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Geophysical Survey of Victoria Harbour and Approaches

M/V Revisor - PGC94002

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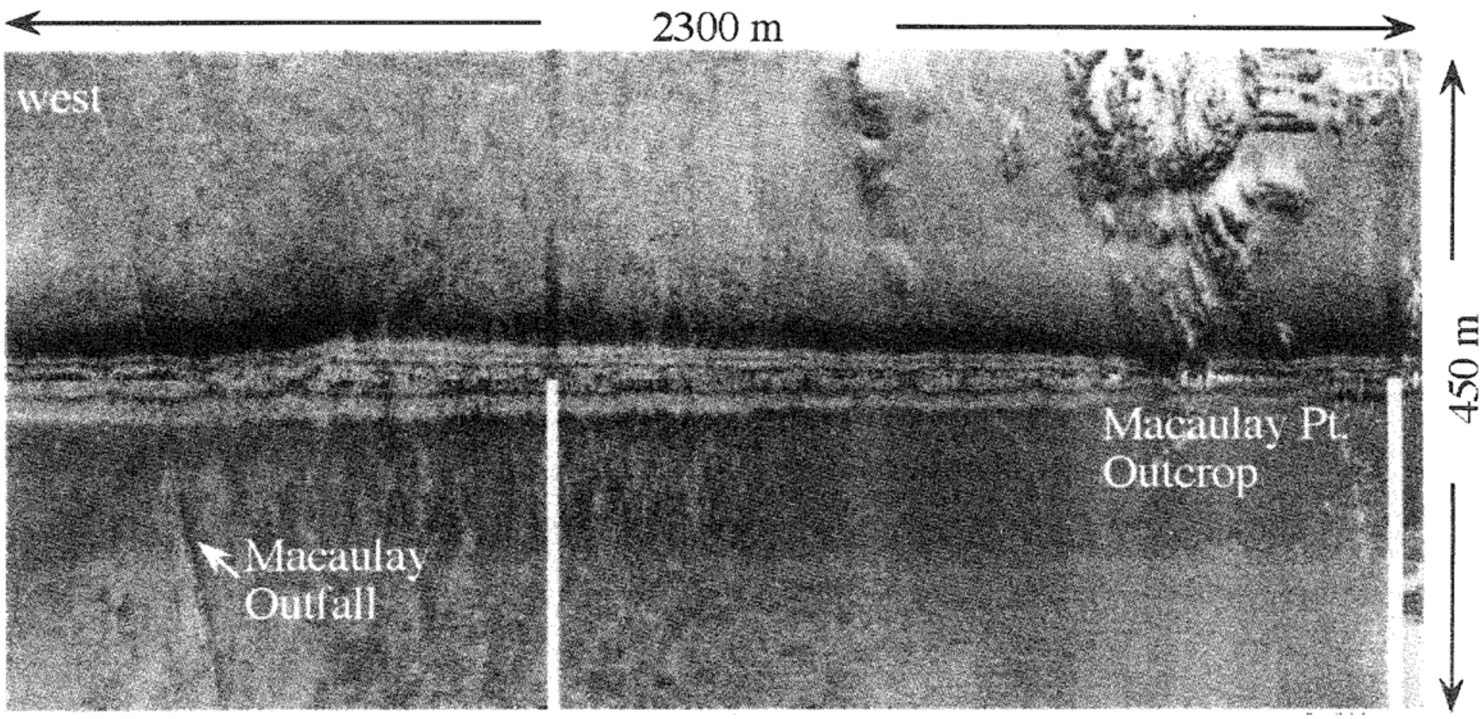

PGC 94002

M/V Revisor

Geophysical Survey of

Victoria Harbour and Approaches

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submitted to:

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Victoria Harbour and Approaches - Geophysical Survey
Executive Summary

The objective of the high-resolution geophysical survey of Victoria Harbour and approaches was to map the seafloor and subsurface geology of these areas. The approaches include an area of the nearshore to about 80 m water depth, bounded by Trial Island to the east and Esquimalt Lagoon to the west. This investigation was part of a broader study to map and understand the geological setting and processes affecting the Saanich Peninsula and Greater Victoria regions and coastal zones of British Columbia in general. The study region encompasses Macaulay Pt. and Clover Pt. sewage outfalls. One of the objectives in geologic mapping was to examine any effects on sedimentation patterns as a result of the outfalls, or as a result of other anthropogenic activities within the harbour or approaches, thus providing baseline information for more detailed environmental studies. These objectives were met by geophysical surveying of the region with sidescan sonar and subbottom profiling techniques.

Survey lines with 150-200 m spacing were run approximately parallel to the coast in an attempt to acquire >100% coverage of the seafloor with sidescan sonar data and to provide good control for seismic reflection and bathymetric interpretations; several cross-lines normal to the coast were also surveyed. In addition, several lines were run within the harbour up to Gorge Bridge (a total distance of about 5.6 km from the mouth of the harbour). 44 lines totalling 246 km of geophysical data, including 120 and 330 kHz sidescan data and Seistec subbottom profiling seismic reflection data were collected. Navigation was by differential GPS, recorded at 10 second intervals.

In general, sidescan sonar data suggest the sediment type of the Victoria Harbour approaches is primarily sand to sandy gravel and gravelly sand that it is relatively evenly distributed throughout the study area. Good penetration with the Seistec subbottom profiler suggests that if gravel forms the seafloor sediment it is likely thin (< 0.2 m). To the west, nearer the Esquimalt Lagoon, the sediment likely becomes finer-grained, interpreted from the lower backscatter intensities. There are no discernible sediment deposits nor change in echocharacter of the seafloor in the vicinity of either of the outfall pipes, implying little discharge is being deposited in the immediate area. In fact, there are no obvious recent sediment depo-centres in the entire survey area, implying: (1) little sediment supply; (2) sediment is evenly deposited throughout the area; or, (3) sediment is being transported out of the area in suspension.

Only adjacent to the inshore portion of the Macaulay outfall pipe, on the east side, are there local changes in sidescan backscatter intensities that may be related to bedforms which are either not well developed or possibly degraded. If these are bedforms, they might be related to disruption in long-shore currents passing over the outfall pipe from the west to the east, from the direction of Esquimalt Lagoon. These features may also simply be caused by local changes in sediment type (patchiness). In either case, their juxtaposition to the outfall pipe implies a relationship to the presence of the pipe. Other changes in acoustic character immediately surrounding both outfall pipes are clearly related to installation of the pipes or the fill used to hold them in place.

There are three identifiable units of the Seistec sub-bottom records related to the character of the reflection patterns. These units can be readily related to the late-Pleistocene to Holocene sedimentation history of the Saanich Peninsula-Greater Victoria region. Above bedrock is glacial till related to the last episode of Pleistocene glaciation (Fraser Glaciation). Conformably overlying this till is a sequence of glaciomarine sediments - probably related to ice-proximal sedimentation as the glaciers receded from the area. The acoustic character suggests these are composed of interbedded silts and sands. This unit likely represents the Capilano Glaciomarine Silt identified from onshore sections. Unconformably overlying this glaciomarine unit is a sequence of sediments that appear to be sands, thought to be early (?) Holocene in age. This unit is likely equivalent to Colwood Delta sediments.

PGC 94002 M/V Revisor Cruise Report

Introduction

Participants:

Scientific Staff:

Dr. David Mosher, PGC, Co Chief Scientist
Dr. Brian Bornhold, PGC, Co-Chief Scientist
Mr. Ivan Frydecky, PGC, Navigation
Mr. Bill Hill, PGC, Technical Support
Dr. Peter Simpkin, INRS, Contractor - Seistec Operations

Ships Personnel:

Mr. Bob Taylor, IOS, Captain of M/V Revisor

Equipment:

1) Simrad sidescan MS992 - 120 and 330 kHz operating frequencies.

2) Seistec high resolution seismic reflection profiling system with a 9 m Benthos external hydrophone array.

3) Knudsen 320M dual frequency (50 and 200 kHz) sounder.

4) MUSE acoustic digital acquisition system for testing of digital acquisition of Seistec and sidescan data.

6) HP3960 4-track analogue recorder.

7) Magnavox MX 4200D GPS receiver with CSI MBX1 differential receiver

Objectives:

Cruise objectives included seafloor and subsurface geological mapping of Victoria Harbour and approaches; the approaches include an area of the nearshore to about 80 m water depth, bounded by Trial Island to the east and Esquimalt Lagoon to the west. This cruise is part of a broader study to map and understand the geological setting and processes affecting the Saanich Peninsula-Greater Victoria region and coastal zones of British Columbia in general. The study region encompasses Macaulay Pt. and Clover Pt. sewage outfalls. One of the objectives in geological mapping was to examine any effects on sedimentation patterns as a result of the outfalls, or as a result of other anthropogenic activities within the harbour or approaches, providing baseline information for more detailed environmental studies. These objectives were to be met by geophysical surveying of the region with sidescan sonar and subbottom profiling techniques. Further to these objectives was a need to test new equipment, such as the Knudsen sounder and the MUSE data logger.

Operations:

Sidescan sonar:

The Simrad Model MS992 was used to collect sidescan sonar records. The sidescan fish was towed from a small boom on the port side of the after deck of the Revisor. A small winch with a wire cable carried the load of the sidescan fish. The sidescan cable was payed-out manually. A metering block was used in the calculation of lay-back. The sidescan sonar was operated primarily in 120 kHz mode, although at times the 330 kHz channels were recorded. Hardcopy records were to have been from the Alden printer, but the printer failed at times, especially early in the cruise, so a second, EPC printer was used as well. All data were recorded in analogue format and data have been played back successfully post-cruise. There are, however, some gain offsets between the two channels on tape. Sidescan sonar data were recorded on Channels 1 and 2 (FM) of the analogue recorder. The sidescan sonar was typically set up with a range of 300 ms, or about 225 m per side, or about 450 m total swath width.

Subbottom Profiling:

The IKB-Seistec sub-bottom profiler was used to collect high resolution seismic reflection data. Details of the Seistec operational setup can be seen in the accompanying INRS report. The Seistec sled was towed off the starboard boom on the after deck. Enough scope was allowed to tow the sled level with, or slightly behind the stern of the vessel (about 10 m of wire out). A Honda 3 kW generator was used for the Geopulse power supply which was required to energize the boomer. The Seistec was run at 280 Joules output, typically firing at a rate of about 0.4 seconds. In the inner harbour, the Seistec was run at 105 Joules with a firing rate of 3/16 sec. Synchronized firing of the Seistec profiler and the sidescan sonar fish avoided interference between the two systems. The sidescan sonar provided the master trigger, the firing rate of which is a function of the swath width of the sidescan sonar system. Hardcopy records were generated on an EPC 9800. In general, the quality of the seismic data was very good, however during periods where the weather conditions were marginal, aeration of the water under the boomer (and possibly the receiver) caused "white-outs" for several seconds. Vertical motion due to wave action on the boomer catamaran exceeded 0.5 m during marginal weather conditions. This motion manifests itself on the seismic profile as displacement of the trace, resulting in deterioration of the overall quality of the image.

