship back to the position (Point U) occupied at Station 200. At this point the ship altered course and carried out the very interesting traverse across the Sound to Station 201. The last profile (WXY) in the Sound was obtained as the ship proceeded north to anchor opposite the Belcher Mining Corporation prospect.

The section between Points M and N starts in the trough running along the eastern side of Omarolluk Sound; the water depth is about 560 feet at the start of the section and decreases to about 310 feet at Point N. The bottom profile is generally flat whereas a few subbottom reflections in the southern end of the section dip to the north. The thickness of drift towards the northern end of the section is around 50 feet.

Section NO has a strong bottom multiple, which is indicative of shallow overburden. Several faults are indicated on this record, namely

faults f_4, f_5, and f_6 which appear to cross the Sound in directions that are almost 45° to the general strike of the country rock. Fault f_4, which passes immediately to the south of South Camp Island, dips to the north and is normal. Faults f_5 and f_6 intersect the Belcher Mining Corporation prospect located at the southern end of Mine Lake. There is especially good supporting evidence from the bathymetric data for faults f_5 and f_6, which appear to form a narrow graben some 1,000 feet wide and are evident on the shoreline as slight fault embayments.

Section OP passes between Walton Islands and the Camp Islands. The depth of water decreases from about 150 feet to about 30 feet between the islands and the resultant profile indicates that Walton Island and North Camp Island are along strike. The bottom profile is much more uneven west of the islands as compared to the profile on the east, and this causes a confusing jumble of hyperbolic traces on the original record, especially noticeable on Section PQ. These may also be due in part to the presence of boulders, and to the fact that the traverse is across the strike.

The bottom reflection of Section QR dips gently to the south. A few shallow subbottom reflections occur, which are relatively flat. Depth of overburden would appear to be some 20 feet in general.

Section RS is one of the most interesting profiles as the deepest subbottom reflections recorded in Omarolluk Sound occur on this section, and assuming a bedrock velocity of 20,000 feet per second the deepest ones would appear to originate from strata some 2,250 feet below the bottom; bedrock is assumed to be Jackson's Unit 15 (Jackson, 1960), which is Precambrian sediment.

Three of the faults previously discussed, namely faults f_4, f_5 and f_6 cross this section, and the character of the bottom topography suggest that there may be a number of others.

The dips of the reflections in the southern part of the section are generally steep and to the south. Most of the other subbottom reflections appear to indicate that locally the folds are tight although because the section is located along the east edge of the western trough in Omarolluk Sound, the appearance of the profile may be deceptive.

Faults f_7 and f_8 cross Section ST and are indicated on the cross-section. Fault f_7 dips to the north and appears to be normal. It passes through the Ridge Passage and there may be some significance in the fact that the copper minerals occurring on the island south of the Gibson Peninsula lies along the strike of fault f_7; this is also true of fault f_8 which is in line with a small fault appearing on Jackson's map located on one of the islands running parallel to French Island. Fault f_7 may form the south side of a narrow graben striking normal to the centre line of Omarolluk Sound. With the two deep troughs crossing its ends the feature forms a saddle across the Sound. The relief from top to bottom is about 340 feet and the effect of the curve of maximum convexity (see Appendix) may cause the sides to appear less steep than they actually are. A small amount of material, probably sediment (about 70 feet thick) fills the bottom of the saddle.

Plate V, which is part of Section RST obtained in Omarolluk Sound, is in direct contrast to the Churchill record (Plate III) and that obtained at the north end of the Sound (Plate IV). It demonstrates the character of the bottom profile in the southern end of the Sound very well. A number of subbottom reflections are readily apparent, although the parallel patterns on the record are due to the instrument and are of no geological significance. There would also seem to be reflections originating from within the Proterozoic rocks, which are sedimentary in part anyway (Jackson, 1960), since it is difficult to visualize how some of the reflections on this section could originate from multiple reflections between the top of the bedrock and the surface of the ocean. Different filter settings were used for the top part and the bottom part of the record given in Plate V. A lower bandpass setting was used for the bottom part of the Belcher record because it was expected that the higher frequencies would be attenuated more rapidly with depth.

Section ST and TU confirm that the centre of Omarolluk Sound is much shallower than the area closer to the shore and the top of this underwater feature is covered by about 30 feet of unconsolidated sediment in most places. The dip of the bedrock formations would appear to be to the north. In the regions where the water is deeper, sediment has accumulated to a greater thickness.

A striking feature occurs on Section UV, part of the east-west traverse across the Sound, and appears to have some expression on Section TU. It has the appearance of a curve of maximum convexity because of its shape and also because of its symmetry. It is approximately 140 feet high, and is interpreted as a dyke-like feature, perhaps a sharp ridge, but because of the masking effect of the resultant hyperbola its width and exact shape are a matter of conjecture. There would seem to be a thickness of 40 feet of unconsolidated sediments immediately to the west of the feature.

Section V - St. 201, which traversed part of the trough on the west side of the Sound clearly shows subbottom reflections that dip into the centre of the trough. There is thus good subbottom evidence that this topographic feature is actually structural, and supports the view that a syncline occurs immediately to the east of French Island.

Section WXY is a profile along the centre of the Sound, which terminates opposite the Belcher Mining Corporation prospect. Part of the record is missing because tests were being made to ascertain the effect of the subbottom depth recorder equipment on the operation of the sea-magnetometer.

Jackson (1960), in his geological map of the Belcher Islands, shows a syncline running along the length of Omarolluk Sound with anticlines along the Kipalu Inlet and Innetalling-Tukarak Islands. Evidence from the subbottom profiler records and hydrographic charts indicate that the structure is somewhat more complicated than this picture. It is readily apparent from Figure 8 that two deep troughs, which are over 500 feet deep in the southern part of the Sound, run parallel to and immediately adjacent to the islands enclosing the Sound, dying out at Gilmour Peninsula, whereas the area in the centre of the Sound is very much shallower. The subbottom profiler records indicate that the bottom of the Sound is only covered with a

thin skin of unconsolidated sediments. It would appear therefore that in addition to the major anticlines mapped by Jackson, which run along the Kipalu Inlet and Innetalling-O'Leary-Broomfield Islands, there is a lesser anticline in the centre part of Omarolluk Sound with concomitant synclines immediately adjacent to the enclosing islands. These folds appear to die out to the north, and consideration of Jackson's cross-section on Map 28-1960, which crosses Gilmour Peninsula, indicates that only a minor flexure in the formations is to be found in that area.

