University of New Hampshire
University of New Hampshire Scholars' Repository

Affiliate Scholarship | Center for Coastal and Ocean Mapping

1989

Pisces IV submersible observations in the epicentral region of the 1929 Grand Banks earthquake

John E. Hughes Clarke
University of New Brunswick, John.HughesClarke@unh.edu

Larry A. Mayer
University of New Hampshire, larry.mayer@unh.edu

David J.W. Piper
Geological Survey of Canada

Alexander N. Shor
University of Hawaii at Manoa

Follow this and additional works at: https://scholars.unh.edu/ccom_affil

Part of the Geology Commons, Oceanography and Atmospheric Sciences and Meteorology Commons, and the Sedimentology Commons

Recommended Citation

Hughes Clarke, J., Mayer, L.A., Piper, D.J.W., and Shor, A.N, 1989, Pisces IV submersible dives in the epicentral region of the 1929 Grand Banks earthquake, in Piper, D.J.W., ed., Submersible studies off the east coast of Canada, Geological Society of Canada Special Paper no. 88-20, pp. 57-69.

This Book Chapter is brought to you for free and open access by the Center for Coastal and Ocean Mapping at University of New Hampshire Scholars' Repository. It has been accepted for inclusion in Affiliate Scholarship by an authorized administrator of University of New Hampshire Scholars' Repository. For more information, please contact nicole.hentz@unh.edu.

— 5 —

PISCES IV submersible observations in the epicentral region of the 1929 Grand Banks earthquake

John E. Hughes Clarke[1], Larry A. Mayer[1], David J.W. Piper[2] and Alexander N. Shor[3]

Hughes Clarke, J.E., Mayer, L.A., Piper, D.J.W., and Shor, A.N., PISCES IV submersible observations in the epicentral region of the 1929 Grand Banks earthquake; in Submersible observations off the East Coast of Canada, D.J.W. Piper, editor; Geological Survey of Canada, Paper 88-20, p. 57-69, 1989.

Abstract

The PISCES IV submersible was used to investigate the upper continental slope around 44°N, 56°W, near the epicentre of the 1929 Grand Banks earthquake. Four dives in water depths of 800-2000 m were undertaken to observe specific features identified with the SeaMARC I sidescan system in 1983. Two dives were made in the head of Eastern Valley where pebbly mudstones of probable Pleistocene age were recognized outcropping on the seafloor. Constructional features of cobbles and boulders, derived by exhumation and reworking of the pebbly mudstone, were also observed. These include gravel/sand bedforms (transverse waves) on the valley floor. Slope failure features in semiconsolidated mudstone were recognized on two dives onto the St. Pierre slope. Exposures in these mudstones are rapidly eroded by intense burrowing by benthic organisms.

Resumé

On a employé le submersible PISCES IV pour examiner la partie supérieure du talus continental aux alentours du point de coordonnées 44°N 56°W, près de l'épicentre du séisme survenu en 1929 dans la région des Grands bancs. On a entrepris quatre plongées entre 800 et 2000 mètres de profondeur pour observer des détails spécifiques identifiés en 1983 au moyen du sonar SeaMARC I à balayage latéral. On a effectué deux plongées dans la partie amont de la vallée est, où l'on a identifié des mudstones caillouteuses datant probablement du Pléistocène, et affleurant sur le fond marin. On a aussi observé des accumulations de galets et blocs résultant de l'exhumation et du remaniement des mudstones caillouteuses. Il s'agit en particulier de structures superficielles sablo-gravelleuses (ondes transversales) sur le fond de la vallée. On a déterminé au cours de deux plongées effectuées sur le talus du banc de St-Pierre, des structures d'effondrement des pentes, à l'intérieur de mudstones semi-indurées. Dans ces mudstones, les affleurements sont rapidement érodés par l'intense activité fouisseuse des organismes benthiques.

[1] Department of Oceanography, Dalhousie University, Halifax, N.S.
[2] Atlantic Geoscience Centre, Geological Survey of Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S., B2Y 4A2
[3] Lamont Doherty Geological Observatory, Palisades, New York

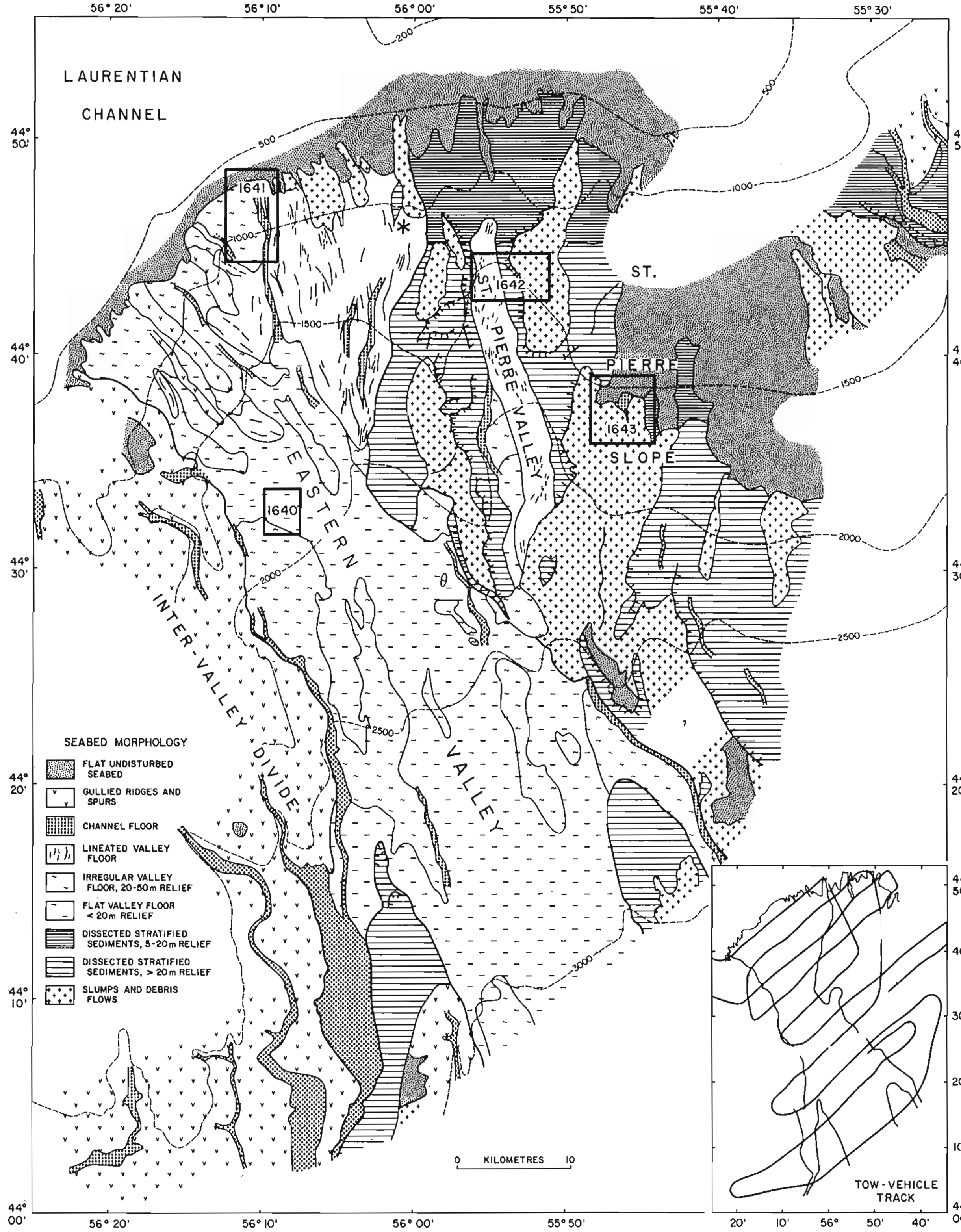

Figure 5.1. Seabed morphology of the area around the 1929 earthquake epicentre (indicated by *) based on SeaMARC I sidescan imagery (from Piper et al., 1985) showing location of Pisces dives.