Bathymetry:

The Knudsen sounder was mounted on the port rail of the quarter deck. The transducer was 1 m below sea surface. The sounder has two modes of operation: High Frequency (200 kHz) which is suitable in shallow water, and Low Frequency (50 kHz), used in deeper water. Chart records were recorded at all times during surveying. Bathymetric data are displayed on paper charts only. There is a serial output for digital storage of sounding data but due to a software bug in the sounder, it was not possible to set the baud rate to the appropriate speed to log the data on the available PCs.

Navigation:

Navigation was acquired by differential GPS. Navigation was logged on a PC at 10 s intervals. All other shipboard clocks were synchronized with this navigation PC, as this is the time that is logged with the navigation. Data are kept with Ivan Frydecky at PGC. The following table shows the start and end times of lines for referencing the navigation and data.

Line No.	Start Time	End Time	Line No.	Start Time	End Time
0	60/15:44	60/16:33	21	60/09:58	60/10:16
1	52/11:15	52/13:15	22	60/10:17	60/10:37
2	55/09:06	55/10:29	23	60/10:40	60/10:59
3	55/12:10	55/13:21	24	60/11:01	60/11:26
4	55/15:20	55/16:52	26	60/13:03	60/13:41
5	56/09:15	56/10:35	27	60/13:45	60/14:28
6	56/12:42	56/13:58	28	60/14:29	60/15:13
7	56/11:23	56/12:40	29	61/08:21	61/08:53
7a	56/14:11	56/15:10	30	61/08:58	61/09:43
8	55/17:10	55/17:50	31	61/09:45	61/10:22
8	56/08:35	56/09:10	Xline1	54/12:00	54/12:40
9	52/13:26	52/15:11	Xline2	54/13:12	54/13:25
10	55/10:29	55/12:03	Xline3	54/13:39	54/13:46
11	55/13:35	55/15:13	Xline4	59/15:10	59/15:30
12	56/15:30	56/16:49	Xline5	59/15:33	59/15:50
13	59/08:40	59/10:20	Xline6	59/16:07	59/16:35
14	59/11:38	59/12:57	Xline7	60/11:37	60/11:59
15	59/10:28	59/11:34	Xline8	60/12:08	60/12:34
16	59/13:10	59/14:51	Xline9	60/15:22	60/15:42
17	60/08:35	60/08:55	Xline10	60/16:35	60/16:45
18	60/08:58	60/09:15			
19	60/09:17	60/09:35	Victoria	53/09:53	53/11:45
20	60/09:38	60/09:56	Harbour	54/08:45	54/10:30

Table 1: Start and end times (in GMT) of survey lines.

MUSE data logger:

A Macintosh-based, high resolution seismic and sidescan sonar digital data logger, developed by MUSE Research INC., was field tested for the first time on this expedition. Unfortunately, due to high electrical noise levels on the vessel (a result of running the seismic and sidescan equipment leading to electromagnetic interference (EMI)), the data logging system failed these field trials. A good summary of the problems with recommendations is presented in the INRS report. Essentially the system was not designed to operate in environments with high electrical noise levels. The problem manifests itself in that EMI seems to set off the sample clock intermittently, thus putting data sampling out of synchronization with firing times and incoming signal periods. No useful data were logged to tape using this system during this expedition.

Analogue Tape Recording:

Sidescan sonar and Seistec data were recorded for the duration of the cruise on an HP3960 4-track am/fm reel-to-reel recorder. Channel configuration is as follows:

Channel 1 - DIR - trigger (for sidescan and seistec)
Channel 2 - DIR - processed seistec (1k-10k bandpass with linear TVG)

Channel 3 - FM - sidescan 120 kHz port
Channel 4 - FM - sidescan 120 kHz starboard

Tape	Start	End	Ch.1	Ch.2	Ch.3	Ch.4
1	52/11:27	52/13:25	sync		120 Port	120 Stbd
2	52/13:27	52/15:25	"		"	"
3	53/09:53	53/11:45	"		"	"
4						
5	54/11:28	54/13:29	sync	seistec	120 Port	120 Stbd
6	54/13:30	55/10:54	"	"	"	"
7	55/10:55	55/12:59	"	"	"	"
8	55/13:00	55/15:04	"	"	"	"
9	55/15:05	55/17:09	"	"	"	"
10	55/17:10	56/09:40	"	"	"	"
11	56/09:41	56/12:19	"	"	"	"
12	56/12:20	56/14:26	"	"	"	"
13	56/14:27	56/16:32	"	"	"	"
14	56/16:33	59/10:24	"	"	"	"
15	59/10:27	59/13:10	"	"	"	"
16	59/13:42	59/16:35	"	"	"	"
17	60/08:25	60/11:46	"	"	"	"
18	60/11:47	60/15:01	"	"	"	"
19	60/15:02	61/09:45	"	"	"	"
20	61/09:46	61/12:41	"	"	"	"

Table 2: Start and end times (in GMT) of analogue 4-track data tapes.

Playback of data has shown that there are some differences in gains between Channels 3 and 4 of the data on tape. It appears it is a DC offset in Channel 4, but closer investigation of raw data on a trace by trace basis shows that there is possibly some loss in dynamic range of the fourth channel.

Operational Logs

Julian Day 49: Test equipment in Saanich Inlet. Digital Data Logger SE880 not functioning, all other equipment working fine.

J.D. 52: Start of survey off Victoria Harbour. Seistec interfering with sidescan sonar records. Ran Lines 1 and 9.

J.D. 53: Run Sidescan sonar only on one line and sidescan and Seistec on return line. Severe wave conditions cause to abort approaches survey. Moved to inner harbour and ran sidescan sonar line within harbour and Gorge

J.D. 54: Laura Taylor (CRD) and Pat Williams (USGS) on board.
am. Seastate too severe for surveying approaches - Ran Seistec within inner harbour and Gorge. Synchronized triggers for sidescan and Seistec - firing from sidescan - eliminates interference so we can now run the two systems synchronously. Sidescan firing at about every 400 ms.
pm. Moved out to approaches and decided to survey north-south cross-lines because of the direction of wave motion. Ran cross-lines 1, 2, and 3 before aborting due to seastate.

J.D. 55: Good weather, Run Lines 2, 10, 3, 11, 4 and part of 8. All systems finally working and operation becoming routine. Tend to lose differential navigation at east end of lines near Trial Island - must be some interference.

J.D. 56: Start at waypoint on Line 8 and head west. 10:30 weather worsening and abort line. Heading in seastate looks better at the western area of the survey. Run Line 7, 6, and 12. Weather improves through the day. Saw some features that look like sandwaves on seismics that we couldn't distinguish on sidescan on Line 7 - rerun at reduced speed, but not evident on sidescan still. Finish up at 16:49.

J.D. 59: 08:00 underway, weather looks good. Peter Simpkin no longer on board. Run Lines 13, 14, 15, 16 and cross lines 4, 5, and 6. Possible boat wreck on Line 16 in 156 m water depth.

J.D. 60: 08:00 underway, weather looks good. Run Lines 17 - 24 west of Trial Island in Ross Bay and Gonzales Bay. Ran Cross Lines 7 and 8. Ran Lines 26-28 at western end of survey area off Esquimalt Lagoon. Shallow gas observable in seismics at this end of the survey. Ran Cross-lines 9 and 10. 16:50 head into harbour.

J.D. 61: Run Lines 29-31 off shore near Esquimalt Lagoon. Significant wave heights (~3 m). 10:22 end survey in this area. Run a line east of Trial Island but seastate very confused with abundant water column noise disrupting acoustic records. End survey at end of Baynes Channel and head back to IOS.

Results

Survey lines with 150-200 m spacing were run approximately parallel to the coast (Fig. 1) in an attempt to acquire >100% coverage of the seafloor with sidescan sonar data and to provide good control on the seismic reflection and bathymetric interpretations. No sediment samples were collected for groundtruth but a number of samples collected in the region and analyzed in 1971 (Goddard et al., 1971) provide some control. This report predates the installation of the outfall pipes however. More recently, the CRD have maintained a monitoring program around the outfall pipes, in which surficial samples are collected and measured for gravel, sand, silt and clay percentages and data from 1991 and 1992 have been made available for this report..

Bathymetry:

A bathymetric chart has been produced based on the data collected during this expedition (Fig. 2). Water depths within the survey area range from 5 m to a maximum of 100 m below lowest normal tide. The data show no significant anomalous bathymetric features from what was already known or was expected. In general, bathymetric contours follow the outline of the coast, increasing in depth in an offshore direction (south). The only significant offshore shoal is Brotchie Ledge. An offshore deep lies just due south of this shoal in about 70 m water depth. The outfall pipes can be clearly seen on the sounding profiles (Figs. 3 and 4), but do not appear to have affected the seafloor bathymetry in any general sense (i.e., there is no substantial shoaling or scouring around the outfall pipes).

Sidescan Sonar:

Sidescan sonar provides acoustic images of the seafloor that, because of its overhead plan perspective, is similar to an aerial photograph in appearance. Sidescan sonar operates from a fish towed behind the vessel. The fish sends an acoustic signal out to each side, thus generating a swath to port and a swath to starboard. In our case, the range is about 225 m to each side of the fish. The return signal from this swath is recorded and provides the sidescan imagery. The intensity of the return from the seafloor, or backscatter intensity, is a function of its reflectivity, which in turn is largely a function of the seafloor sediment type. Acoustic shadowing, analogous to shadows cast by lighted objects, is caused by seafloor relief or objects resting on the seafloor. Using return intensities and shadowing, an experienced user is able to interpret seafloor information from the sonar image. Such information includes sediment types, bedforms, benthic biological colonies, and anthropogenic features (e.g. trawl marks, anchor drags, discarded automobiles, shipwrecks, etc.).

A limitation of this technology, or at least in the configuration it was used for this investigation, is accurate positioning of the sidescan tow body. The "fish" is towed behind the vessel on a cable of sufficient length to keep the fish near the seafloor. Cable is payed-out or hauled-in depending on the water depth being surveyed in order to keep the fish close to the seafloor. There are a number of sources of error for positioning the towed body. There is a lag time between when the survey vessel is at a particular point and when the fish reaches that point, depending on the length of the cable and the angle from horizontal it is being towed. This "layback" can be calculated knowing the length of the cable and the depth of the fish. The greatest source of error for fish positioning is lateral tow angle of the fish, i.e. if the sidescan body is following the vessel to the port or starboard, rather than directly behind the ship. Ocean currents can cause this phenomenon. The tow body itself pitches, yaws, and rolls, also causing inaccuracies in calculating positions of targets that it has insonified. A head sensor package in the sidescan body monitors and records fish attitudes as well as fish water depth, so most of these errors can be corrected. The primary source of error, however, remains lateral tow angle. Estimates based on a number of passes over identifiable targets (such as the ends of the outfalls), indicate there are tow angle errors for this survey, and therefore the best positioning estimates that can be provided are about ±30 m.