CONCLUSIONS

The seismic survey indicated that much geological information concerning the extent of surficial material and the upper part of the underlying consolidated formations can be obtained using the subbottom depth recorder.

The quality of the profiles in the centre part of Hudson Bay was marred by the fact that they were obtained in heavy seas. This caused the signal-to-noise ratio to be poor, and only a few faint indications of subbottom reflections were obtained. The records north of Churchill were much better and the records in general indicated that gently north-dipping Palaeozoic sediments occur immediately to the north of the port.

The profile immediately west of the Belcher Islands seems to indicate that Palaeozoic sediments are present in this area. The records were again poor, and the few subbottom reflections showed that the sediments dipped to the west.

The subbottom depth profiler records in Omarolluk Sound were striking, and provided structural information on the highly-folded Proterozoic formations that occur in the islands. Profiles were obtained right down to the southern part of the Sound and support the view that a minor anticline occurs along the central part of the southern end of the Sound, with synclines, which are tightly folded, on either side of it. An attempt was made to interpret a number of faults from the records; little displacement was noted on the air photos and their actual existence must await confirmation by geological mapping.

The method has its best application in the study of relatively shallow, complex, subbottom structures, because the depth of penetration of the equipment is limited by the relatively low power of the seismic source. It gives a continuous record in the form of an unmigrated time profile equivalent to a geologic cross-section; thus an immediate picture is gained of the subsurface structure. The method is a rapid one and a considerable distance may be covered in a single day. It is also safer, cheaper, and logistically much simpler than conventional marine seismic surveys.

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APPENDIX

CURVE OF MAXIMUM CONVEXITY

A small feature such as a boulder on the bottom of Hudson Bay, which projects above its surroundings, will act as a point reflector to the seismic energy produced by the spark.

Consider an oblique reflection from the boulder to the electrodes using the notation in Figure 9. If d is the depth of water, a is the displacement of the track from the point immediately above the point reflector, v is the velocity of sound in water, and t is the travel time between the instant the spark (i.e., explosion) occurs and the arrival of the reflection from the boulder at the hydrophone, then using the Pythagorus theorem:

$$\left(\frac{vt}{2}\right)^2 = x^2 + d^2 + a^2.$$

Rearranging this equation

$$\frac{t^2}{4(d^2+a^2)/v^2} - \frac{x^2}{d^2+a^2} = 1,$$

which is the equation of a hyperbola

cf $$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1.$$

Now the seismic record from the subbottom profiler is an unmigrated one, so that the reflection is plotted directly under the electrode position. The form of the curve will therefore be a hyperbola and the apex will be at the boulder ($x = O$) if $a = O$ and below if $a > O$; also the curve will be symmetrical about this point. The shape of the curve will also be modified by the vertical exaggeration of the record.

Since the slopes (m) of the asymptotes to the hyperbola are given by $m = \pm\frac{b}{a}$, the slope will be $\pm\frac{v}{2}$. Thus the effect of increasing the displacement (a) of the track from the position vertically above the point source is to cause the feature to appear deeper than it actually is; this will flatten the top of resultant hyperbola (see Fig. 10), but it will not affect the slope of the asymptote. Thus, if the speed of the ship is known, the velocity of sound through water may be determined directly by this method.

The slopes of dipping reflections and the sides of the hyperbola are, of course, affected by the vertical exaggeration of the seismic records. Figure 11 indicates the extent of the effect for various degrees of vertical exaggeration. If s is the speed of the ship, v the velocity of sound through water, p the paper speed, and m the vertical scale of the seismic record, then the vertical exaggeration of the record is given by $\frac{s}{p} \div \frac{v}{m}$, i.e. $\frac{sm}{vp}$, which is the horizontal scale divided by the vertical scale. The average vertical exaggeration of the records obtained during the survey was 4:1. Then the slope of the asymptotes with a vertical exaggeration of $\frac{sm}{vp}$ becomes $\frac{vp}{2sm}$. The family of hyperbolas i.e. curves of maximum convexity of reflections from a point source, for a vertical exaggeration of 4:1 is given in Figure 10.