INTRODUCTION

Scientific background to the area

The epicentre of the 1929 Grand Banks earthquake occurs at 44°42'N, 56°00'W (Dewey and Gordon, 1984). The magnitude 6.8 earthquake is known for an unusual sequence of breaks in underwater communication cables synchronous with and following the event at 2032Z on November 18, 1929 (Doxsee, 1948). Heezen and Ewing (1952) suggested that the sequence of cable breaks resulted from a turbidity current that flowed across the continental rise into the adjacent Sohm Abyssal Plain. Heezen and Drake (1964) suggested that this turbidity current was due to a large scale slump on the upper continental slope. More recent investigations (Masson et al., 1985; Piper et al., 1985) found no evidence for a single major slump. A SeaMARC I survey of a region of 100 by 100 km over the epicentral region (HUDSON cruise 83-017, Fig. 1, Piper et al., 1984; 1985) showed widespread shallow failure on the St. Pierre Slope and at the head of the Eastern Valley of the Laurentian Fan, around the epicentre of the 1929 earthquake (Fig. 5.1). The uppermost continental slope, in less than 600 m water depth, was not affected by slumping. 3.5 kHz seismic reflection profiling and subsequent coring (DAWSON cruise 84-003) also demonstrated widespread stripping of the top 5-10 m of Holocene gas-charged muds on the St. Pierre Slope. In Eastern Valley, headwall scarps on the SeaMARC imagery progress downslope into an area of irregular, discontinuous lineations that appear erosional in origin. Below 2000 m water depth, areas of high intensity of acoustic backscatter with transverse features have been interpreted as gravel waves resulting from the 1929 turbidity current (Piper et al., 1985).

Scientific objectives

On the basis of the SeaMARC I sidescan imagery, eight submersible dive sites were selected to ground truth the imagery and to observe relief below the limit of SeaMARC resolution (pixel size 2.5 m). Diving was limited to four of the eight days available because of fog. Four dives were undertaken, two in the head of Eastern Valley and two on St. Pierre Slope (Fig. 5.1).

The dive objectives in Eastern Valley were to investigate a transition from the headwall scarps, through suspected erosional terrain to a region where the shallowest transverse features (possible gravel waves) developed in the area of high acoustic backscatter occur. Particular attention was to be paid to the identification of features which may have resulted from recent sediment failure or current erosion.

The two dives on the St. Pierre Slope were designed to examine the St. Pierre valley floor and margins and a series of small scarps (appearing like "thumbprints" on SeaMARC sidescan images) that closely resemble rotational slumps on land (LaRochelle et al., 1970; Bentley and Smalley, 1984). An attempt was made to determine the age of these features by examining the extent of bioturbation and the thickness of overlying sediment.

Methods

The program was carried out from the submersible PISCES IV and mother ship M.V. PANDORA II. The operational features of PISCES IV are described by Syvitski et al. (1983). Bottom still photography was by hand-held cameras within the submersible. A continuous video was made by external camera. Navigation of PANDORA II was by Loran-C, corrected by manually logged satellite navigation. Problems were encountered in attempting to identify precise dive locations relative to the 1983 SeaMARC sidescan images. Although the ship's track for the 1983 survey is well known through Loran-C and satellite navigation, the SeaMARC towbody position was not well constrained. In addition, the sidescan mosaics used are only accurate to within 100-200 m, because of problems associated with correction for variations in ships speed and curved track corrections.

PISCES navigation was provided by using surface logged range and bearing from PANDORA II with a Honeywell short baseline acoustic tracking system. Positions were recorded manually every 5-10 minutes. The system performance was poor for dive 1640, but operated satisfactorily thereafter.

Brief descriptions of each dive are presented, based on observations, shipboard reports, and video coverage. Scientists on each dive are identified by their initials.

Acknowledgments

We thank the entire PISCES IV crew for their skillful handling of the submersible and willingness to operate very long, deep-water dives; we also thank the Captain and crew of PANDORA II. Norman Silverberg contributed significantly to observations and ideas reported for Dive 1642. This work was partly supported by the Canada Program of Energy Research and Development and by the Natural Sciences and Engineering Research Council. Manuscript was reviewed by P.R. Hill, G.B. Fader and B. MacLean.

EASTERN VALLEY FLOOR AT 2000 m (DIVE 1640: ANS, JEHC)

This dive consisted of a Z-shaped traverse across the central part of the Eastern Valley floor (Fig. 5.1 and 5.2) between 2000 and 1900 m. The dive was designed to examine an elongate channel developed in a low acoustic reflectivity facies which is parallel to the axis of Eastern Valley and the shallowest occurrence of transverse linear features seen on the sidescan images. These transverse features are better developed down valley, beyond the 2000 m depth limit of PISCES IV, where they appear as asymmetric gravel wave fields.

The major bathymetric feature in the region is an elongate channel or thalweg, striking NW-SE, 30 to 40 m below the main valley floor (Fig. 5.3). The dive began on the thalweg floor at 2006 m and during the first traverse, the submersible climbed out of the thalweg and across two E-W striking low ridges or swells (Fig. 5.4). The second leg of the dive traverse, to the southwest, crossed low amplitude features transverse to the valley, interpreted as gravel

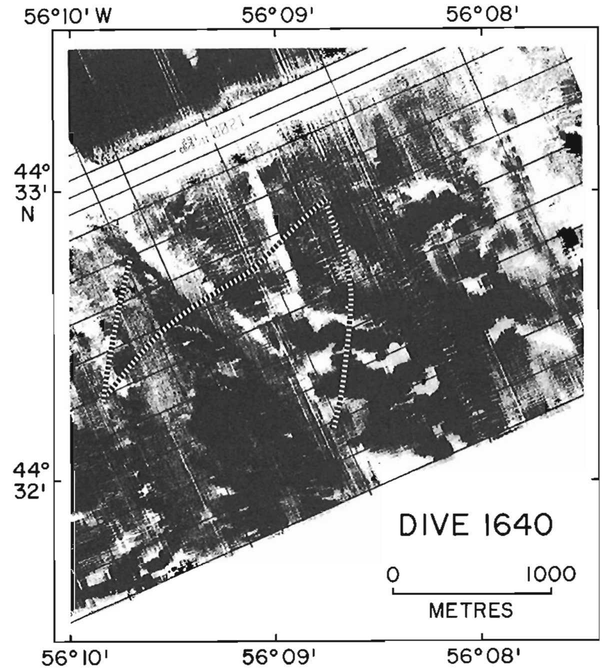

Figure 5.2. SeaMARC I sidescan imagery near dive site 1640 showing approximate position of dive track (dotted line).

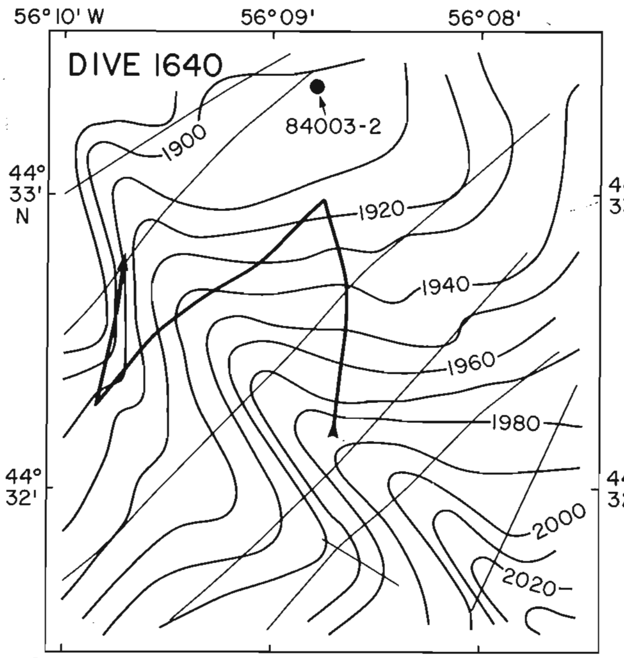

Figure 5.3. Bathymetric map of seafloor in the vicinity of dive 1640 showing dive track (thick continuous line). Bathymetry based on surface sounder profiles (thin continuous lines), using v = 1500 m/s.