The 150-200 m line spacing used in this survey ensured abundant overlap between adjacent lines, given the total swath setting of about 450 m (both channels). All areas within the survey region, therefore, have been insonified. In most areas, backscatter reflection intensity on the sidescan sonar records is relatively high and quite uniform throughout. Intensities decreased towards the western end of the survey area, west of the Macaulay outfall pipe and proceeding towards the mouth of Esquimalt Lagoon. In the transition region, from higher to lower backscatter intensities, the area is marked by local changes in intensity, resulting in a mottled appearance to the seafloor (Fig. 5). Very few features of any size (> 2 m), casting significant shadows, were observed in the study area. Rare, scattered objects, usually about boulder-size, are noted, and these objects tended to be more frequent around the outfalls (e.g. Figs. 6 & 7). There also seem to be patches of increased seafloor roughness around the outfalls (Figs. 8 & 9). These changes are very subtle, however. Outcrop at the headlands (e.g. Clover Pt., Finlayson Pt., Macaulay Pt., Ogden Pt.), Brotchie Ledge, Trial Island, and close to shore were readily apparent, but none was observed elsewhere on the seafloor.

High-resolution Sub-bottom profiler (Seistec):

Similar to sidescan sonar, a sub-bottom profiler sends out an acoustic signal, but rather than side-looking it looks in the vertical sense and records return signals (reflections) from the seafloor and layers underlying the seabed. A high frequency (1-10 kHz) boomer system with a narrow beam width and focussed receivers was used for this study to achieve very high resolution in both the vertical and horizontal planes. The outfall pipes can be readily observed on seismic profiles, attesting to the systems horizontal resolution (Figs. 10 - 13). The pulse shape of the outgoing acoustic signal indicates vertical resolution is on the order of 5-10 cm. Sub-bottom penetration of up to 50 m within the sediments of the Victoria Harbour Approaches was achieved with this system, providing high quality images. An experienced user can interpret the surface and subsurface geology of the region based on the character of these records.

In general, the Seistec system was able to penetrate overlying sediment through to basement rocks, except in the most offshore lines where sediment thickness is greater than about 50 m. As a result, it provided good quality stratigraphic images of the sediments comprising the seafloor and subseafloor of Victoria Harbour and Approaches. Sediment thicknesses ranged from 0, where basement rocks outcrop at the seafloor, to > 50 m. Sediment thicknesses tend to follow the basement morphology, infilling low areas and thinning on basement highs. The basement tends to undulate quite drastically in its surface topography; high areas can be observed as headlands on shore. The fact that this acoustic system does penetrate the seafloor to such depths qualitatively implies that the seafloor sediments are not too dense, which otherwise would result in a high amplitude seafloor return and little subbottom information. Shallow gas within the sediments, most probably methane, generated from in situ organic material, attenuates acoustic energy and prevents acquisition of subbottom stratigraphic data; gas was most prevalent in the westernmost region of the survey area, near the mouth of Esquimalt Lagoon.

Four distinguishable seismic units or facies can be recognized from the sub-bottom profiles:

1) the lowermost unit forms acoustic basement, below which no acoustic energy is returned. It is the bedrock that underlies the region;

2) the unit above bedrock appears massive, with little internal character (amorphous) and occasional semi-coherent reflections. The original surface of this unit appears hummocky. This unit accounts for much of the sediment thickness overlying basement rocks;

3) the next stratigraphically higher unit, which is not always present, is a section with numerous, high amplitude, coherent, parallel reflections at its base. The number of internal reflections decreases upward and are truncated at the top, resulting in an unconformable relationship with the overlying unit. This unit is thickest in the western end of the survey area, and absent in the east;

4) the uppermost unit appears to form the seafloor everywhere, except where basement outcrops. It contains low amplitude internal reflections which are sometimes parallel and sometimes sigmoidal or clinoform in shape, forming offlap and onlap sequences. It tends to infill low areas on the underlying topography. Its lower bounding surface appears to be a major regional unconformity.

Interpretations:

In general, the consistent, relatively high backscatter intensities of the sidescan sonar data suggest the surficial sediment of the Victoria Harbour and Approaches is primarily sand to sandy gravel that is relatively evenly distributed throughout the study area (i.e. it is not patchy). Grain size results of surficial sediment supplied by the CRD are consistent with this interpretation, showing consistent sand percentages in excess of 50% and more typically >60% for all samples analysed. Good penetration with the Seistec subbottom profiler suggests the surface sediment is not too reflective (i.e. acoustic signal is transmitted through the surficial sediment); thus it is unlikely that gravel forms the seafloor sediment type, or if it does, it cannot be very thick (i.e., less than a few cm). To the west, nearer Esquimalt Lagoon, the sediment appears to become finer-grained (fine sands), interpreted from the lower backscatter intensities. There are no distinguishable sedimentary bedforms in the region, implying no regional bedload transport of sediment. Only adjacent to the Macaulay outfall pipe, on the inshore portion and only to the east of the pipe, are there local changes in backscatter intensities (the mottled appearance mentioned above), that may be related to bedforms, apparently not well developed or possibly degraded (Fig. 5). If these are bedforms, they might be related to disruption in longshore currents passing over the outfall pipe from west to east. These features may also simply be caused by local changes in sediment type (patchiness). In either case, their juxtaposition to the outfall pipe implies a relationship to the presence of the pipe. Other changes in acoustic character immediately surrounding both outfall pipes are clearly related to installation of the pipes or the fill used to hold them in place.

There are no obvious recent sediment depocentres, implying: (1) that there is little sediment supply; (2) sediment is evenly deposited throughout the area; or, (3) sediment is being carried out of the area in suspension and is not being deposited in the region. There are rare scattered positive relief features on the seafloor identified from the sidescan sonar that may represent either boulders, or anthropogenic debris. They are more prevalent around the outfalls, and in these cases may be related to fill material used to bury the outfall pipes, or the engineering activity related to the installation of the pipes.

Bedrock in the region is composed of Paleozoic migmatites of the Saltspring Intrusion and meta-volcano-sedimentary rocks of the Sicker Group in the west (Clover Pt. to Esquimalt). To the east, in Gonzales and McNeill Bays, bedrock is argillite and chert of the Leech River Complex.
The three uppermost units of the Seistec sub-bottom records can be readily related to the late Pleistocene to Holocene sedimentation history of the Saanich Peninsula-Greater Victoria region. Above bedrock is an amorphous unit with occasional semi-coherent reflections that probably represents glacial till related to the last episode of Pleistocene glaciation (Fraser Glaciation). Onshore, this unit is referred to as Vashon Glacial Diamicton. Conformably overlying this till is a section with strong internal reflections merging upwards into a more amorphous section. This character is suggestive of a glaciomarine unit - probably related to ice-proximal sedimentation as the glaciers receded from the area. The acoustic character suggests it is composed of interbedded clay, silt and sand. This unit likely represents the Capilano Glaciomarine Silt or Victoria Clay, identified from onshore sections. It is thickest in the western part of the survey area and completely missing in some areas, especially to the east. The top of this unit, where it is present, represents an erosional unconformity, thus unconformably overlying this glaciomarine unit is a sequence of sediment that appears to be sand, from its acoustic character. Where the glaciomarine section is missing this unit lies on top of the till or bedrock. It can show faint internal reflections which offlap and onlap lower reflections, suggesting sand transport and bedload deposition has occurred. It infills low areas and forms the seafloor everywhere except where bedrock outcrops. This unit probably represents reworking of the underlying glacial till, glaciomarine sediments and glacial outwash material. It is equivalent to Colwood delta sediments and is likely early Holocene in age.

Macaulay Outfall

As mentioned above, the outfall pipes are readily identifiable on all geophysical records: sidescan sonar, seismic, and bathymetry. These methods provide an accurate means of locating them and observing their surrounding environment. The end of the Macaulay outfall pipe has been located at latitude 48.402° and longitude -123.411°, from sidescan records (see discussion on sidescan positioning errors and Table 3). The pipe extends to a maximum water depth of 58 m.

Nearhore, the Macaulay outfall pipe lies just to the east of the bedrock high that forms Macaulay Point. Offshore, the bedrock is well buried under a 30 m-thick sediment sequence that thickens to the west towards Esquimalt Lagoon. Sediment thicknesses near the pipe range from 0 at the inshore portion to about 30 m offshore. Sediment thickness increases markedly to the east of the pipe, coming off the bedrock high. The outfall pipe lies on the sand unit described above; only about a metre below the seafloor the unconformity is encountered below which is a thick glaciomarine section overlying till.

Sidescan sonar records show two regional types of seafloor character within the study area, and the Macaulay outfall pipe, either by coincidence or cause, falls within the transition zone. To the west of the outfall pipe the seafloor returns relatively low backscatter intensities, with mottles or patches of higher intensity. This character suggests perhaps a muddy seafloor with patches of sand or gravel. Backscatter intensities increase towards the east but increase markedly just at and after the Macaulay outfall pipe. This change in seafloor character may be related to the source material forming the seafloor: in the western part of the region the glaciomarine unit is abundantly present and reworking of this fine material may form part of the present seafloor. To the west, this glaciomarine unit is not present and so the seafloor may be made up of reworked till, which provides more sand and gravel. Increased patchiness just to the east of the outfall pipe, and for the length of the pipe, may be related to bedform formation as a result of the disruption in currents crossing over the pipe. There is no discernible deposit nor change in echocharacter of sediment just off the outfall at the mouth of the pipe, implying little of the discharge is being deposited in the immediate area.

Clover Point Outfall

The end of the Clover Point outfall pipe has been located at latitude 48.394° and longitude –123.346°, from sidescan sonar records (see above discussion of sidescan positioning errors and Table 3). The pipe extends to a maximum water depth of 65 m. The Clover Point outfall lies approximately on top of the offshore extension of the bedrock high that forms Clover Point. Inshore it is just to the east of the shallowest point of bedrock, but it crosses over and lies just to the west of it offshore. Nearshore there is no discernible sediment thickness underlying the outfall pipe, but it thickens gradually offshore to a maximum of about 20 m at its most offshore point. Sediment thickness increases markedly immediately to the west of the pipe as the bedrock surface dips coming off the Clover Point high. Offshore, the outfall pipe seems to lie on the Holocene sand unit which appears to be only 1-2 m thick overlying the till unit. The glaciomarine unit is not obvious in this section, nor is it just to the west where the sediment section thickens in the adjacent basin.

Sidescan sonar records show a relatively high intensity backscatter return surrounding the outfall pipe. This character suggests a relatively uniform bottom type which, as has been indicated, is probably sand to sand and gravel. The character of the records from the outfall pipe shows more abundant fill material covering the Clover Point outfall pipe than the Macaulay pipe. There also appears to be more debris on the seafloor in the immediate area of the Clover Point pipe, particularly on the east side of the pipe and probably related to the rip-rap material. Once again there is no visible evidence of discharge accumulating at the end of the pipe.