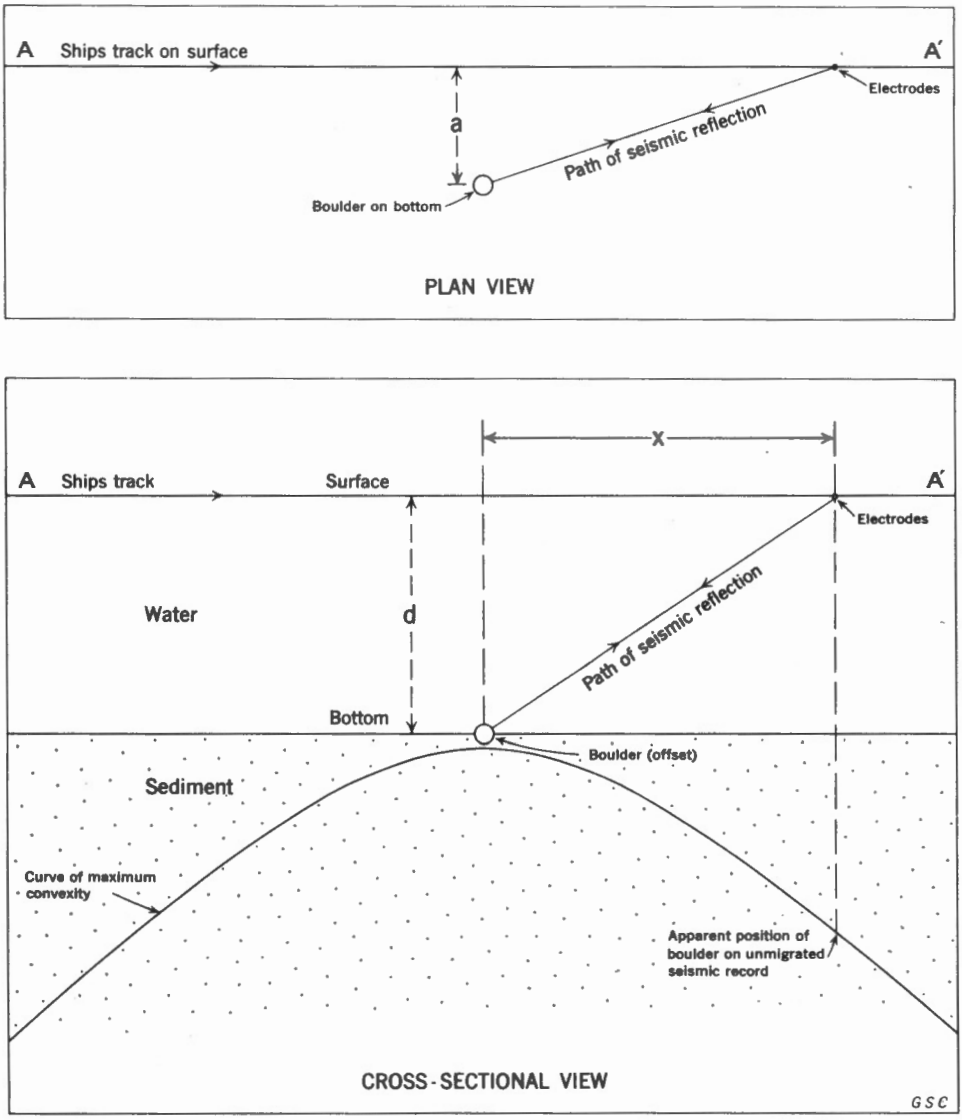


Figure 9. The point reflector.

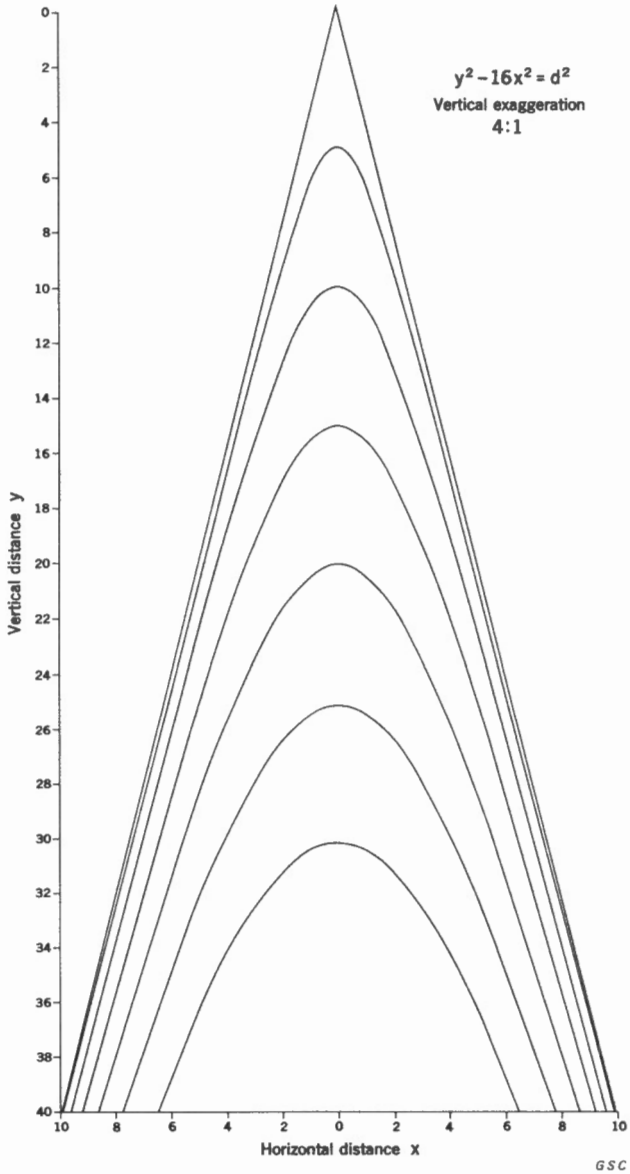


Figure 10. Curves of maximum convexity.