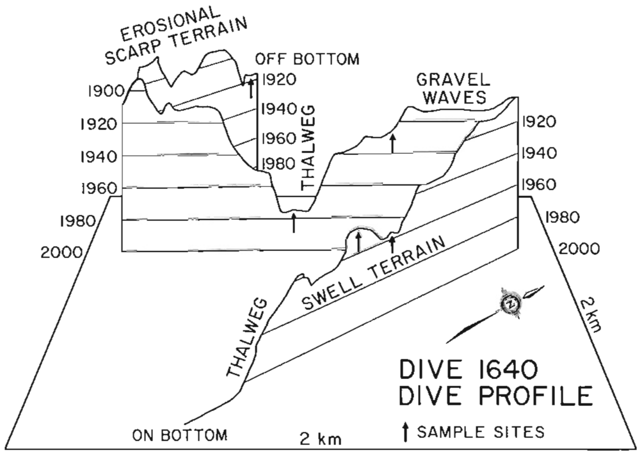

Figure 5.4. Profile of dive 1640 showing geologic terrains (based on submersible pressure depths).

waves, entered the thalweg and then crossed a terrain dominated by scarps and crests of outcropping pebbly mudstone (Fig. 5.4). The third leg, to the northeast, crossed this erosional scarp terrain and re-entered the thalweg. The four geomorphic regions or terrains are described individually below.

Swell terrain

This region corresponds to E-W striking troughs and swells seen on the sidescan immediately to the east of the thalweg. Two swells with an amplitude of 16 m were traversed on the first leg of the dive traverse. Outcrop of pebbly mudstone was seen only in the trough between the two swells and on the south-facing slope at the edge of the gravel wave region to the north. Elsewhere the terrain was characterized by scattered boulders with a thin mud drape. Throughout the region, there were occasional blocks of pebbly mudstone amongst the boulders.

Between the gravel waves and the thalweg on the southwest leg, the submersible crossed the western end of the northern swell. Outcrop of mudstone and pebbly mudstone became more common as the swell was approached. There was a high density of boulders as the swell was crossed, but no outcrop was associated with the 15 m high slope at its eastern edge (Fig. 5.4).

Gravel wave region

This region, situated to the northeast of the swell terrain, consisted of areas of boulders and areas dominated by mud. Wherever the mud was probed, it was underlain by gravel. A series of steep faces were traversed, 2 to 4 m high, striking 030° to 060°, with a spacing of 15 to 20 m. These steep faces sloped at 30° to 40° down valley and were commonly draped by 20 cm of mud. They appeared to be constructional features of clast-supported cobble gravel. The crests of these faces were followed and were seen to bifurcate or die out within 50 m. Between the steep faces, boulders were common on the flatter seafloor (Fig. 5.5) with increasing boulder density towards the base of the faces. These faces

Figure 5.5. Bottom photograph of boulders on seabed in trough in gravel wave field, dive 1640 (1640-P022).

correspond to the gravel waves interpreted from the side-scan images, with boulder lags on the stoss sides of the waves, an increase of boulders in the troughs, and a mud drape over the lee slopes. Other local troughs and depressions in the seafloor may result from scour.

On the southwest leg of the dive transect, low mudstone and pebbly mudstone outcrops were interspersed with these gravel wave constructional features. These outcrops displayed a streamlined morphology which appeared to have been flow moulded. At the base of one crest, a 5-m-long displaced block of red pebbly mudstone was observed. The block had no obvious source and there was no outcrop on the adjacent wave crest.

The presence of flow-moulded outcrop within the gravel wave field implies that the gravel waves and boulders occur in a thin layer overlying an eroded pebbly mudstone. The swell terrain probably is a seabed morphologic expression of outcrops of the underlying pebbly mudstones.

Thalweg channel

The dive began and ended in the thalweg channel, and the channel was crossed a third time in the middle of the dive. Where the dive began, the channel floor was smooth and mud covered, with coarse clastics conspicuously absent. The thalweg channel wall was 30 m high, with an average slope of 20° and consisted of rare exposure of cobbles and boulders in an otherwise mud dominated terrain. East-west striking crests, 3 to 5 m high with the steeper face downslope, were traversed. An isolated, heavily bioturbated mudstone block, apparently sculpted by flow, was seen.

On the southwest traverse in the middle of the dive, the northeast wall of the thalweg was 37 m high, exhibiting no outcrop and had lines of boulders down spurs on the wall. Mudstone blocks were observed at the base of the wall. The crest of the wall was defined by a break in slope and a zone of boulders, which passed upslope into flat muddy seafloor. The thalweg floor was covered with unconsolidated silty clay to the limit of core penetration from the submersible (30 cm), and exhibited low (10-30 cm), axially-aligned mud ridges. The southwest wall was 27 m high and had boulder scree up to the crest, but no outcrops of mudstone were seen.

The dive terminated close to the southwest wall of the thalweg channel, after the submersible had descended 18 m across successive ledges of outcropping pebbly mudstone. Below each ledge, displaced pebbly mudstone blocks occurred. The thalweg channel floor was not reached before the dive was terminated.

Erosional scarp terrain

This region lies southwest of the thalweg, about 70 m above its floor. The seabed consisted of angular crests and scarps, 3 to 5 m high, of outcrop of pebbly mudstone, which lacked any alignment. The presence of large fresh slide blocks below scarps suggested that sediment is continuing to fail. The slide blocks appeared to have been broken up, partly by bioturbation, exhuming large volumes of cobble and boulder sized gravel from within the blocks (Fig. 5.6). The largest boulders observed were 2 m in diameter. Some streamlined, flow-modified outcrop was seen. Most of the relief appears due to failure during the 1929 event and subsequently throughout the last 56 years.

EROSIONAL UPPER PART OF EASTERN VALLEY (DIVE 1641: DJWP, LAM)

This dive was in the upper part of the Eastern Valley of Laurentian Fan (Figs. 5.1, 5.7 and 5.8). It began at a depth of 1268 m on the valley floor and continued for five kilometres up the valley to a depth of about 1000 m. From there, the dive continued upward on one of the ridges that separates the head of the valley into a number of tributaries, terminating at a depth of 647 m where slump scars incise the smooth upper continental slope at the head of the valley (Figs. 5.7 and 5.8). Seven geologically and morphologically distinct zones are distinguished along the dive track (Fig. 5.9).

Figure 5.6. Bottom photograph of pebbly mudstone outcrop from erosional scarp terrain, dive 1640 (1640-P55).

