MID-RANGE SIDESCAN AND 4.5 kHz SUB-BOTTOM PROFILER SURVEY OF MASS-MOVEMENT FEATURES, SCOTIAN SLOPE AT 61°40'W

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Abstract

A 50 x 50 km area of the Scotian Slope just west of Verrill Canyon was surveyed using Sea MARC II, a deeply-towed sidescan sonar with a 5 km swath width and a 4.5 kHz sub-bottom profiler. In the study area, the slope is generally smooth, with a gradient of about 2.5°; it is crossed by only two small valleys, a few hundred metres wide and 100 m deep. Two exploratory wells (Acadia K-62 and Shubenacadie H-100) have been drilled on the upper slope in this area.

Much of the seabed shows surficial slumping or sliding, which has resulted in the removal of the top 10 - 20 m of sediment. A series of slide scars have been left that give the seabed a step-like morphology. Two debris flows extend from the 600 m isobath to about 1800 m, where they thin out. Streamlined erosional depressions are found near the downslope edge of the debris flows, cutting both the flow and the downslope sediment: they may be produced by a turbidity current associated with the debris flows.

This widespread sediment failure on relatively low slopes was probably the result of a large earthquake: this event can be dated from cores as between 5000 and 12000 y B.P.

This open file consists of a photographic mosaic of sidescan images, selected larger-scale sidescan records, and examples of sub-bottom profiles, together with an explanatory report.

Introduction

Purpose

The work reported here is part of project 6.1.3.2, Seabed Stability on the Continental Slope, within the Department of Energy, Mines and Resources, Energy Research and Development program. The objective of this project is to identify and where possible alleviate geological constraints to production of hydrocarbons from the offshore.

Under the objectives of this project, detailed studies are being made in areas of present hydrocarbon exploration and areas of demonstrable seabed instability. One such area is the Scotian Slope between 61° and 62°W, in which the exploratory wells Acadia K-62, and Shubenacadie H-100 have been drilled.

The purpose of the sidescan survey was to investigate the style, and to map the extent of seabed instability features, particularly slumps, slides and debris flows. From these data, experiments to determine both the age of such features and their geotechnical properties will be designed and carried out. The reasons why particular types of instability occur in particular settings will be evaluated, and the results used to pred slope stability.

Geological Setting

The eastern part of the Scotian Slope (Fig. 1), as far west as longitude 61°30'W, is highly indented by submarine canyons. In contrast, the western part of the Scotian Slope has almost no large canyons, and appears smooth on large scale maps, although detailed surveys (Hill, in press) show that it is highly gullied in places.

The area studied in this survey includes the boundary between these two major morphologic regions (Figs. 1, 2) and extends from the shelf break at 200 m to about 2500 m water depth. Verrill Canyon is located in the eastern part of the study area; the western part is a relatively smooth continental slope. This western area is underlain by about 1.5 secs of evenly stratified Pleistocene sediment (Piper et al., in prep), while Verrill Canyon appears to have been the site of a major slope valley throughout the Quaternary, and shows multiple episodes of cut and fill.

Previous 3.5 kHz (Geomarine Associates, 1982) and high-resolution deep-towed sparker profiles (Piper and Wilson, 1983) from the upper slope (Fig. 3), in water depths of less than 1000 m, showed two large debris flows within the area studied. Preliminary core data (Piper and Wilson, 1983) suggest that these debris flows are of late Pleistocene or early Holocene age.

Methods

The survey was carried out using Sea MARC I (Ryan, 1982) on C.S.S. Hudson cruise 82-014. Sea MARC I is a neutrally buoyant vehicle towed about 300 m off the seafloor (Fig. 4). It is equipped with 27 and 30 kHz side-looking sonars, giving a total maximum swath width of 5 km. Acoustic backscattering in the slant range time domain is converted by real time digital processing to horizontal range and is displayed on electrosensitive graphic recorders. The depth of the vehicle is measured with a semi-conductor strain gauge and altitude is detected with a 4.5 kHz subbottom profiler. The vehicle has instrumentation to determine its heading, speed through the water and its acoustic slant range from the surface ship, which allows vehicle position to be reconstructed from ship navigation data. A mosaic of the sidescan images recorded was constructed at a scale of 1:40,000.