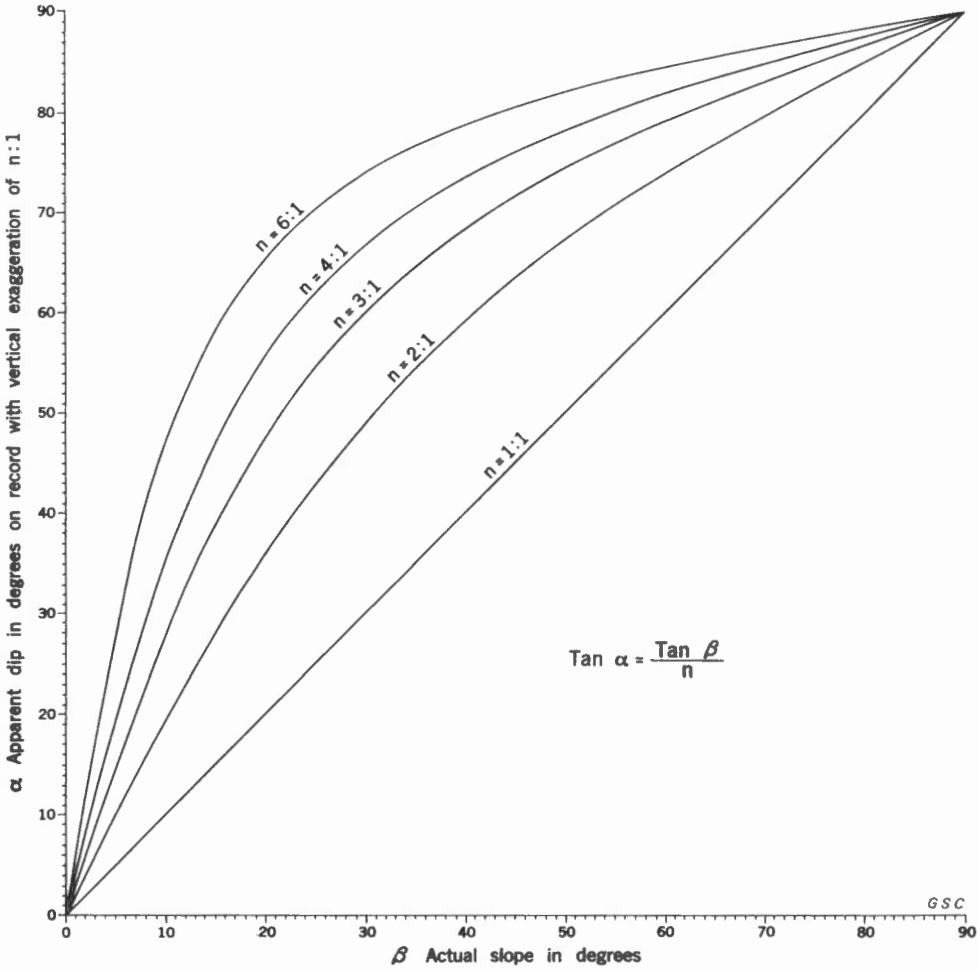
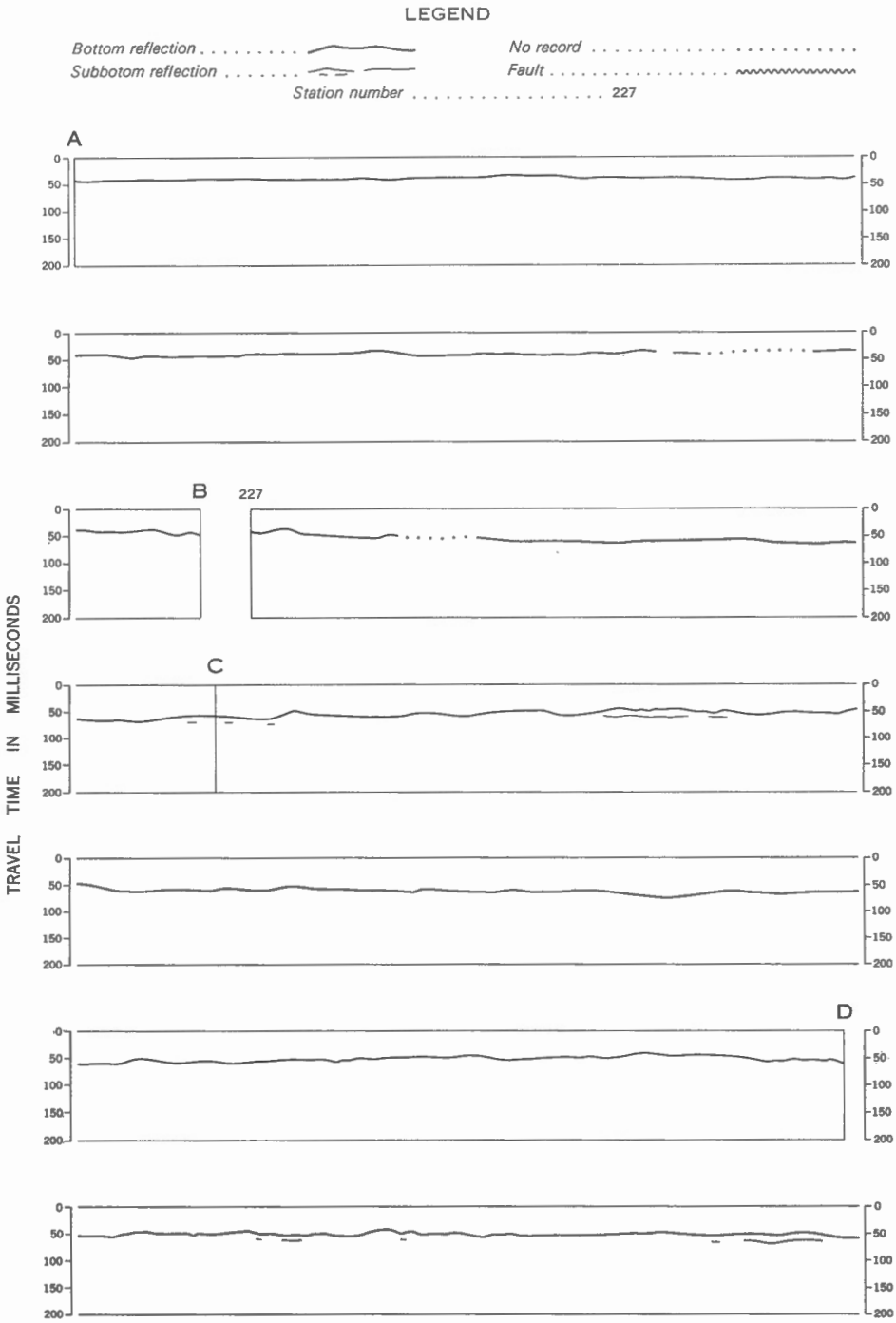
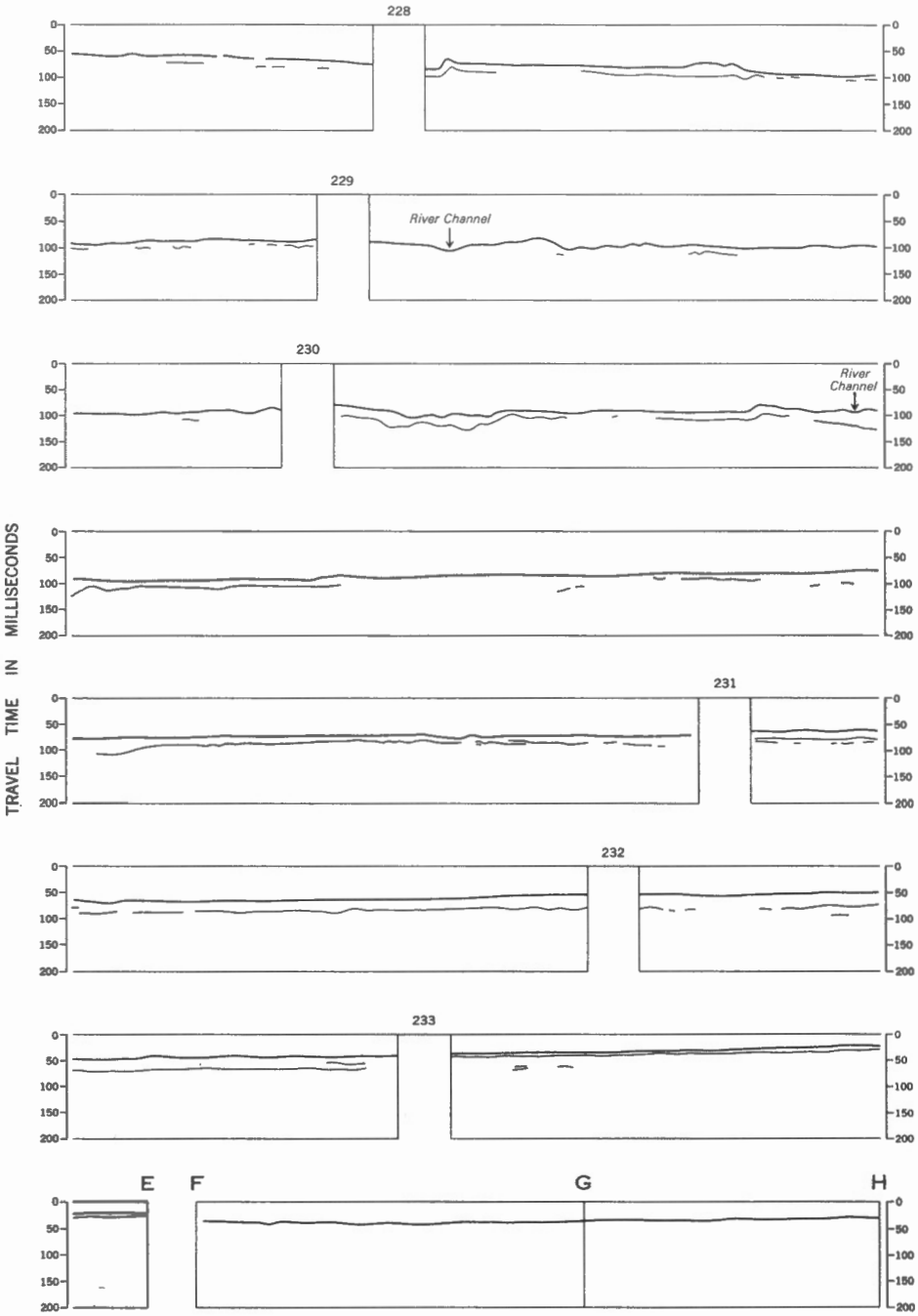