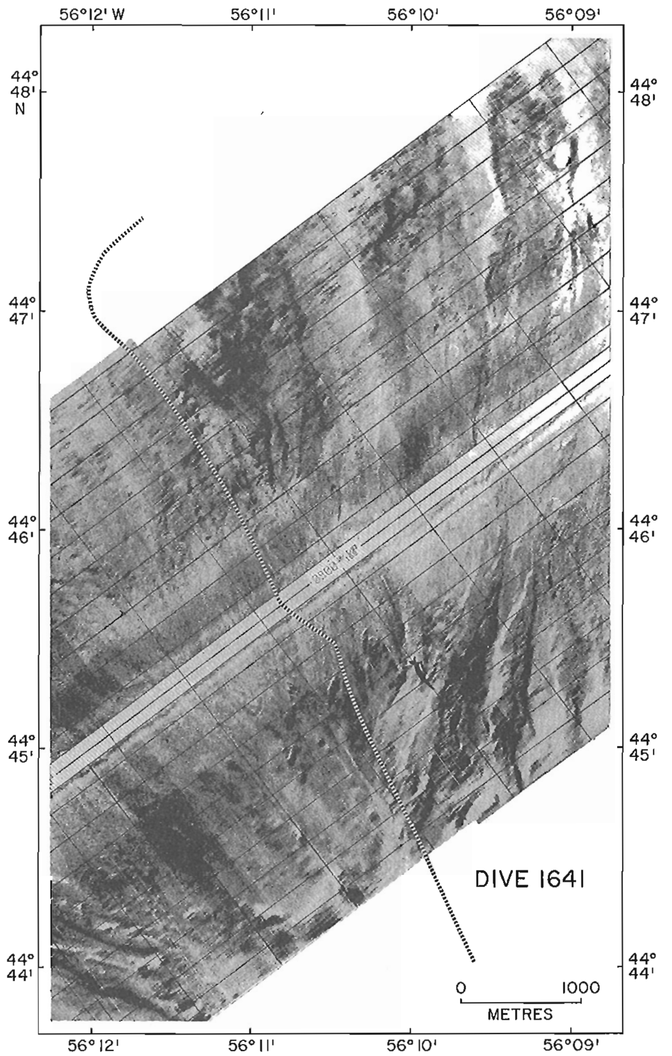

Figure 5.7. SeaMARC I sidescan imagery showing location of dive 1641 (dotted line).

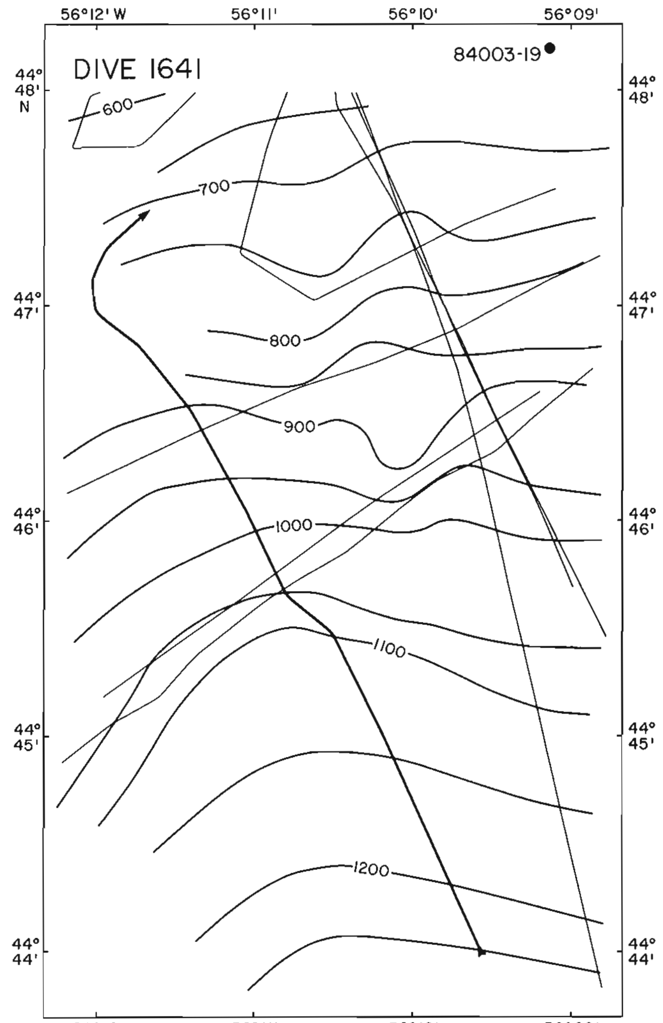

Figure 5.8. Bathymetric map of seafloor in the vicinity of dive 1641 (thick continuous line). Bathymetry based on surface sounder profiles (thin lines) using v = 1500 m/s. Also shows location of piston core 84003-19.

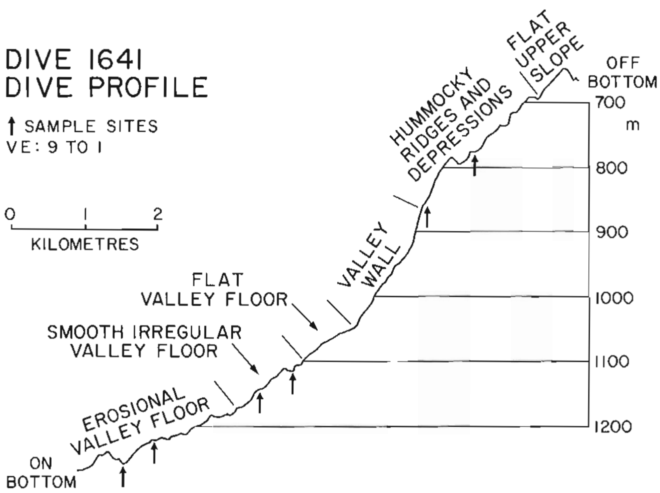

Figure 5.9. Profile of dive 1641 showing geologic terrains (based on submersible pressure depths).

Erosional valley floor

This zone consisted of red mudstones and pebbly mudstones, mantled by soft grey mud. The mudstones outcropped in a series of scarps typically a few metres high and oriented roughly north-south. These scarps alternated with flat terraces apparently defined by bedding and joint planes. Talus slopes and angular blocks of red mudstone occurred at the base of the scarps. Rarely, blocks that were partially detached along joint planes from the subhorizontally bedded outcrops were seen. Some scarps had a scalloped appearance, with chutes. On some flat terraces, there were low elongate depressions (20-30 cm deep) also oriented roughly north-south; these may have formed at the same time as more deeply incised linear chutes.

Outcrops of mudstones were commonest in the deeper part of the erosional valley floor, whereas pebbly mudstones were common in the shallower part. Pebbles, cobbles and boulders were seen embedded in the pebbly mudstone where it outcropped. There was frequently a concentration of these gravel size clasts (resembling winnowed lag) on the flat terraces immediately above the scarps and on low upstanding areas of mudstone. Clasts were also seen on many talus slopes. Elsewhere, small clasts and red mudstone matrix material appeared to have been brought to the surface through the surficial grey mud layer by bioturbation. There appeared to be a correlation between the abundance of surface clasts and the abundance of clasts locally seen in the mudstone, suggesting that the clasts may represent a lag winnowed out of the mudstone (perhaps from partially broken, slumped blocks).

Blocks of mudstones were common below outcrop scarps. They were generally angular, and sometimes appeared like pieces of a jigsaw puzzle, that could be reconstructed. Some showed steeply dipping bedding. They thus appeared to have been derived locally by slumping off the scarps.