Ship navigation was by hyperbolic Loran-C, which gives fixes good to ±100 m in the survey area. Unfortunately the ship's 3.5 kHz sounder was inoperative during most of the survey, and hence ship-vehicle ranges were not possible. Wire-out readings were used to estimate ranges during the survey.

Correlation of sub-bottom acoustic reflectors

The 4.5 kHz Sea MARC I sub-bottom profiles have been correlated with 3.5 kHz profiles and high-resolution deep-towed sparker profiles from previous cruises (Fig. 3) to develop a seismic stratigraphy for more than half of the study area. Five key reflectors, termed orange (O), green (G), yellow (Y), red (R) and pink (P) have been identified and correlated. The sub-bottom depths of these reflectors at selected points within the study area are given in Table 1, and they are illustrated in the plates.

Observations

Introduction

The sub-bottom profiler data shows that much of the seabed in the area studied comprises conformably stratified sediments that dip gently to the south at about 2.5°. Locally, the stratified sediments show steep dips of up to 10° that are usually oblique to the regional dip. Some of these steeply-dipping areas form the walls of flat-floored valleys approximately 500 m wide. These are filled with acoustically poorly stratified sediment, interpreted as either debris flow or sand. These valleys generally trend

SSE. In the southwestern part of the survey area there are several small relatively straight channels, only 50-100 m wide, that have relief of 2-3 metres.

Over much of the study area, the upper 5 to 20 m of the stratified sediment sequence is missing. Individual horizons terminate in step-like escarpments. This "stripped-off" morphology results from submarine sliding. In the southeastern part of the study area, much thicker sediment sequences are missing, and there are erosional scarps with escarpments up to 50 m high.

Two debris flows have deposited sediment up to 20 m thick over parts of the stripped-off morphology. The flows are each some 10 km wide, and pinch out down-slope, disappearing at about the 1800 m isobath. They partly fill some of the adjacent valleys.

In the following section of this report, each class of feature recognised in sidescan or sub-bottom records is described individually. Then a synthesis of the late Quaternary geologic evolution of the region is attempted.

Major valleys in southwestern survey area

Two major valleys trend SSE across the southwestern part of the survey area (Fig. 5), and are informally named the West Acadia and East Acadia valleys. Both have somewhat sinuous courses and, over much of their length, have an asymmetric valley cross-section with a steep eastern wall some 50-150 m high and a low western levee about 1 km wide with a crest 20-50 m above the valley floor (Plates 6 and 17). A third smaller valley with a symmetric cross-section lies between East and West Acadia valleys (Plates 11, 12). It dies out in about 2100 m water depth. Other small valleys (Plate 14) lie west of West Acadia valley (Fig. 5).

The floor of the West Acadia valley appears highly reflective as if floored with sand. The southern part of the valley is much more symmetric in cross section than the northern part. In most crossings of the East Acadia valley the surficial fill has the rough acoustically transparent character of debris flow deposits (Plates 7, 8 and 17). Its steep eastern wall is somewhat gullied and in places has thin debris flow deposit draped over it (Plate 2). The East Acadia valley appears to die out in water depths of around 2500 m.