		UTM Coordinates (m)		(Decimal Degrees)	
Outfall	Tow scenario	Eastings	Northing	Latitude	Longitude
Clover Pt.	Tow angle no Yaw	474380	5360195	48.39440	123.34610
Clover Pt.	Tow Angle and Yaw	474375	5360180	48.39426	123.34617
Macauley Pt.	Tow Angle no Yaw	469612	5361089	48.40223	123.41057
Macauley Pt.	Tow Angle and Yaw	469609	5361060	48.40197	123.41061

Table 3: Calculated positions of the ends of the outfall pipes from sidescan sonar records. Each position is based on at least two lines run past the outfalls. In one scenario it was assumed there was a tow angle, but the fish towed facing the same angle as the tow line (i.e. was directed toward the vessel) - this is called no yaw. In the second scenario, it was assumed there was tow angle but the fish towed parallel to the ships track (i.e. with yaw). Observations suggest this latter case is the more likely scenario for towing behaviour.

Victoria Harbour

Victoria Harbour is defined as the area from Ogden Point to Gorge Bridge. Shallow *in situ* gas obscures some of the seismic reflection data from this area but in sections where the gas is absent the stratigraphy is similar to that of the approaches with all 4 seismic units being present. The outer harbour (from Ogden Point to Johnson St. Bridge) shows a very irregular bedrock surface (Unit 1) overlain in places by till (Unit 2) which also has a very irregular surface. Glaciomarine sediments (Unit 3) are preserved in low areas of the till or bedrock, or form a very thin cover over high areas. Very little sediment of Unit 4 appears, except perhaps as a very thin (< .25 m-thick) veneer at the seafloor. The seafloor, therefore, may be composed of any of the above units: bedrock, till, glaciomarine sediments, or a very thin cover equivalent to Unit 1 (but not necessarily composed of sand). Acoustic basement (bedrock) is at most 11 m below the seafloor. The seafloor is quite rough, probably the result of dredging, anchorages, and other anthropogenic activity.

The inner harbour, from Johnson St. Bridge to the Gorge Bridge, is where *in situ* gas is most prevalent. It is difficult to determine the seismic stratigraphy as a result of this gas, however small windows of sediment without gas do appear. From these windows it appears there is a 5-20 m-thick accumulation of glaciomarine sediment (Unit 3) overlying acoustic basement (till or bedrock) in most of this area. The unconformity at the top of Unit 3, separating it from Unit 1 can even be seen in places. Unit 4, or the equivalent of Unit 4 (it is probably mud in this location, as opposed to sand in the harbour approaches), is as much as 2 m-thick and probably forms the seafloor in much of this region. At locations where the inner harbour widens, small basins are formed in which the sediment section thickens. Particularly good examples of these basins can be seen just prior to the Gorge Bridge and just inward of the railway bridge. The sediment section, mostly glaciomarine materials of Unit 3, is up to 20 m thick within these basins.

Field recorded sidescan sonar hardcopy data are of poor quality, making it difficult to determine sediment characteristics from it. Within the inner harbour, as expected from any harbour survey, a large number of seafloor objects can be noted from sidescan sonar records, many of which appear to be logs. Pylons, pipelines, dredge spoils and scour marks can also be identified. Seafloor reflectivity tends to be high in areas where the harbour width is restricted and lower where it widens, supporting observations of the seismic profile data; bedrock or till appears to come closer to the surface, and may well form the seafloor, at restricted locations. The wider areas are characterized by basins and thicker sediment sections. It is likely that muds of Units 3 or 4 form the seafloor.

The seafloor of the outer harbour is complex. Seafloor reflectivity data indicates a very patchy region with areas of high and low reflectivities. Overall, the reflectivity is higher compared to areas of the harbour approaches. These results support observations based on the seismic profile data which indicate a fairly thin sediment cover and that bedrock, till, glaciomarine sediments, and recent sands or muds may form the seafloor. It appears that cobbles and gravel occur over a large part of the outer harbour floor. There is a patch about 40 x 40 m in area, showing well-formed sand waves in the centre of the harbour between Shoal Pt. and Laurel Point. Other targets include cables, mooring anchors, abundant logs, boats, and abundant unidentified debris.

Figure Captions

Figure 1: Location diagram with ships track and line numbers of survey area.

Figure 2: (Map Roll) Bathymetric contour map generated from data collected on this survey and supplemented with data from published Hydrographic charts.

Figure 3: Shipboard bathymetric record showing the crossing over Macaulay outfall pipe (Line 9) in about 60 m water depth.

Figure 4: Shipboard bathymetric record showing crossing over Clover Pt. outfall pipe (Line 3) in about 38 m water depth.

Figure 5: Sidescan sonar record crossing the Macaulay outfall pipe (Line 11). Note the higher intensity backscatter (darker record) to the east of the pipe, and the patchy appearance of the record. The line across the centre of the figure is the fish track.

Figure 6: Sidescan sonar record crossing the Macaulay outfall pipe (Line 28). The end of the pipe can be seen on the lower part of the record (starboard channel or south of the centre line). At these water depths the patchiness and gain offsets between either side of the outfall are not obvious. Note the rougher seafloor and obstacles on the seafloor around the outfall pipe, especially to the east.

Figure 7: Sidescan sonar record crossing the Clover Point outfall pipe (Line 6). Note the similarity in backscatter intensity across the whole record - indicating a similar seafloor sediment type throughout the area. The outfall pipe is buried by rip-rap, giving it a rough, blocky appearance. Debris can be seen around the outfall.

Figure 8: Sidescan sonar record over the Clover Point outfall pipe (Line 7), showing the end of the pipe to the south of the centre line. There is no noticeable debris or sediment deposit as a result of discharge from the end of the pipe.

Figure 9: Sidescan sonar record over the Clover Point outfall pipe (Line 4). Note the rougher appearance of the seafloor just to the east of the outfall pipe. Its origin is unknown, but may be related to burying the outfall pipe with rip-rap.

Figure 10: Seistec high-resolution sub-bottom profile over the Macaulay Point outfall pipe (Line 4). A bedrock high, which forms Macaulay Point on land, can be seen underlying about 12 m of sediment directly under the outfall pipe.

Figure 11: Seistec high-resolution sub-bottom profile over the Macaulay Point outfall pipe (Line 12). This section shows the most recent sediment, Colwood delta sands, unconformably overlying Capilano glaciomarine sediments, overlying Vashon till. The till section is too thick to see through to basement. Note that east is on the left in this section, and the uppermost sediments thicken towards the west.

Figure 12: Seistec record over the Clover Point outfall pipe (Line 3). Bedrock outcrops at the seafloor just to the west of this section and there appears to be only about 1.5 m of sediment overlying bedrock underneath the outfall pipe at this location.

Figure 13: Seistec record over Clover Point outfall pipe (Line 7). The sediment section appears to be about 17 m thick directly below the outfall pipe. Surface sediment looks to be a thin layer of the most recent sands and gravels directly overlying the Vashon Till.

References

Goddard, J.M., King, P.M., and Frewing, T. 1971. Report of the Victoria District Sea-Bed Survey, " Opportunities for Youth" Summer Project, 1971. Secretary of State of Canada internal report, September, 1971.

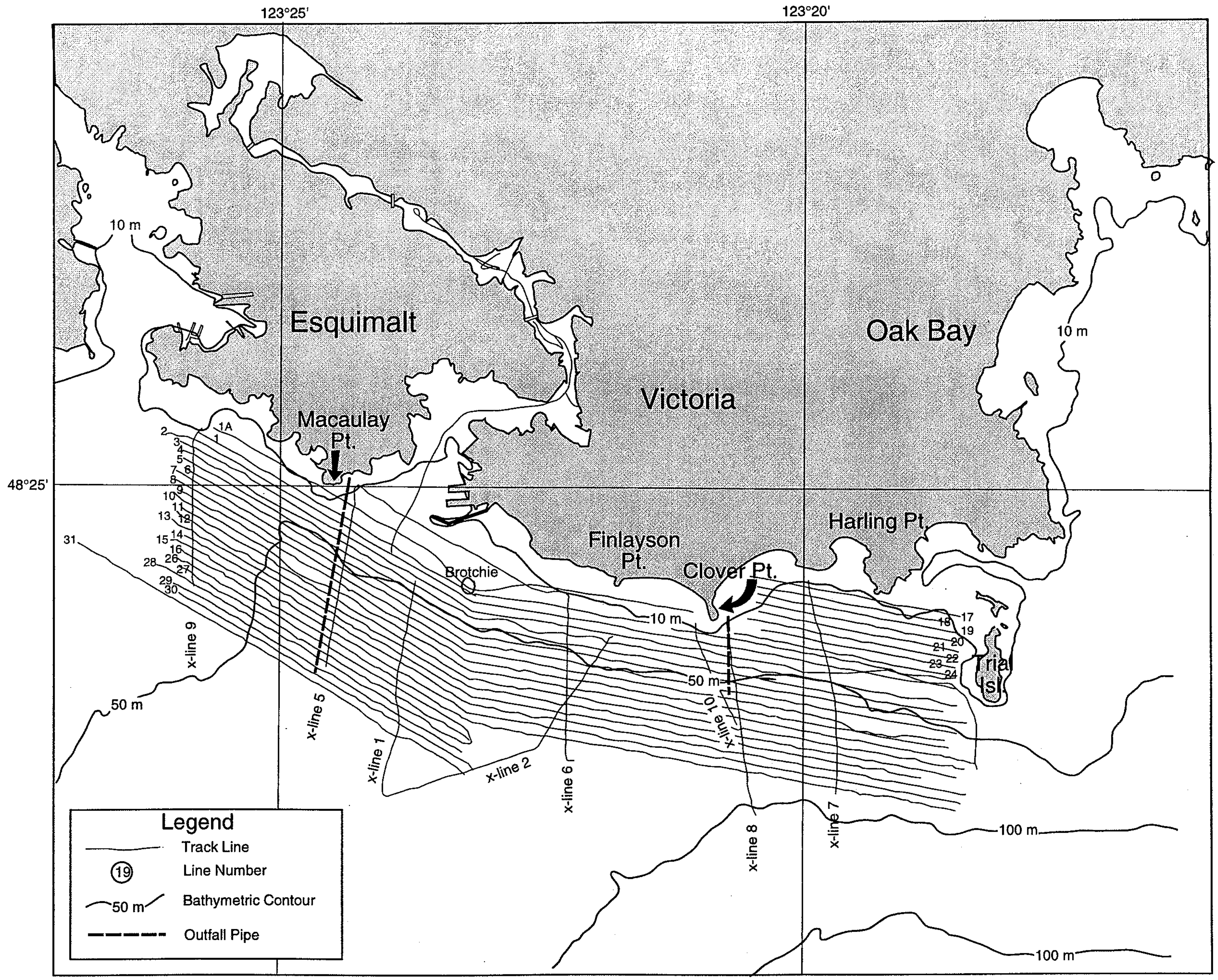

123°25'
123°20'
48°25'
Esquimalt
Victoria
Oak Bay
Macaulay Pt.
Finlayson Pt.
Clover Pt.
Harling Pt.
Trial Isl.
Brotchie
10 m
50 m
100 m
x-line 1
x-line 2
x-line 5
x-line 6
x-line 7
x-line 8
x-line 9
x-line 10
Legend
Track Line
Line Number
Bathymetric Contour
Outfall Pipe