At the beginning of the dive, a communications cable was found, which was covered with considerable epifaunal growth (Fig. 5.10a). The cable ran over the edge of several

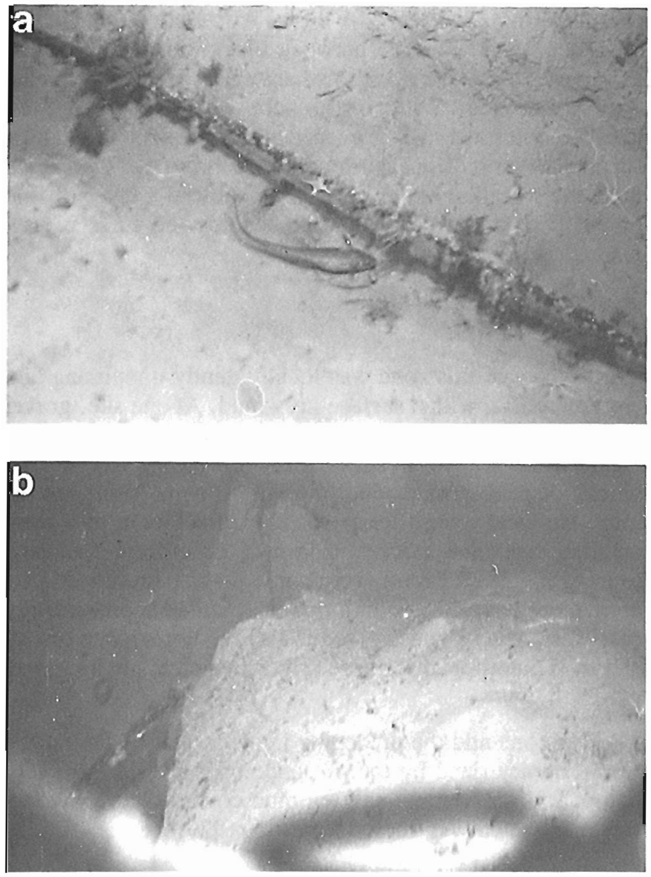

Figure 5.10. Bottom photographs of seabed telecommunication cable on floor of upper Eastern Valley (a: 1641-P04, b: 1641-S09).

scarps including a 10 m high mudstone scarp, and into areas of large mudstone blocks below the scarps. The cable was bent through an angle of about 50° around blocks up to several metres in size (Fig. 5.10b). The cable was frequently buried in talus and under grey mud. In at least two places it appeared to be buried beneath large blocks of red mudstone (but this observation is not unequivocal). On the basis of these observations, it may have been one of the cables broken in 1929. The Commercial Cable Co. C1 cable was laid closest to the site at which the cable was found.

The scale of the major scarps and terraces, and the preservation of the cable segment which passes over several scarps, indicate that these larger features may have existed before 1929. The mudstone blocks may have been displaced in 1929. If the surface lag of clasts resulted from in situ winnowing, the concentration of clasts in the pebbly mudstone indicates that only a few metres of mudstone or mudstone blocks would have to be broken up to produce the observed concentrations.

Irregular valley floor

This was an area of irregular topography with occasional low scarps. Red mudstone or pebbly mudstone outcropped only rarely and appeared "weathered" and friable compared with that seen in the scarps to the south. (This friable character may be due to a higher silt content). The significance of the contrast between blocky mudstone on the erosional valley floor and "weathered" mudstone in this zone is not clear. Most of the zone was mantled by grey mud. Cobbles and finer gravel occurred intermittently at the surface, as on erosional valley floor to the south. Two cores from the irregular valley floor both showed a layer of fine gravel with a red sandy matrix beneath the surface grey mud.

Flat valley floor

The surface of this zone was locally gently undulating and elsewhere flat, with a surface grey mud. At one site, gravel was found beneath 1 cm of grey mud. Clasts were seen only locally at the seabed. In one area, there were several isolated blocks of pebbly mudstone, the largest some three metres long. No local source scarp was seen; the blocks may have resulted from ice rafting, slumping or current transport (during the 1929 event) from some distant source. In one area, there were 10-cm-high ridges, oriented approximately east-west, with a spacing of 50-100 m. Sorted fine gravel and mud outcropped on these ridges, which might be gravel waves.

This zone and the preceding irregular valley floor zone were characterized by the presence of gravel immediately below a fairly continuous grey mud cover. They may thus represent a thalweg facies from the 1929 event.

Valley wall

The steep valley wall between 1010 m and 863 m consisted of a series of irregular ridges. Red mudstone and pebbly mudstone outcropped in scarps 1 to 5 m high. These scarps were much more irregular than on the erosional valley floor, and lacked terraces. Much of the slope was covered with grey mud. Cobbles and gravel patches occurred locally.

Hummocky ridge and depression terrain

A distinctive seabed morphology, correlated with ridge and gully terrain in SeaMARC sidescan images, occurred between 863 m and 657 m. The scale of features observed from PISCES was much smaller than the ridges and gullies in the SeaMARC sidescan images. This terrain consisted of a very hummocky pattern of ridges and depressions with a resemblance to badland topography seen on land. However, not all of the depressions were continuous, and some, up to 1 m deep, were closed. Many of the ridges were rounded in profile, whereas others exhibited pinnacle-like crests composed of grey and red mudstone. These were very intensely bioturbated on their flanks, particularly by large sub-horizontal burrows. Chutes of sediment at the angle of repose were visible. Pebble lags were seen along gully axes and appeared to represent concentration of pebbles exhumed through bioturbation of the gully walls (Fig. 5.11). Mass wasting through bioturbation offers an explanation for the irregular surface morphology. However, prior slope dissection to form the ridge and gully system was necessary.

Figure 5.11. Bottom photograph of gravel lag below outcrop of gravelly mudstone on Eastern Valley wall (1641-S51).

Flat upper slope

This zone was monotonously flat and smooth, with a highly bioturbated grey mud surface. It is correlated with the smooth upper slope seen on SeaMARC sidescan images.

Upper slope recessional slumps

Recessional slumps were seen on either side of the flat upper slope, cutting into it to form a series of steep, scalloped scarps and terraces. The scarps were many metres high and exposed grey-green sediment. Large blocks appeared to have fallen off the scarps, and remnant ridges with pinnacles occurred.

ST. PIERRE VALLEY WALL (DIVE 1642: ANS, NS)

This dive began on the floor of St. Pierre valley at 1620 m (Fig. 5.1) and traversed to the east across the floor to the valley wall, climbed 370 m up the wall, and crossed into wrinkled to smooth mud terrain at 1170 m (Figs. 5.12, 5.13 and 5.14). Three main geomorphic regions have been distinguished on the basis of SeaMARC sidescan images and the dive observations.

St. Pierre Valley floor

The floor appeared largely erosional, with linear mud ridges oriented down valley, spaced at 5 to 7 m and with an amplitude of 40 to 150 cm. The bottom was stiff mud, as indicated by the dropweight and arm probing. Small flakes of semi-lithified clay aggregates occurred scattered on the surface. The ridges were sometimes developed as a series of benches as the valley axis was approached, implying outcropping bedding planes. Rare, widely scattered boulders were present, although none appeared to be part of outcrop. These ridges and benches are believed to correspond to the axially oriented sidescan features imaged on the valley floor by SeaMARC.