Small channels in the southwestern of the survey area

Three gently sinuous narrow channels have been mapped west of the West Acadia valley (two, termed A and B, are shown in Fig. 5). These channels are 50-100 m wide and 1-3 m deep (Plate 1). At one point two channels appear to join (Fig. 5 and Plate 15). They are barely resolved by the 4.5kHz sub-bottom profiler flying 300 m off the bottom (Plate 6). The underlying reflectors appear continuous and no sub-bottom buried channels are seen, suggesting that the small channels may be recent features. In some places, the valleys appear to follow a break in slope on the back-side of a low levee (Plates 8, 16). Neither the origin of the small channels, nor the relationship between these features and the much larger valley and channel topography to the east is clear. Small channels are well resolved on side-scan sonar (Plate 1), although relief is very low, suggesting steep walls. They parallel, rather than feed, the major valleys. They consist of straight segments 2 to 3 km long, relatively sharp bends, and broader, more sinuous turns. The only targets of similar clarity or continuity are escarpments, which are generally contour-parallel. The small channels, however, are not one-sided, nor do they bear any obvious relationship to debris flow or slump distribution.

Stripped-off morphology

Over more than half the survey area, the upper 5-20 m of stratified sediment has been removed to yield a terraced, "stripped-off" morphology which is in places overlain by debris flow deposits. Scarps formed by the removal of sediment are generally relatively linear and are although dominantly facing downslope some are oriented downslope across the contours (Plate 2) and many of the largest scarps are irregular and sub-parallel to contours (Plates 1,3). Most scarps appear steep in both sidescan and sub-bottom profiles (Plates 17, 21, 23).

Sub-bottom reflectors have been correlated in the area east of East Acadia Valley, to produce a map showing the horizons exposed as a result of the sliding (Fig. 6). Within the mapped area of Figure 5, approximately 3.5×10^9 m^3 of sediment have been removed. The correlation cannot be extended with certainty to the southwest of East Acadia valley. Estimates of sediment removal in this area, and at other localities within the survey area not imaged by Sea MARC suggest a minimum loss of sediment of 10^{10} m^3.

It is possible that some areas that we have interpreted as residual sediment surrounded by slide scars are in fact slide blocks. For example, the block illustrated in Plate 1 could be allochthonous. The sub-bottom profile (Plate 13) is consistent with either interpretation.

Debris flows

Two large debris flows cover about half the study area (Figs. 5 and 7). Their upslope limit is not seen in sidescan sonar images, but 3.5 kHz profiles (Piper and Wilson, 1983) suggest they originate from short upper-slope gullies. They overlie the stripped-off morphology (Plates 20, 23) and in places infill and mask shallow valleys (Plate 28). Their thickness and surface roughness is dependant on local gradients (Plate 22). Sets of long, sinuous, sub-parallel ridges (resembling straight-crested ripples but probably pressure ridges) occur in many places on the debris flow surface. Typically, they are 1-2 m high, with a wavelength of 50 m. Generally they are parallel to contours (transverse to flow direction); at debris-flow margins they ted to swing round and become sub-parallel to the margin (Plate 4). Elsewhere, the debris flows have a less regular surface roughness; over topographic highs where the debris flow is thin, the surface often appears smooth. Blocks up to 25 m wide occur on the shallowest parts of the debris flows. In places, the margins of the flows are confined by scarps of the stripped off morphology; elsewhere, they thin at their margins on low gradients (Plates 18, 19, 21, 26). The western debris flow has spilled over into the East Acadia valley, and thins out downslope at around the 1800 m isobath.

The debris flows are generally 5 to 20 m thick (Fig. 7). They are thickest on the upper slope near the mouths of steep, upper-slope gullies that open out in about 800 m water depth. Elongate thick tongues extend downslope from these gullies (Fig.9). The debris flows gradually thin downslope. This may represent a decrease in the amount of sediment deposited rather than the failure of the flow to reach the area, since flow remnants occur in much deeper water in East Acadia valley. The total volume of debris flow deposits is approximately 5×10^9 m^3.