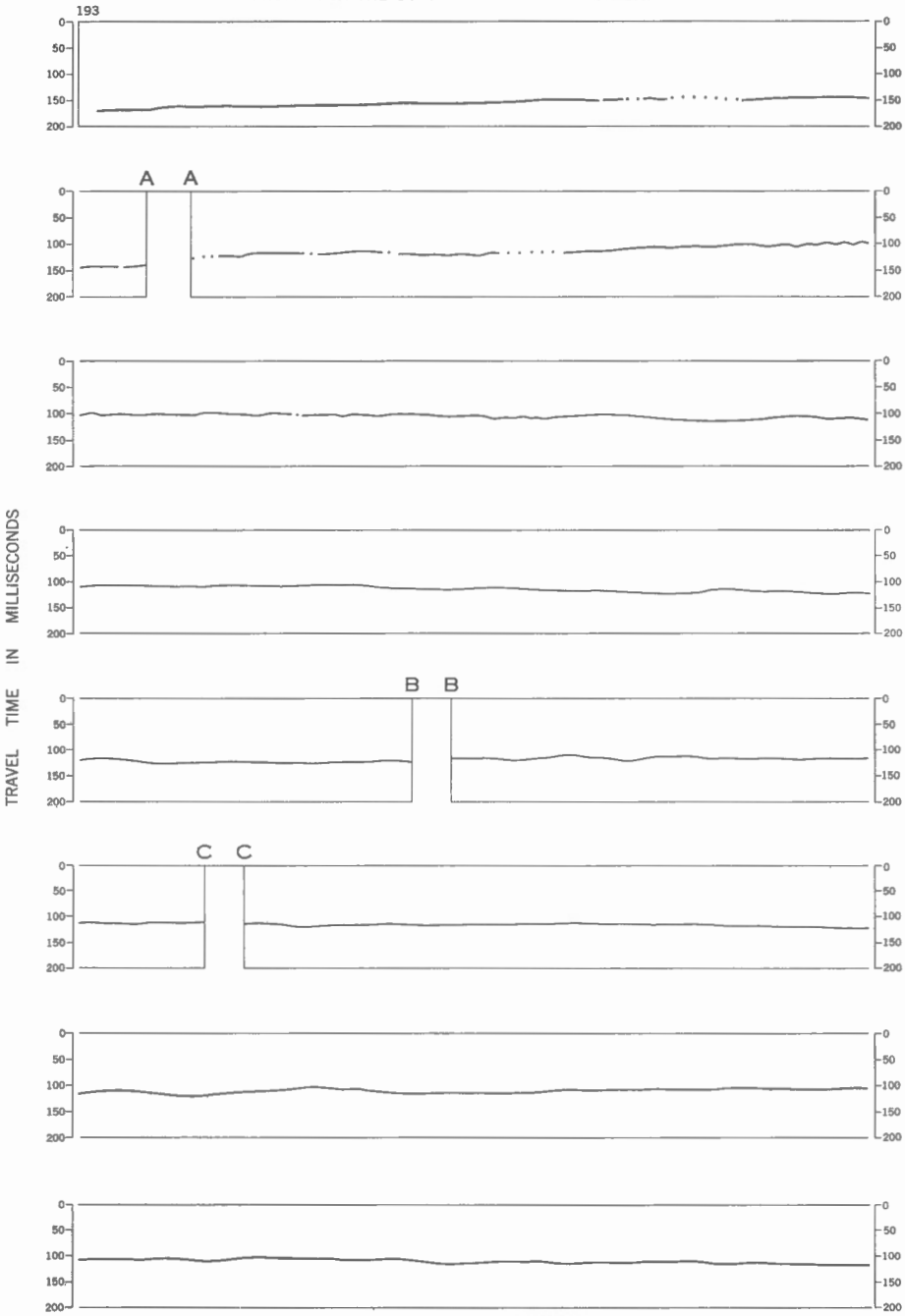
Figure 11. Effect of vertical exaggeration of records on slopes of reflecting interfaces.