Figure 1

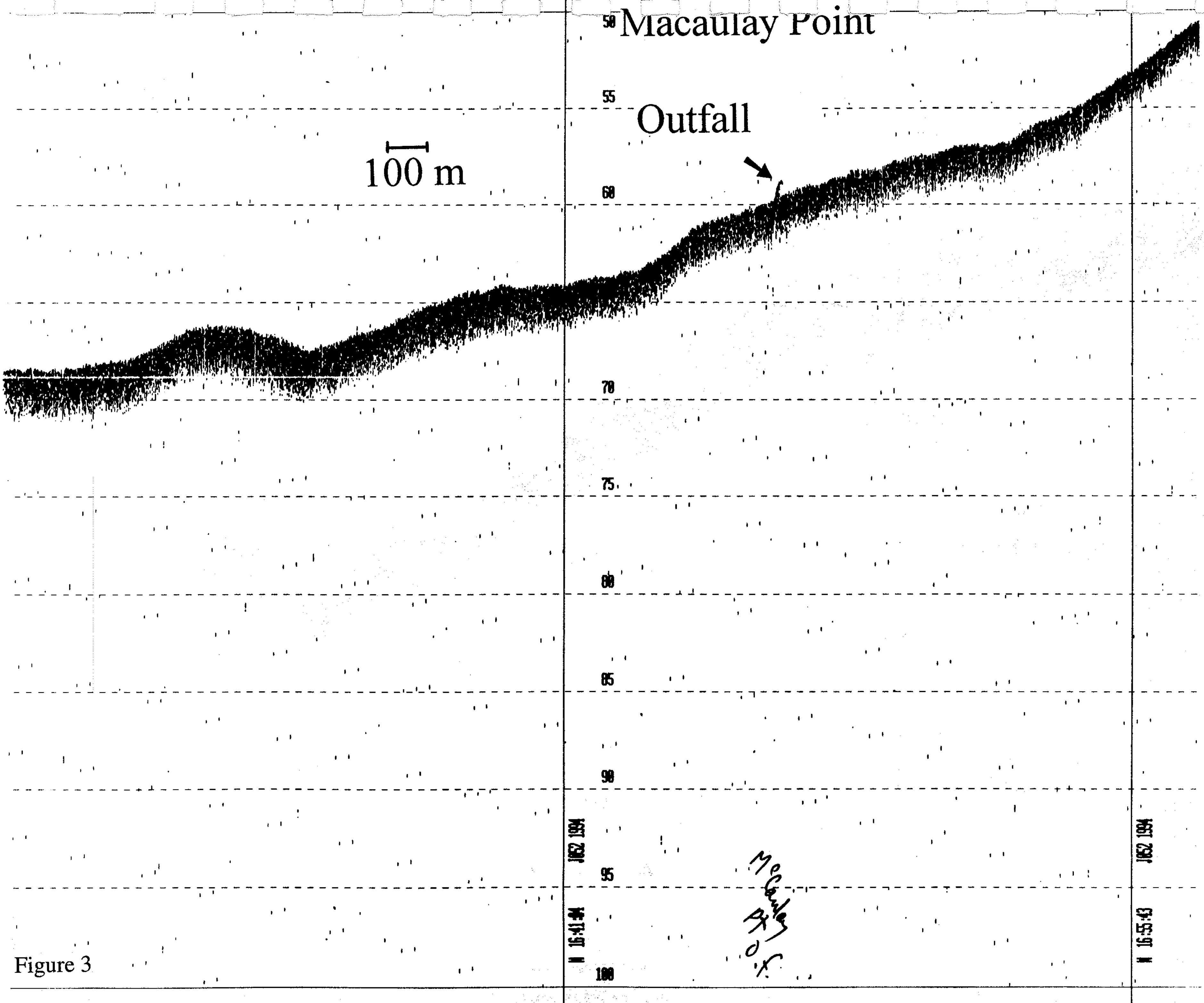
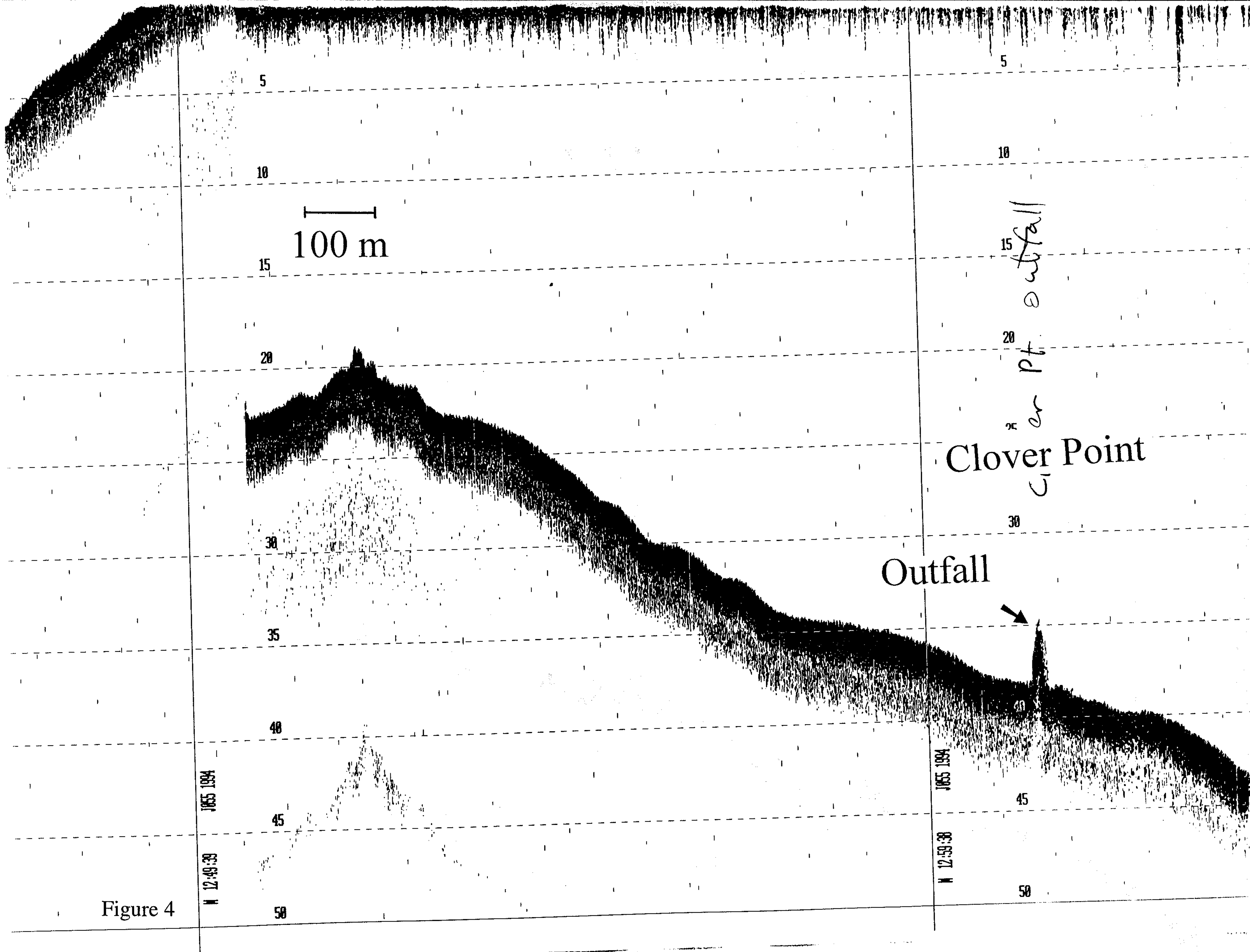

Macaulay Point
Outfall
100 m
50
55
60
70
75
80
85
90
95
100
J062 1994
16:41:04
16:55:43

Figure 3



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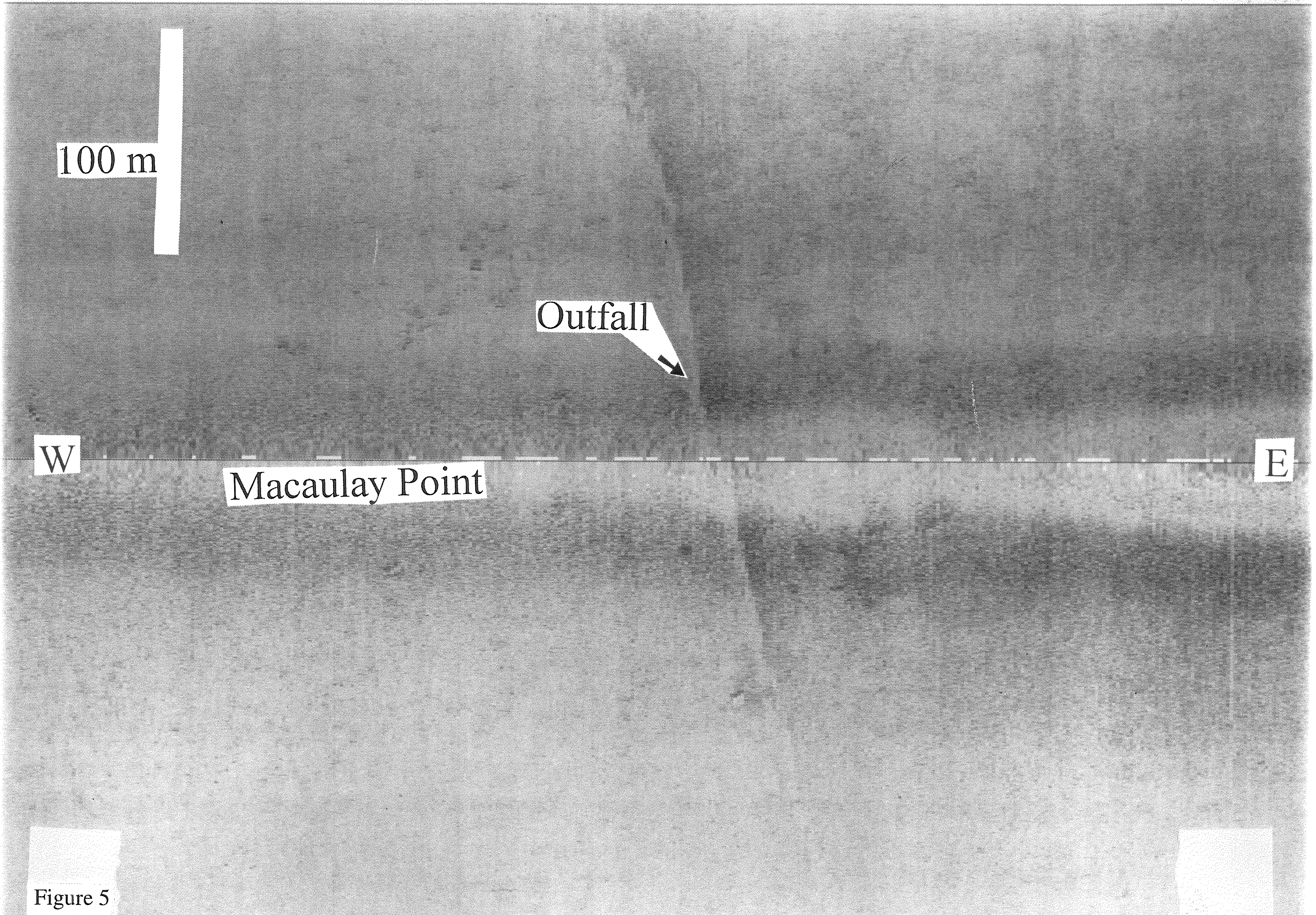