Streamlined erosional depressions

The western debris flow deposit gradually pinches out near ≈ 1800 m. The seafloor in this region is marked by groups of closed, downslope-trending streamlined erosional depressions (Plates 2,3). Their plan view size and shape varies considerably, but everywhere they have flat floors and are only a few metres deep. The largest ones are over 2 km long and 700 m wide. The smallest identifiable on 5-km-swath Sea MARC I records are <10 m wide. Length to width ratios range from 20 to less than 2 with 4 being most common. Their margins at the up- and down-slope ends are generally pointed, but some show subrounded to complexly indented patterns. Several of the streamlined depressions display two erosional levels in their floor with one closed depression within another. It appears that both the thinnest portion of the debris flow (Plate 24) and the acoustically well-bedded slope immediately seaward (Plate 10) are cut by the depressions. A field of the streamlined depressions abruptly terminates at the headwall of a sediment detachment scar (Plate 3). Their group association, elongate downslope shape, sharply defined bounding walls and lack of identifiable debris downslope seems to preclude a simple downslope sliding mechanism of formation. Instead, their streamlined form and orientation suggests that they are eroded by downslope-traveling currents. Their morphology implies that these currents selectively scour away easily eroded sediments. When a more resistant level is reached, erosion spreads laterally producing in flat floors.

Large slump features in the southeastern part of study area

In the south-east of the study area, both downslope from the eastern debris flow and near the edge of Verrill Canyon, large arcuate slump scars are common (Fig. 5). One complex zone of slump scars is U-shaped in plan (4 km wide, 10 km long), with marginal escarpments 50-150 m high (Plate 27). It is locally floored by reflective sediments, or by debris flow deposits, and appears to have a small valley leading to its upstream end. It may be a partially filled tributary of Verrill Canyon, or may be an elongate retrogressive slide (Prior and Coleman, 1982).

One sub-bottom profile shows stratified sediment at the base of a low scarp with asymmetric waves (Plate 30): a feature that Hill et al. (1983) suggest as evidence of creep.

Gullied Morphology

In the northeastern part of the study area, between water depths of 700 and 950 m, there are a series of flat-floored valleys separated by steep, sharp-crested ridges some 150 - 300 m high and 0.5 - 1.5 km wide (Plates 5, 29). Sidescan images indicate that the valleys are fed by side gullies up to 1 km long that extend up to the crest of the ridges. Similar intercanyon ridges have been found both on the Atlantic slopes of Europe (Kenyon et al., 1978; Belderson and Kenyon, 1976) and the middle-Atlantic slopes of the U.S.A. (Farre et al., 1983).

The presence of sharp-crested intercanyon divides indicates that the entire slope in this region has been subjected to erosion. In places where canyons are not spaced sufficiently close, or entrenched sufficiently deep, gently seaward-dipping flat-topped mesas separate adjacent canyons. The side gullies that feed the main canyon are ascribed to headward erosion through a variety of mass-wasting processes. The resulting morphology resembles the badland topography of the southwestern United States.

Zones of steeply-dipping stratified sediment

Zones of steeply dipping stratified sediment are illustrated in plates 9 and 22. In sparker seismic reflection profiles, the sediment in these zones appears draped over an irregular surface 70-100 msec subbottom. High resolution multichannel seismic lines show that these zones have no significant deeper sub-surface expression. Many steeply-dipping zones are paired with an opposite facing slope or inflection, suggesting an original valley form.

Sub-bottom profiles in the area between the East and West Acadia valleys show evidence for leveed valleys a few hundred metres wide that are nowburied beneath 5-20 m of stratified sediment (Plate 13). Their morphology is similar to the small valley seen at the surface (Plates 11, 12). Similar buried features (Plate 25) occur east of East Acadia valley. Correlation between Sea MARC and other high resolution lines allows a tentative correlation of these various inferred buried valleys (Fig. 9). This shows that there may have been, at about 70 msec sub-bottom, a set of parallel downslope gullies, a few hundred metres wide and with an average spacing of 3 km. East and West Acadia valleys are the only gullies that have maintained themselves as continuous sediment conduits since that time. However, several large slump scars on the lower slope (Fig. 5) have developed along these buried gullies.