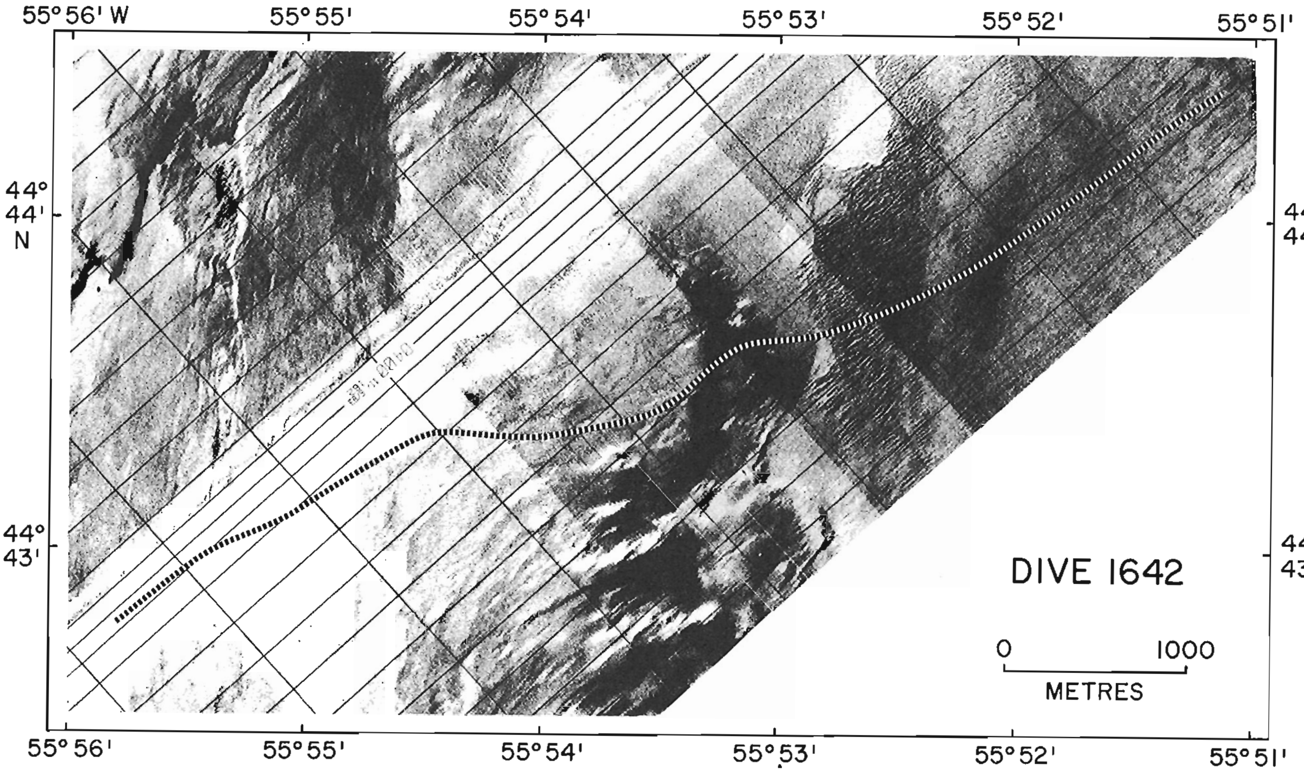

Figure 5.12. SeaMARC I sidescan imagery showing location of dive 1642 (dotted line).

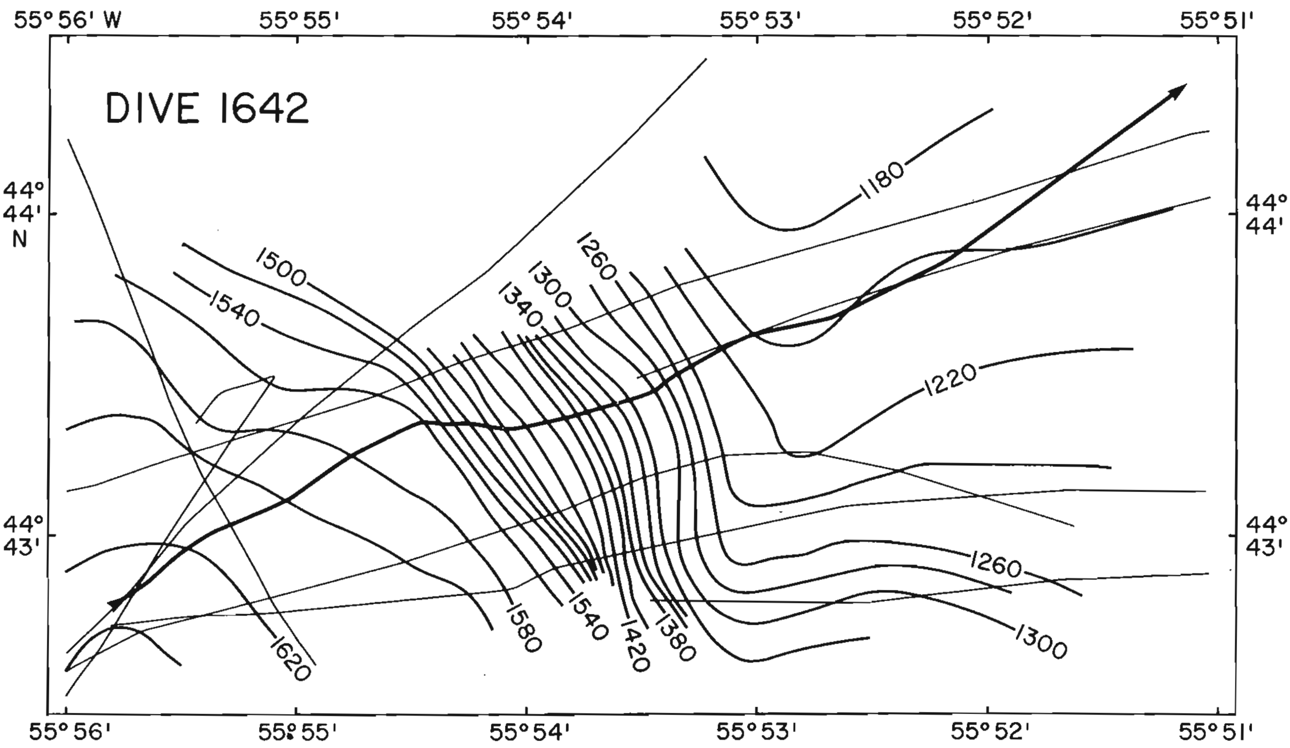

Figure 5.13. Bathymetric map of seafloor in the vicinity of dive 1642 (thick line). Bathymetry based on surface sounder profiles (thin lines) using v = 1500 m/s.

Valley wall

As the eastern wall was approached, isolated mudstone blocks occurred. The gradient of the wall averaged 30° and was steeper and dissected into gullies and spurs where there was extensive outcrop. Outcrops included well bedded red mudstone and occasional semilithified mudstone with a few pebbles and cobbles were also seen in the outcrop. Displaced blocks were seen with sharp unbioturbated faces, some with a brownish stain. Angular scarps from which blocks presumably had been detached were observed.

Wrinkled terrain

Over the top of the valley wall, elongate asymmetrical ridges were again common, with the steeper faces to the south. The orientation of these ridges was variable, with strikes from 060° to 140°. The ridges merged and diverged across the terrain. The submersible sonar indicated that the region was one of poorly aligned ridges and mounds spaced approximately 3 m apart. These ridges correspond to the finely wrinkled terrain on SeaMARC sidescan images. No cobbles or boulders were seen and outcrop was rare. A possible gas escape structure was seen.

ROTATIONAL SLUMPS ON ST. PIERRE SLOPE (DIVE 1643: DJWP, JHC)

This dive crossed the ridges which resemble thumbprints on SeaMARC I sidescan images (Fig. 5.15) east of St. Pierre Valley, in about 1600 m of water depth (Fig. 5.1). A gully leading down from an amphitheatre-shaped scarp was

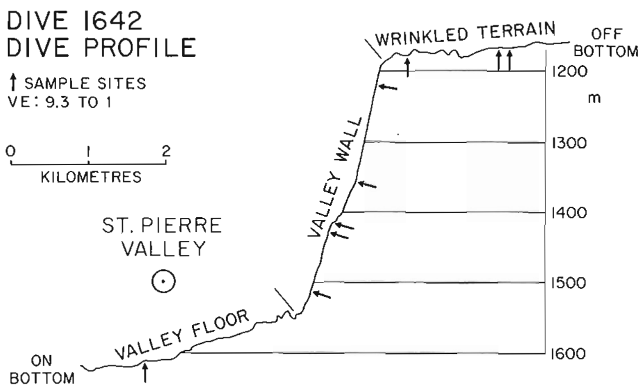

Figure 5.14. Profile of dive 1642 showing geologic terrains (based on submersible pressure depths).