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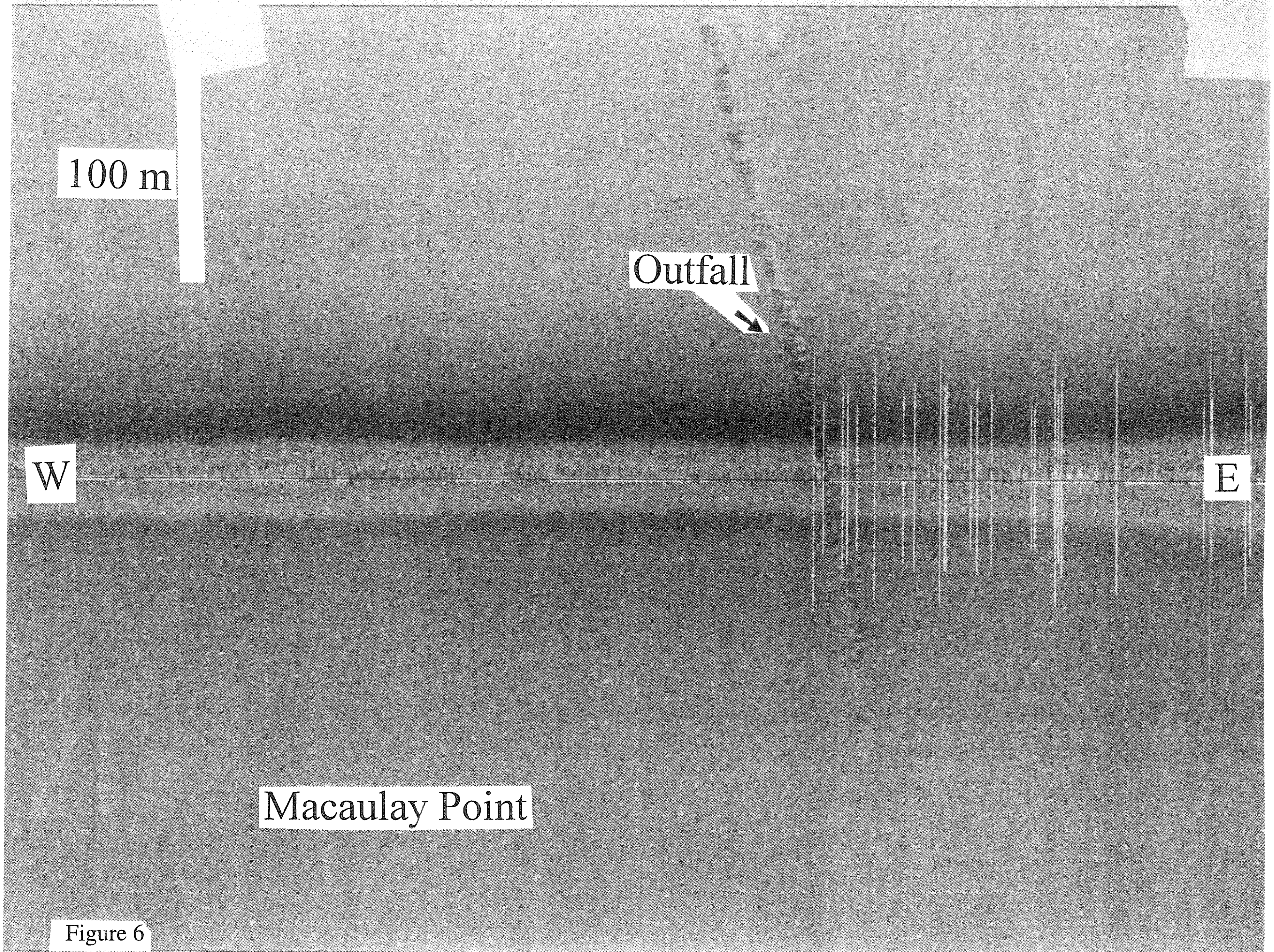

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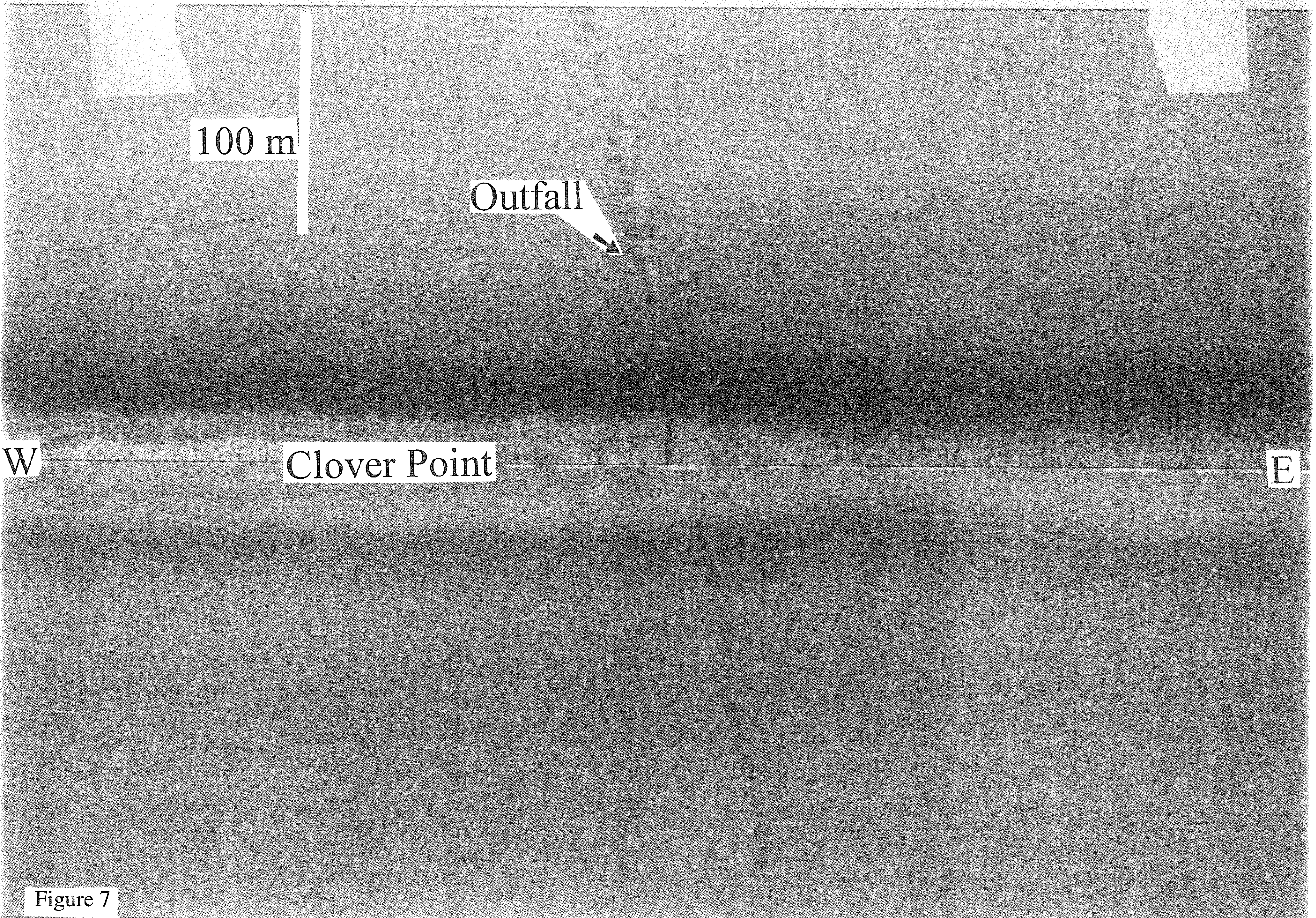