Discussion and synthesis

Stratigraphic Setting

Both high-resolution deep-towed sparker profiles and piston cores are available from the northern part of the survey area (Piper and Wilson, 1983). The sparker profiles show that the uppermost 100 msec of sediment are generally well stratified, except for the surface debris flows and some debris flows about 50 msec sub-bottom. Both the valleys and the upper slope gullies that lead to the debris flows are eroded into these stratified sediments.

Four lithostratigraphic units are recognised in piston cores (Piper and Wilson, 1983). The upper unit 1 of olive-grey mud is generally less than 2 m thick, and rests on about 2 m of brownish muds and sandy muds of unit 2.

Lithostratigraphic unit 1 and part of 2 rest on stiff, inpenetrable muds of the eastern and western debris flows. In the undisturbed section, thin red-brown muds in unit 2 may be the lateral equivalent of the debris flows.

In core 1, from the undisturbed section between the two debris flows, the base of unit 1 is marked by a change in foraminifera present, with an increase in sinistral _Neogloboquadrina_ _pachyderma_ and _Elphidium_ _excavatum_ f. _clavata_ passing from unit 1 to unit 2. Further west, at longitude 63°15'W, Hill (1981) found a similar faunal change in slope sediments. Three ^{14}C dates suggest an age between 5000 y B.P. and 8500 y B.P. for the faunal change. At about 5 m depth in core 1, beneath unit 2, a transported mollusc shell gave an age of about 12000 y B.P.

This stratigraphic control suggests that the main debris flows have an age between 5000 and 12000 y B.P., with the most probable age being in the middle of this range. Holocene unit 1 has a low sedimentation rate between 5 and 50 cm per 1000 years, and has a ponded configuration. Late Pleistocene unit 2 has a sedimentation rate of the order of 1 m per 1000 years.

Cause of the sliding and debris flows

Seismic reflection profiles show that large debris flows and sliding of surface sediment are not frequent events within the stratigraphic sequence of the study area. The slide scars and the debris flows are both surface features, which are not covered by an acoustically detectable thickness of younger sediment. Bedding plane slides occur over an area of at least 50 x 50 km, in water depths of 800 to 2500 m, and on gradients as low as 2.5°. This sliding is therefore not the result of oversteepening by valley undercutting, nor of cyclic loading by waves on the upper slope. It is most probably seismically triggered.

No large slump scars have been recognised on the upper slope that might be sources of sediment to the large debris flows although there could have been widespread shallow creep failure. The volume of the debris flows is similar to the volume of stripped-off sediment in the same area. These observations suggest that the debris flows consist largely of material derived from sediment slides that has flowed downslope.

Debris flows and turbidity currents

The streamlined erosional depressions (scours) that have modified the downslope margin of the western debris flow and the seabed further downslope are probably the result of powerful downslope currents. Hampton (1972), on the basis of theory and model experiments, predicted that some subaqueous debris flows should transform into turbidity currents. The scours provide evidence that such a process has occurred.

Morphology of the slope prior to slumping and debris flows

Quaternary sediments are about 1 km thick within the study area.

There was a large slope valley on the site of the present Verrill Canyon throughout the Quaternary, while within the study area a well-stratified, prograding slope sequence accumulated with no major valleys. At 50-100 msec sub-bottom (close to the limit of penetration with the sparker system), there is an irregular surface which appears to be the top of a debris flow on the upper slope. On the mid-slope, it shows a series of gullies with about 3 km spacing. Later sediments appear evenly draped over this surface, so that its morphology can still be recognised at the seabed. Only East and West Acadia valleys have maintained themselves as distinct valleys, with erosional valley walls and levees.

Holocene sediments form only a veneer that is generally less than 2 m thick over the study area, and are thickest in ponded depressions. The upper part of the draped sequence that has been cored comprises periglacial muds, with a sedimentation rate of about 1 m per 1000 years.