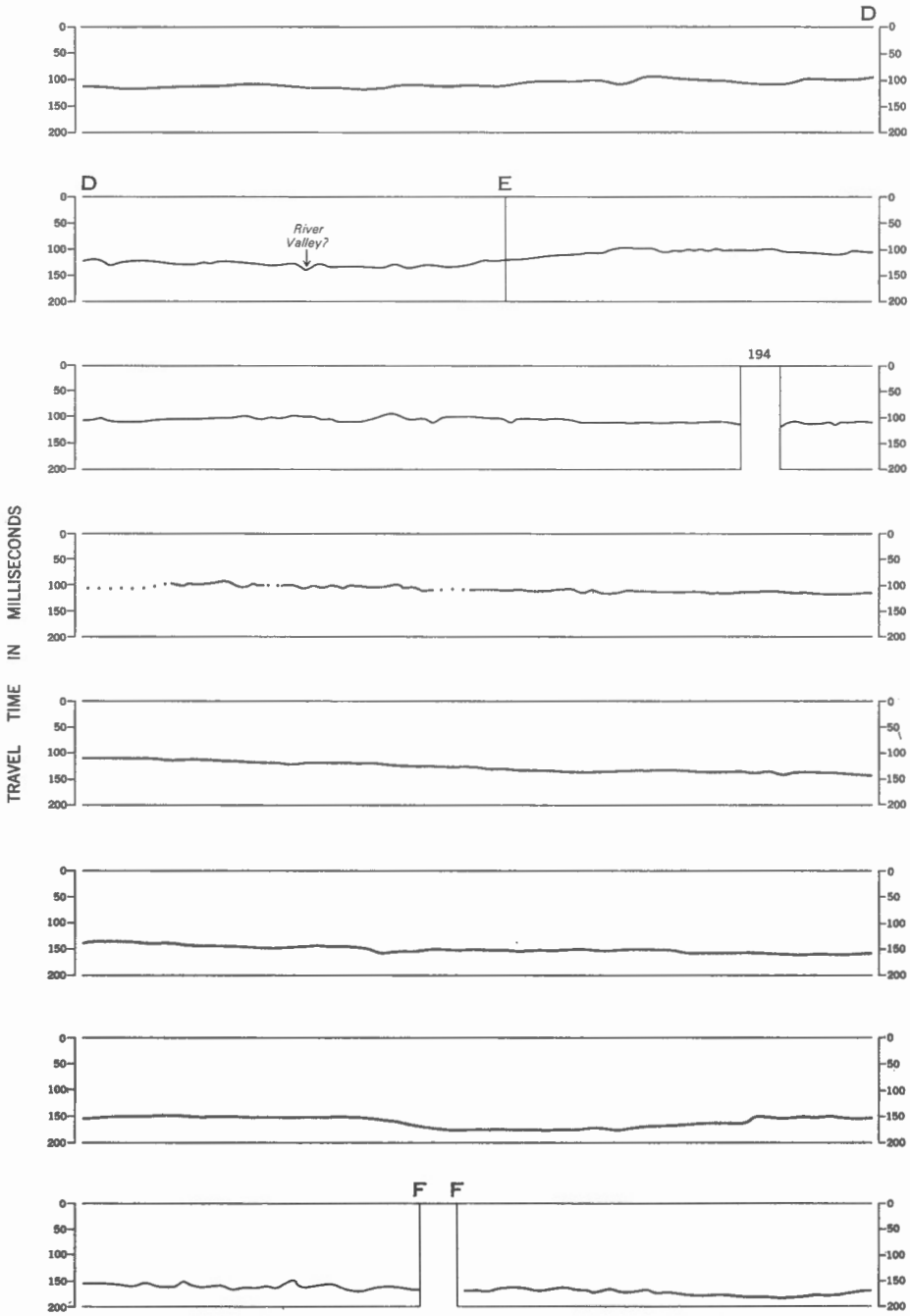


PROFILES NORTH OF CHURCHILL


228
229
River Channel
230
River Channel
231
232
233
E
F
G
H
TRAVEL TIME IN MILLISECONDS
0
50
100
150
200