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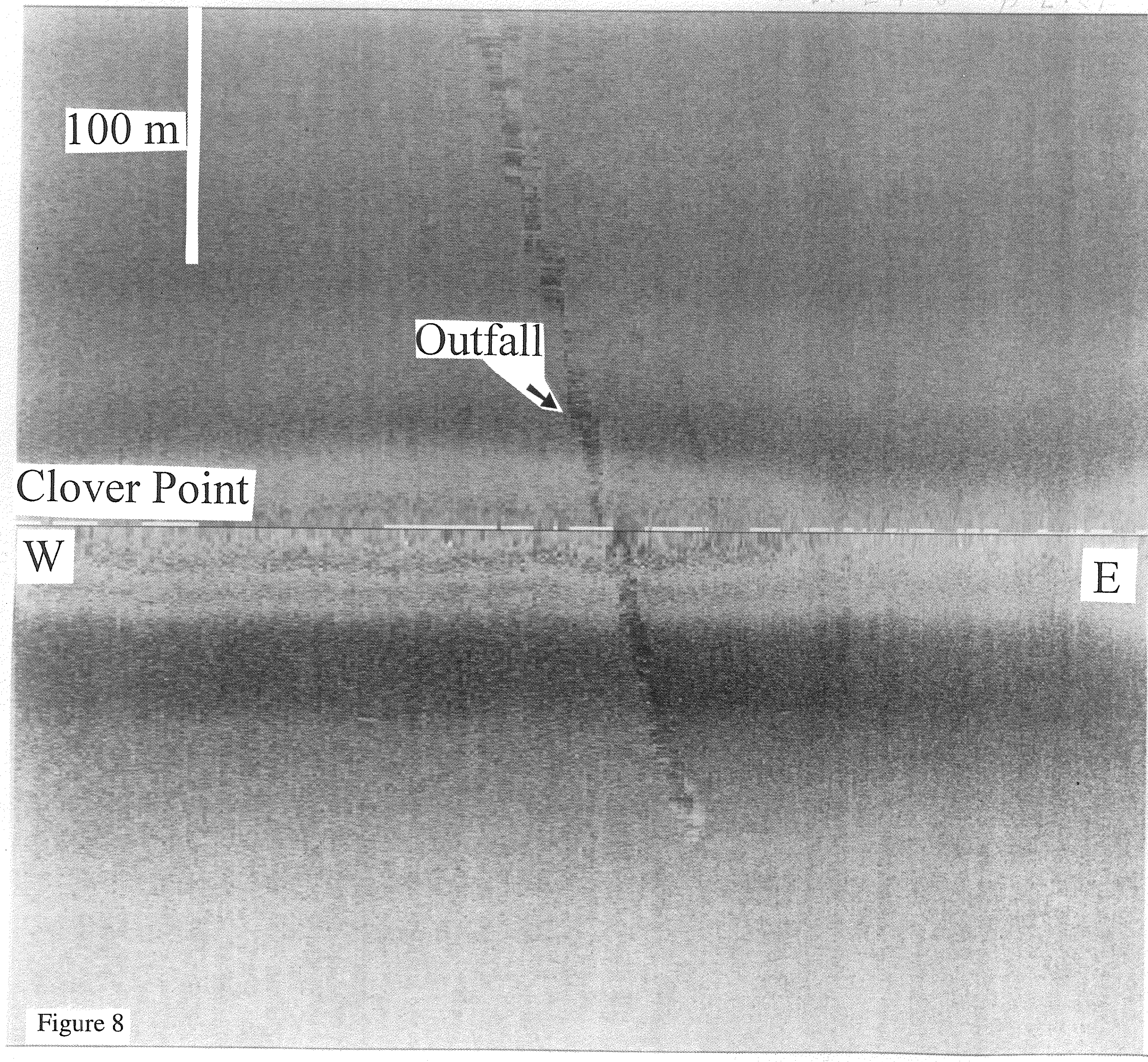

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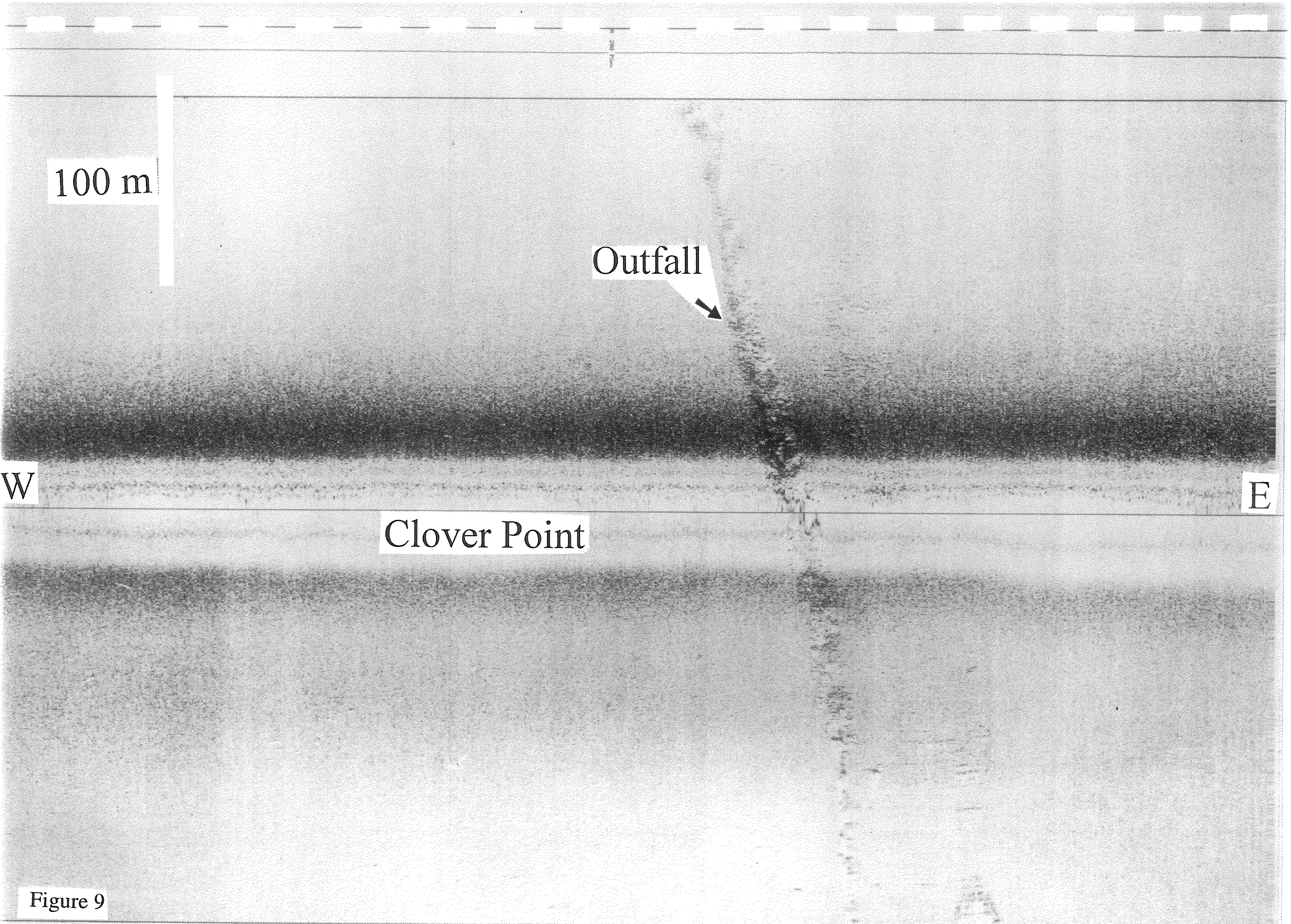
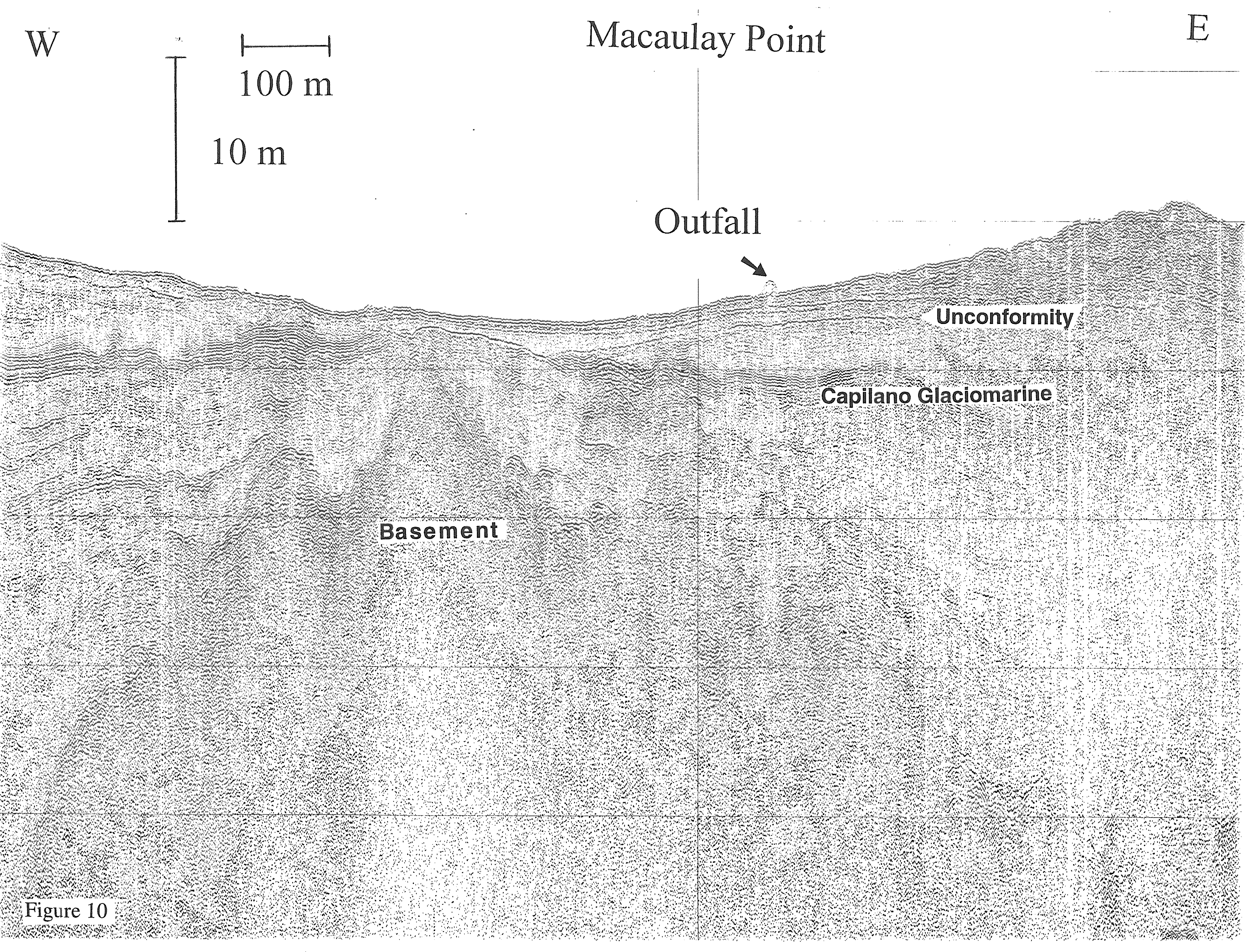


Figure 9

Clover Point Line 9


W
E
Macaulay Point
100 m
10 m
Outfall
Unconformity
Capilano Glaciomarine
Basement
Figure 10