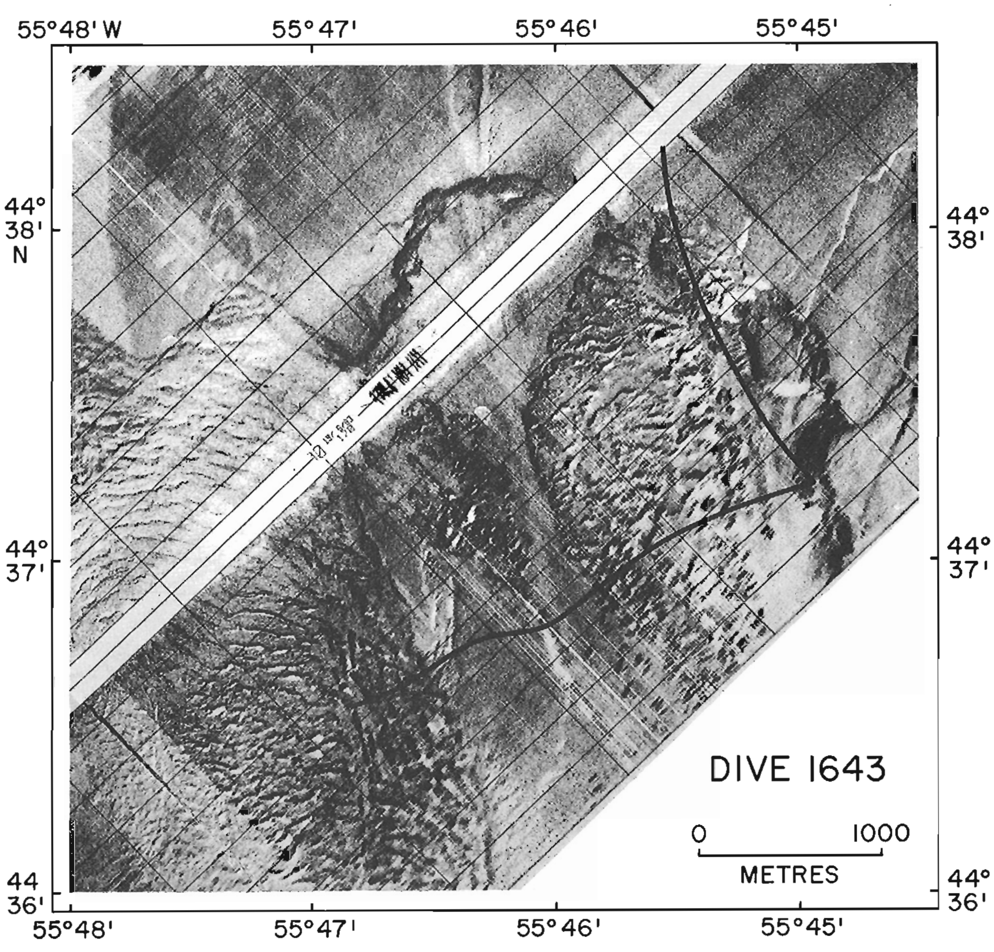

Figure 5.15. SeaMARC I sidescan imagery near dive site 1643 showing approximate position of dive track (dotted line) across "thumbprint" slumped area.

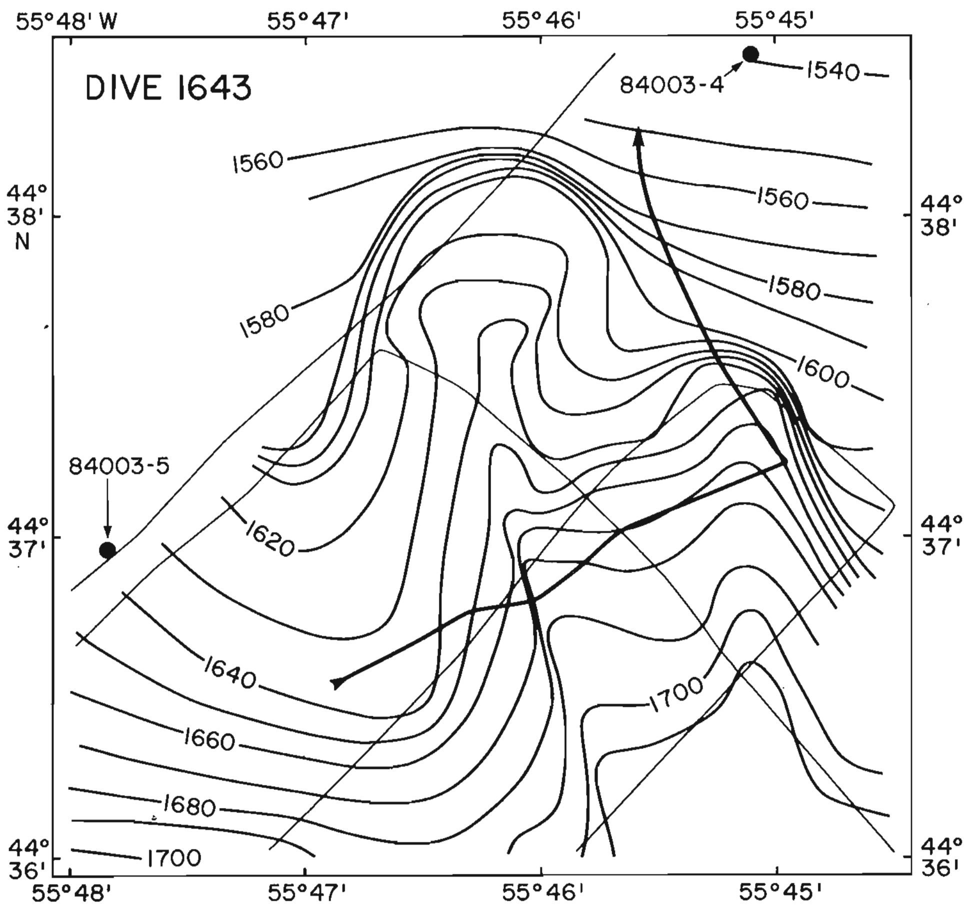

Figure 5.16. Bathymetric map of seafloor in the vicinity of dive 1643 (thick line). Bathymetry based on surface sounder profiles (thin lines) using v = 1500 m/s. Also shows location of piston cores 84003-4 and -5.

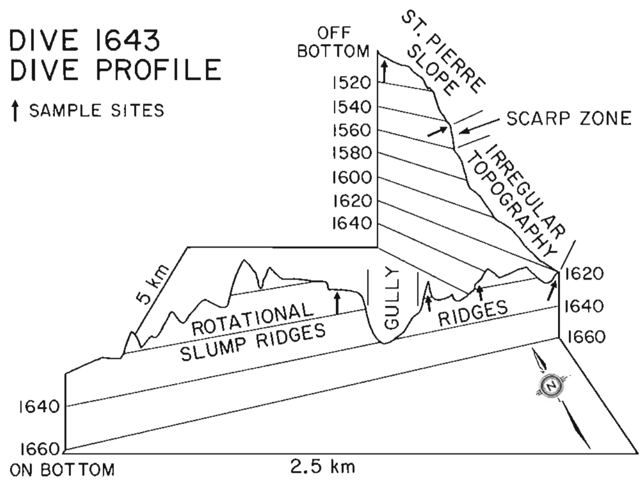

Figure 5.17. Profile of dive 1643 showing geologic terrains (based on submersible pressure depths).

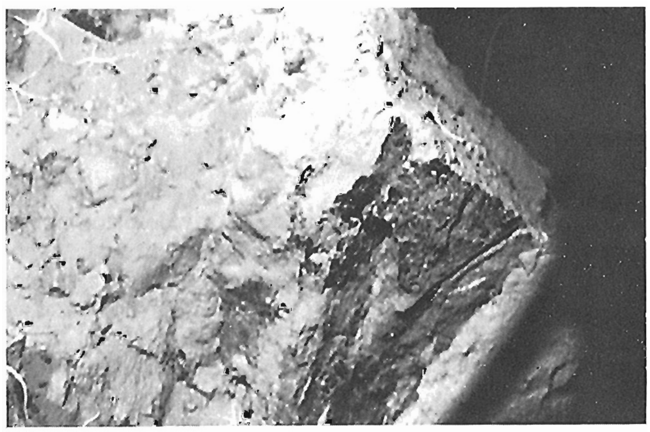

Figure 5.18. Outcrop of mudstone on crest of rotational slump ridge on St. Pierre Slope, dive 1643 (1643-S13).

crossed (Fig. 5.16). The dive then traversed upslope across irregular terrain onto the smooth St. Pierre Slope at about 1490 m water depth.