Conclusions

Between 5000 and 12000 y B.P., a large earthquake appears to have caused widespread surface sediment failure over an area 50 km by 50 km on the Scotian Slope west of Verrill Canyon. Over large areas, the upper 10-20 m of sediment slid away, leaving a distinctive step-like seabed morphology. Much of this sediment moved downslope in two large debris flows which thin downslope. Turbidity currents developed from these debris flows, and scoured the lower parts of the debris flows and the seabed beyond them.

Implications for hydrocarbon exploitation

1. This study has documented the type of seabed morphology that occurs in the region between the Acadia K-62 and Shubenacadie H-100 wells and its implications with respect to seabed stability. Despite the low slope of 2.5°, debris flows and sediment slides are widespread. Most of this movement appears to have occurred as a result of an earthquake between 5000 and 12000 y B.P. However, possibly active creep has been identified on slopes leading to Verrill Canyon, and continuous deformation can lead to mass failure.

2. The study has provided evidence for a major recent seismic event in an area previously considered seismically inactive (Basham and Adams, 1982).

3. Sliding and slumping appears to have occurred preferentially along the trend of small slope gullies, now buried 50-100 msec sub-bottom, that may represent zones having a higher risk of slumping.

Acknowledgements

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Figure Captions

Figure 1. Map showing regional setting of survey area box.

Figure 2. Generalised bathymetric map of survey area showing ship's track for cruise 82-014. Solid lines are contours with good control from side-scan images.

Figure 3. Track chart for northern part of survey area, showing ship's track for Sea MARC survey, other high-frequency seismic lines, high-resolution multichannel seismic lines, and cores. In southern part of survey area, only Sea MARC data (Fig. 2) is available.

Figure 4. Schematic configuration of Sea MARC I system.

Figure 5. Map showing principal morphologic features of the survey area.

Figure 6. Geologic outcrop map at the sea-floor, north-east of East Acadia Valley.

Figure 7. Isopach map of debris flows, north-east of East Acadia Valley.

Figure 8. Map showing inferred distribution of gullies at 50-100 msec sub-bottom.

Figure 9. Key to location of plates.

Table 1. Sub-bottom depths of key reflectors (in metres, V=1.5 km/s)

Location	A	B	C	D
Day	157	157	157	152
Time	1530	1845	1950	1950
REFLECTOR				
Surface	0	0	0	0
Orange	7			
Green	9		23	
Yellow	12		28	11
Red	18	19	37	18
Pink	25	26	?	25

Plate Captions

Plates 1-5 are selected processed orthorectified sidescan sonar images. Scale in km.

Plate 1. Small channel A; West Acadia valley and west levee; and large feature that is either a slide block, or a residual area surrounded by slide scars.

Plate 2. Slide scars in area of stripped off sediment with streamlined erosional depressions in shallow valley; East Acadia Valley; and downslope edge of western debris flow, showing flow into valley and streamlined erosional depressions.

Plate 3. Slide scar in area of stripped off sediment, just south of downslope edge of western debris flow, and streamlined erosional depressions.

Plate 4. Area of undisturbed sediment, cut by unidentified scars; edge of eastern debris flow showing orientation of surface ridges parallel to edge; main part of eastern debris flow with transverse ridge pattern.

Plate 5. Series of flat-floored valleys separated by steep, sharp-crested ridges dissected by gullies.

Plates 6-33 are selected sub-bottom profiles. Horizontal scale lines are at 10 m intervals. Vertical 15-minute time lines have an average spacing of 750 m.

Plate 6. Small valley A, showing small dimensions and lack of disruption of underlying reflectors. On the right is the western levee of West Acadia Valley.

Plate 7. East Acadia Valley showing steep east wall with outcropping strata, valley floor filled with debris flow deposits, low west levee, and stripped-off morphology with strealined erosional depressions beyond levee.

Plate 8. Area between East and West Acadia showing stripped off morphology and possible debris flow deposit.

Plate 9. Area of undisturbed stratified sediment showing draped character and the occurrence of "steps" or changes in gradient.