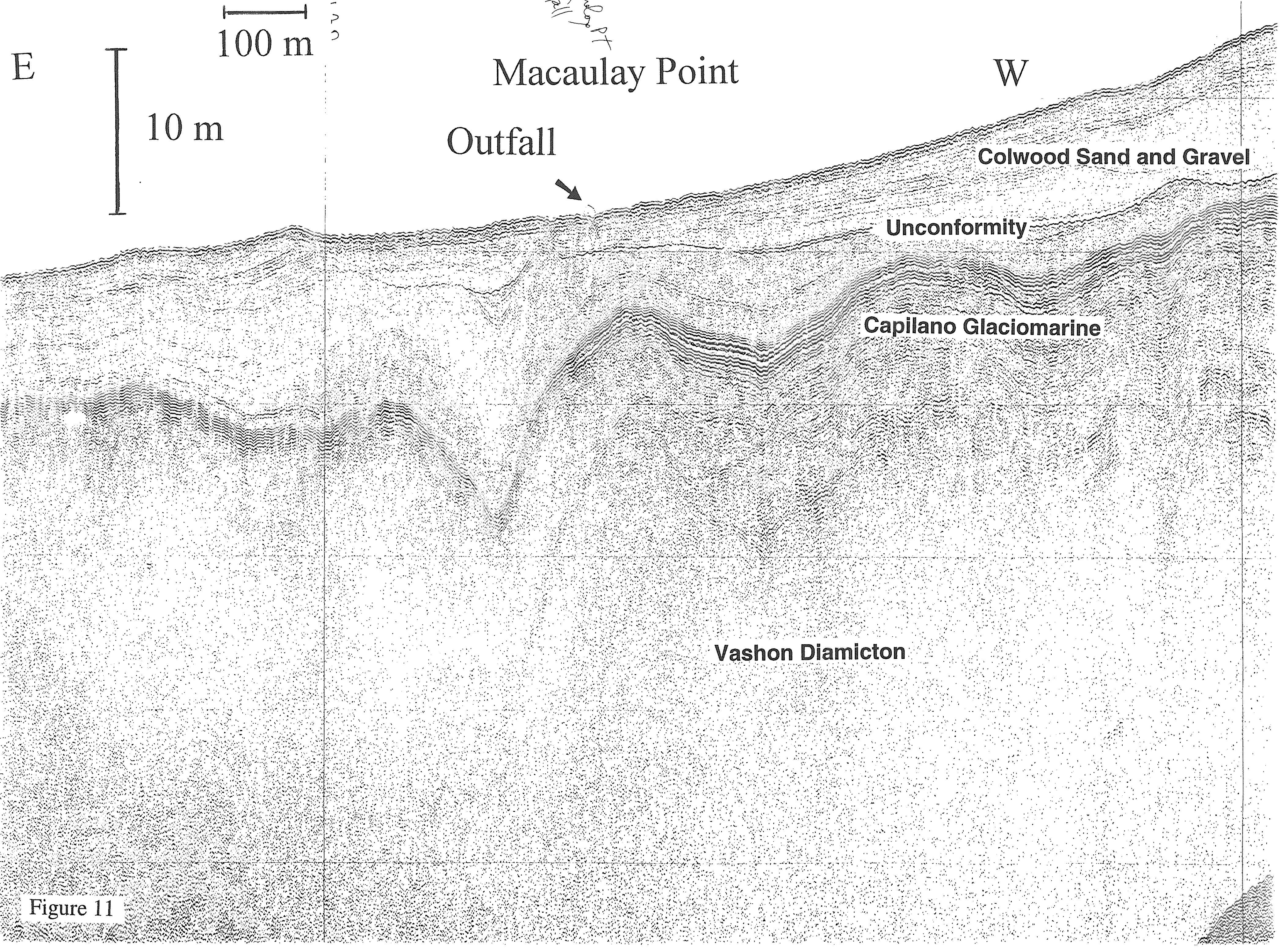

E
W
100 m
10 m
Macaulay Point
Outfall
Colwood Sand and Gravel
Unconformity
Capilano Glaciomarine
Vashon Diamicton

Figure 11

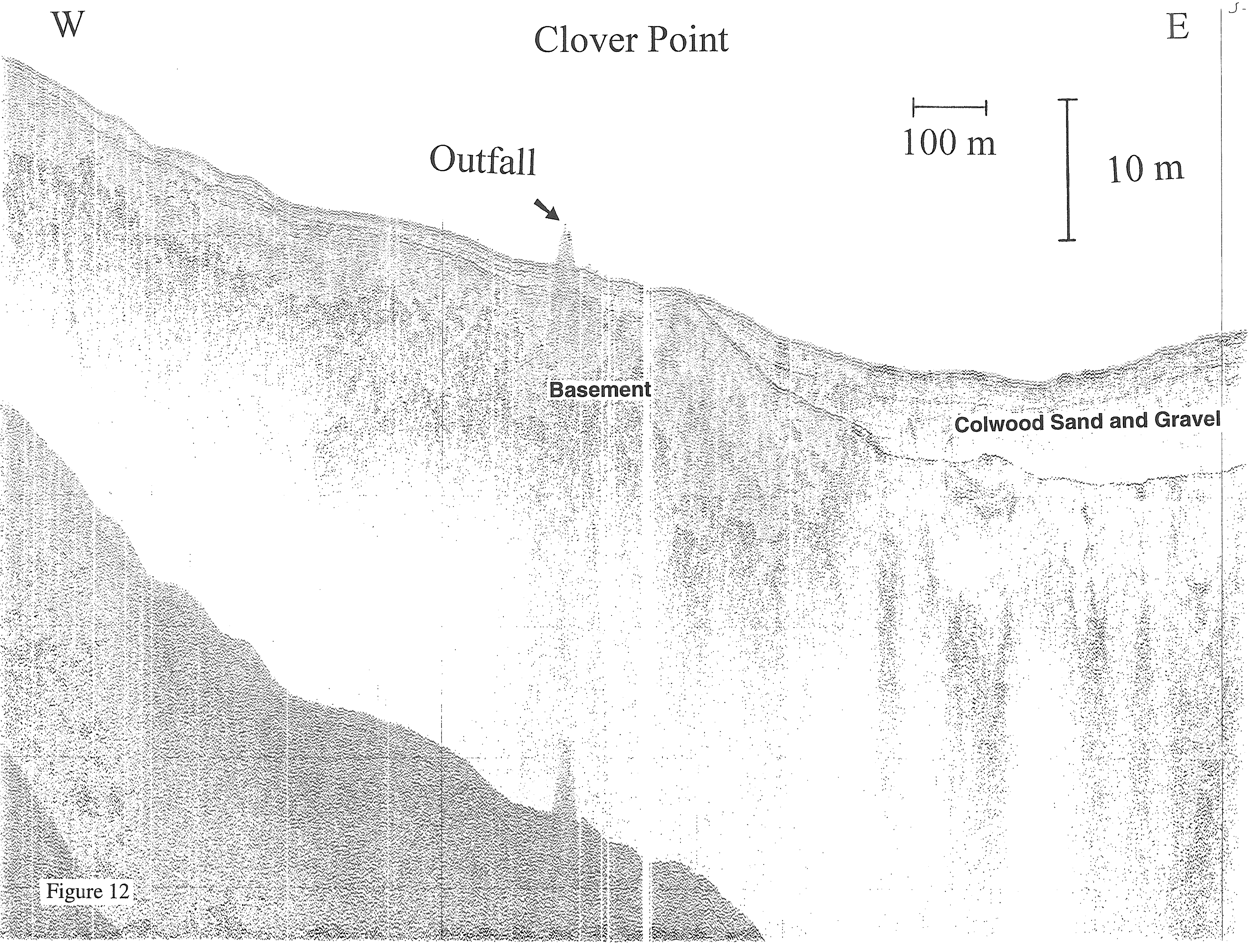

W
Clover Point
E
100 m
10 m
Outfall
Basement
Colwood Sand and Gravel

Figure 12

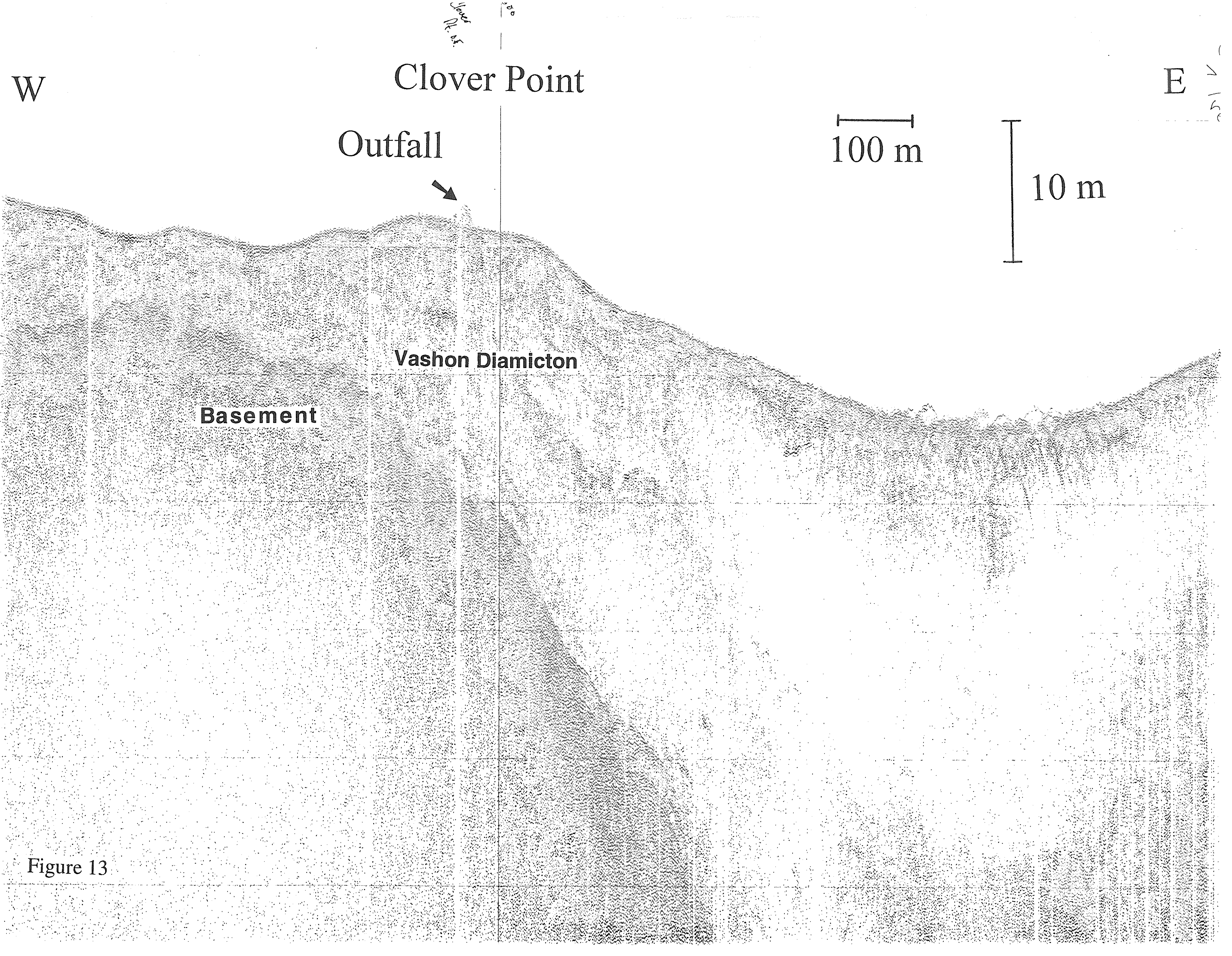

W
Clover Point
E
Outfall
100 m
10 m
Vashon Diamicton
Basement

Figure 13