Six geomorphic regions are distinguished on the basis of the sidescan images and dive logs (Fig. 5.17).

Rotational slump ridges

Seven discrete ridges were crossed. The ridges had an amplitude of 5 to 15 m, were spaced 200 m apart, and consisted of fresh outcrops of red and green mudstone, with some bedding inclined at up to 60°. Fresh failure surfaces were observed, with displaced angular mudstone blocks and yellow staining on exposed faces (Fig. 5.18), suggesting that the outcrops are eroding today. Between the ridges were low regions of irregular relief of 50 to 100 cm amplitude, of intensely bioturbated, randomly oriented mud blocks. A series of blocks were seen that demonstrated the transition from fresh failure, through progressive degrees of biodegradation to intensely bioturbated mud mounds. Similar ridges continued to the east of the gully, but became more subdued and died out before the northern leg of the dive.

Smooth region

A low relief zone of seafloor was crossed between the area of rotational slump ridges and the gully. This corresponds to the north-south oriented featureless region west of the gully on the sidescan images (Fig. 5.15). There was no outcrop and the only relief features were smooth, 20-cm-high mounds.

Gully

The floor of the gully was reached below a 20-m drop over a series of steep cliffs which did not show any outcrop. The floor of the gully was smooth and muddy, with a conspicuously low faunal density. Low relief lineations oriented NNW-SSE were recognized.

Irregular topography

A transition from slump ridges to poorly defined irregular topography occurred east of the gully. The irregular topography was similar to the slump ridge terrain in that it consisted of alternating regions of ridges (though with little outcrop) and low areas, but relief was more subdued. The ridges were more rounded and the regions of subdued bottom more extensive. The irregular topography continued up slope to 1560 m where the gradient steepened.

Scarp zone

From 1560 to 1540 m fresh outcrop was again observed. This was the steepest section of the dive, and corresponds to the upper limit of a distinctive topography interpreted on the sidescan images as due to creep. A series of steep faces were traversed, one of which demonstrated outcropping red mudstone with bedding dipping at 60° to the northwest. This zone is interpreted as the headwall scarp of the rotational slump zone.

St. Pierre Slope

The lower part of St. Pierre Slope, just above the scarp zone, has irregular rounded hummocky topography with a relief of up to 2 m. Possible similar irregularity was seen on dive 1642 just above the steep eastern wall of St. Pierre Valley. Upslope, the roughness decreased, and the bottom above 1500 m was flat. The origin of the hummocky bottom is unclear.

DISCUSSION AND CONCLUSIONS

The outcrops and talus slopes observed on all the dives indicate that the region has experienced recent extensive mass wasting. On steep valley walls and headwall scarps, the fresh outcrops suggest that occasional mass wasting is continuing. This is in contrast to the heavily bioturbated rotational slump observed in dive 1643, which was inferred to have formed during the 1929 event. The PISCES observations did not provide clear evidence for the amount of failure in Eastern Valley. The cable that was found on Dive 1641 indicated that the major scarps and terraces of the erosional valley floor were probably present before 1929, and that mass wasting was restricted to the failure of large blocks from these scarps. The erosional scarp terrain on Dive 1640 gave the appearance of much more extensive failure.

The PISCES observations provide supporting evidence that the "thumbprint" terrain on St. Pierre Slope represents rotational slumps, probably dating from the 1929 earthquake. The relief in this area, however, was unexpectedly muted; deposition of sediment either during the 1929 event, or subsequently as a result of bioturbation, has infilled the depressions and rounded most of the ridges. Thus useful seabed observations were restricted to the rare outcrops. To the northwest, the smaller scale "wrinkles" were observed to consist of low ridges, but useful clues as to their origin were not seen.

Outcrops on the St. Pierre Valley and St. Pierre Slope consisted almost entirely of mudstone; coarse clasts were rare either in outcrop or as an erosional or mass wasting lag. In contrast, there were extensive outcrops of Pleistocene pebbly mudstone in Eastern Valley to water depths of at least 2000 m. These may reflect a major supply of glacial detritus through the Laurentian Channel; it is not known whether they are mass flow deposits, ice rafted facies, or (on the uppermost slope) true tills. They correspond to a seismic facies of incoherent reflections beneath the uppermost part of Eastern Valley described by Meagher (1984). The pebbly mudstones, with clasts up to boulder size, provide a source for the widespread coarse clasts recognized in Eastern Valley (Hughes Clarke, 1987).

The observations on the suspected gravel waves were inconclusive. They appear to overlie irregular topography eroded into Pleistocene pebbly mudstones. They were constructed of apparently locally-derived clasts, reworked into asymmetric dune-like features. The main gravel-wave fields of Eastern Valley were beyond the depth range of PISCES IV.

REFERENCES

Bentley, S.P. and Smalley, I.J.
1984: Landslips in sensitive clays; in Brunsden, D. and Prior, D.B. (eds.), Slope instability; New York, J. Wiley, p. 457-490.

Dewey, J.W. and Gordon, D.W.
1984: Map showing recomputed hypocenters of earthquakes in the eastern and central United States and adjacent Canada; U.S. Geological Survey, Miscellaneous Field Studies, Map MF-1699.

Doxsee, W.W.
1948: The Grand Banks Earthquake of November 18, 1929; Publications of the Dominion Observatory Ottawa, v. 7, no. 7, p. 323-335.

Heezen, B.C. and Ewing, W.M.
1952: Turbidity currents and submarine slumps and the 1929 Grand Banks earthquake; American Journal of Science, v. 250, p. 849-873.

Heezen, B.C. and Drake, C.L.
1964: Grand Banks slump; American Association of Petroleum Geologists Bulletin, v. 48, p. 221-225.

Hughes Clarke, J.E.
1987: Surficial morphology of Eastern Valley, Laurentian Fan; Geological Survey of Canada Open File 1425.

LaRochelle, P., Changon, J.Y., and Lefebvre, G.
1970: Regional geology and landslides in marine clay deposits of eastern Canada; Canadian Geotechnical Journal, v. 7, p. 145.

Masson, D.G., Gardner, J.V., Parson, L.M., and Field, M.E.
1985: Morphology of Upper Laurentian Fan using GLORIA long-range side-scan sonar; American Association of Petroleum Geologists, v. 69, p. 950-959.

Meagher, L.
1984: Interpretation of Quaternary and upper Neogene seismic stratigraphy on the continental slope off St. Pierre Bank; Geological Survey of Canada, Open File 1077.

Piper, D.J.W., Sparkes, R., Mosher, D.C., Shor, A.N., and Farre, J.A.
1984: Seabed instability near the epicentre of the 1929 Grand Banks Earthquake; Geological Survey of Canada Open File 1131.

Piper, D.J.W., Shor A.N., Farre, J.A., O'Connell, S., and Jacobi, R.
1985: Sediment slides and turbidity currents on the Laurentian Fan: Side-scan sonar investigations near the epicenter of the 1929 Grand Banks earthquake; Geology, v. 13, p. 538-541.

Syvitski, J.P.M., Fader, G.B., Josenhans, H.W., MacLean, B., and Piper, D.J.W.
1983: Seabed investigations of the Canadian east coast and arctic using Pisces IV; Geoscience Canada, v. 10, no. 2., p. 59-68.