PROFILES IN THE CENTRAL PART OF HUDSON BAY

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D
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River Valley?
194
F F
TRAVEL TIME IN MILLISECONDS
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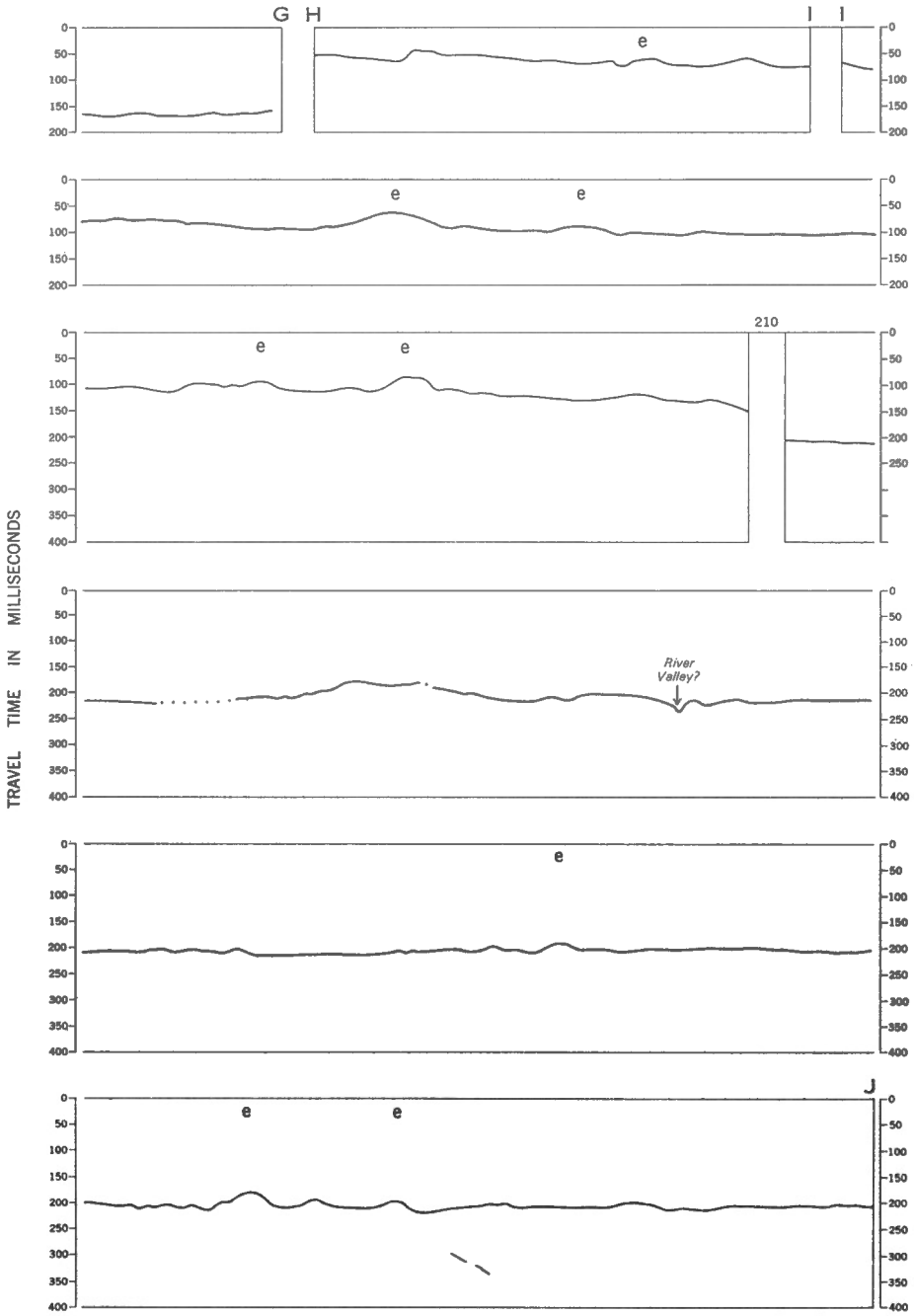
G
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I
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e
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e
e
e
210
River Valley?
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J
TRAVEL TIME IN MILLISECONDS
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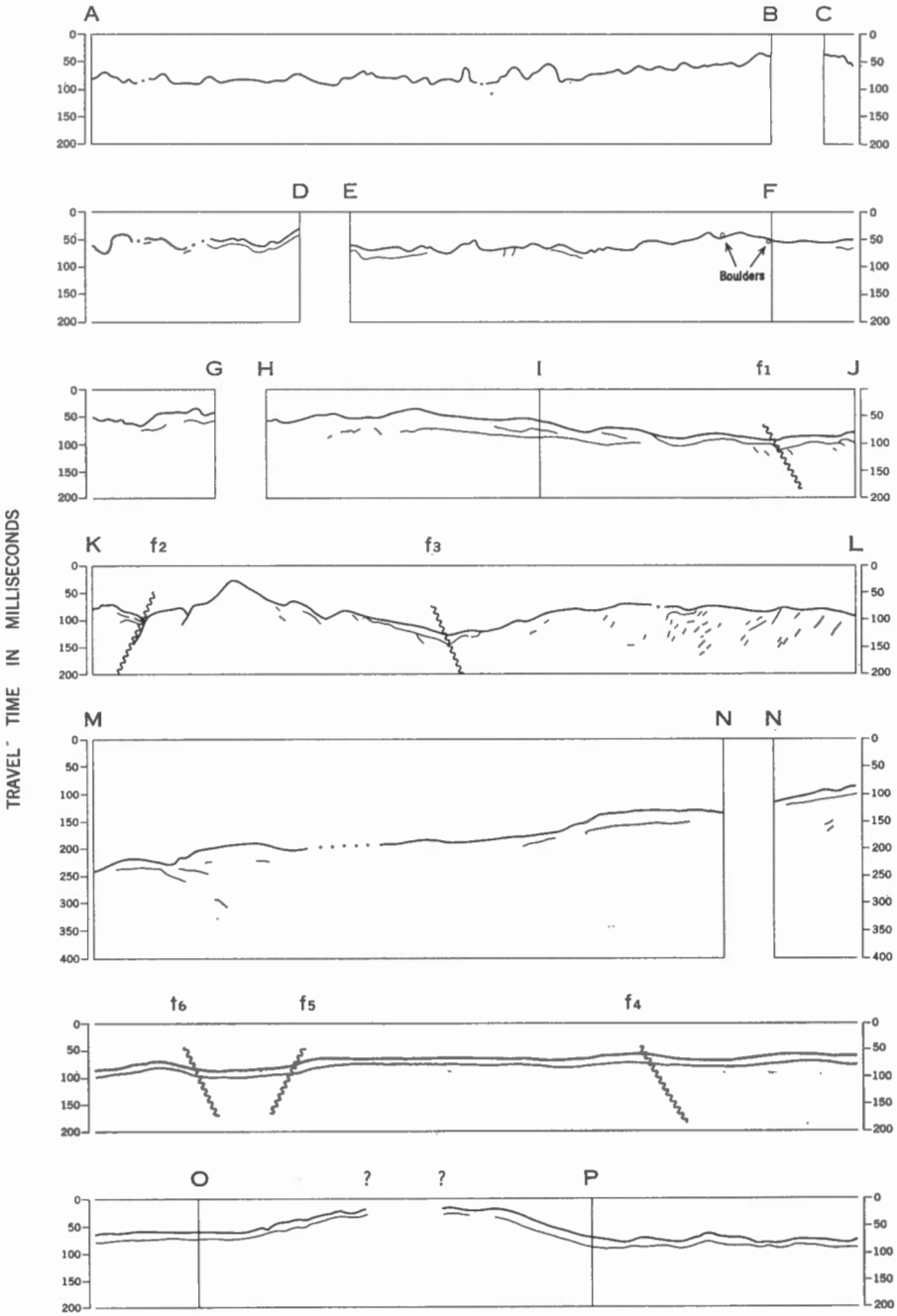
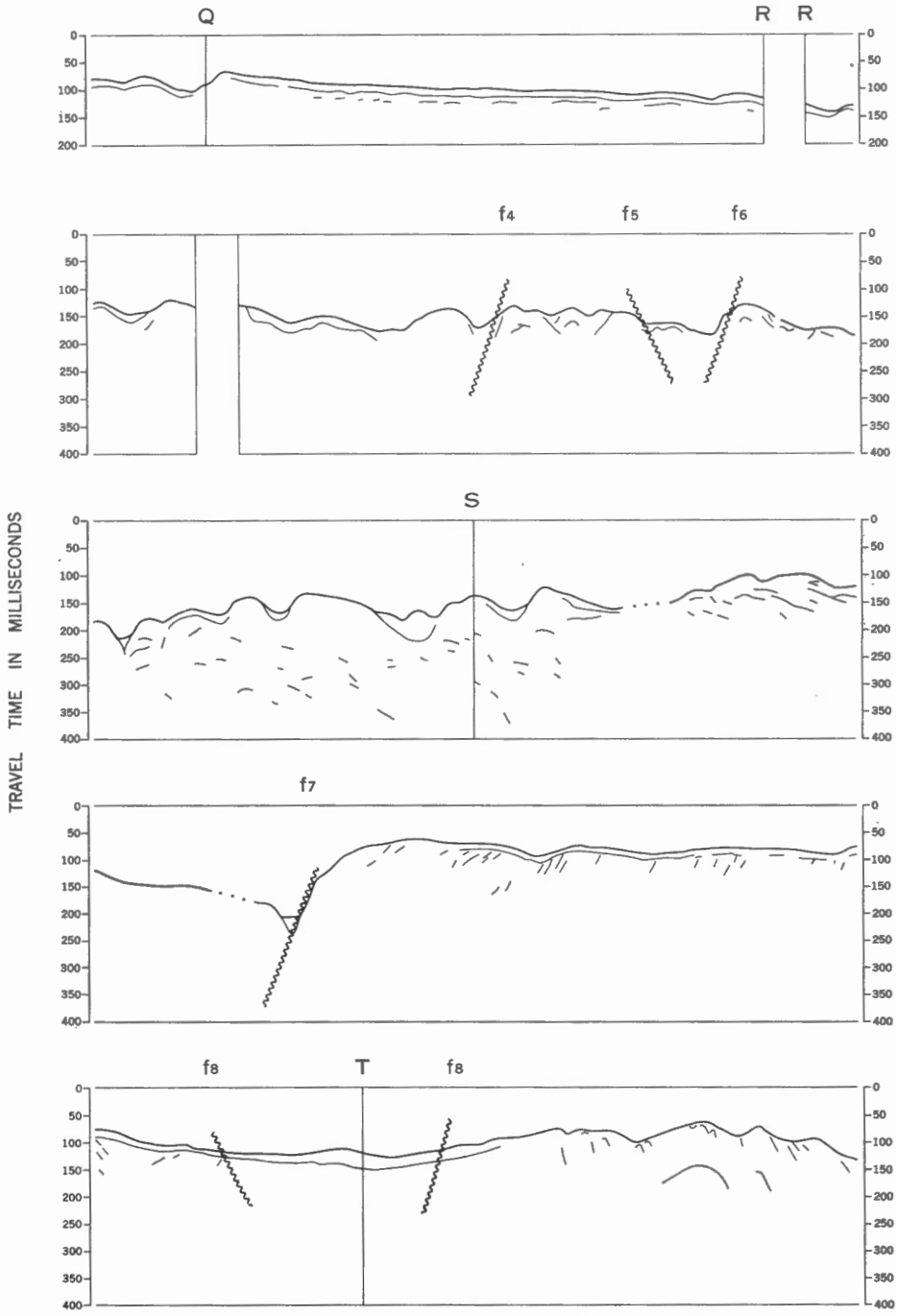
100
150
200
250
300
350
400

PROFILES IN THE BELCHER ISLANDS

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R
f4
f5
f6
S
f7
f8
T
f8
TRAVEL TIME IN MILLISECONDS
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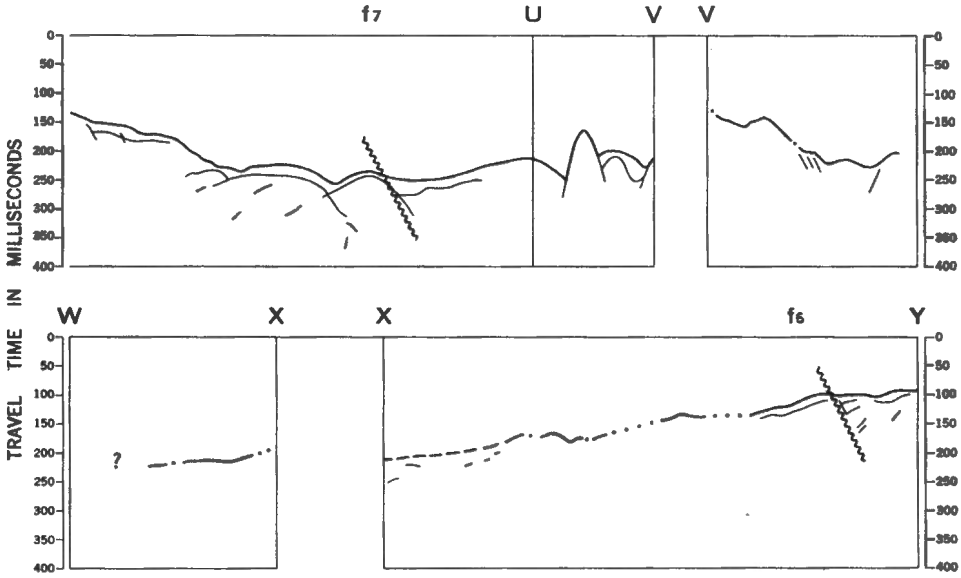
250
300
350
400


f7
U
V
V
W
X
X
f6
Y
TRAVEL TIME IN MILLISECONDS
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200
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400
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