Plate 10. Irregular surface erosion in area showing streamlined erosional depressions in sidescan sonar records, downslope from edge of debris flow.

Plate 11. Crossing of small valley, showing stripped-off morphology. Compare with plate 12.

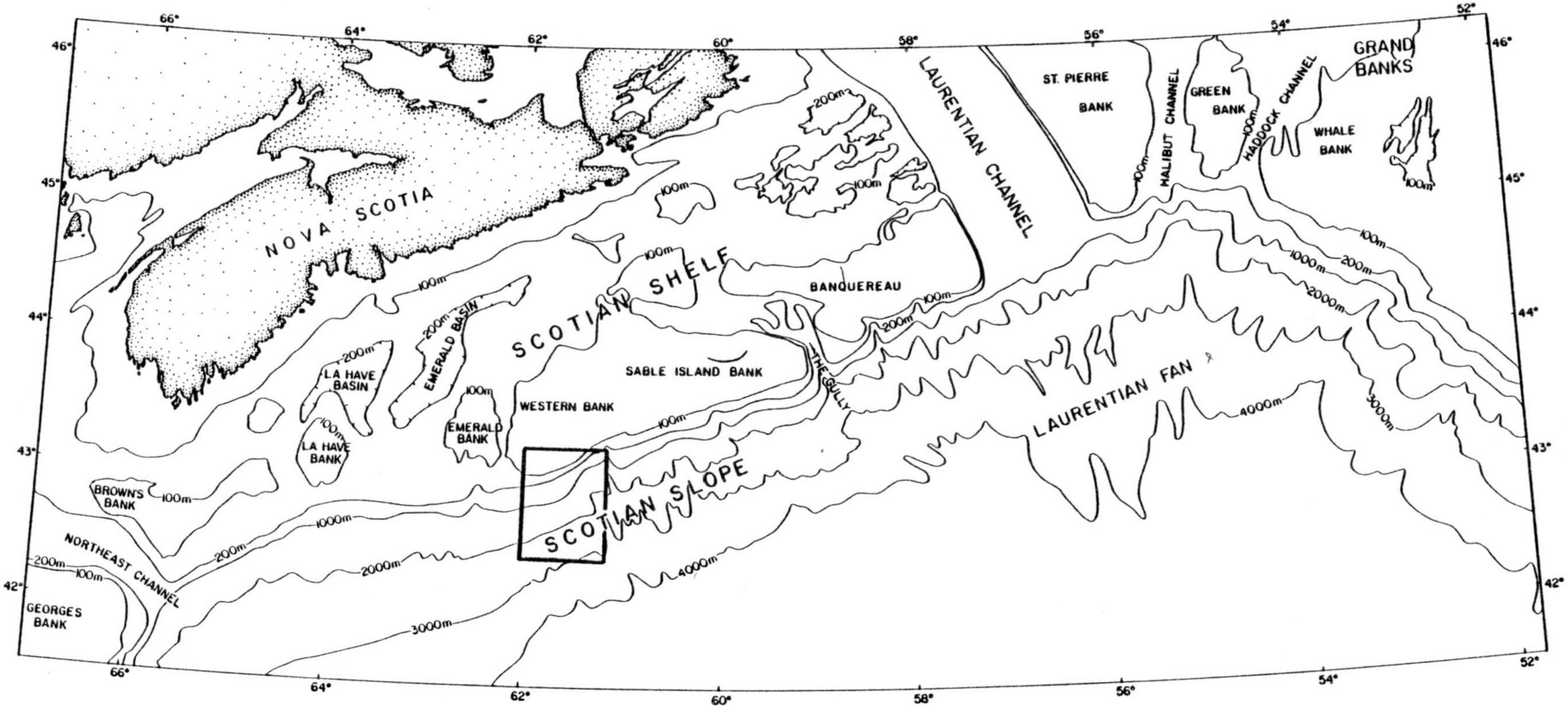
Plate 12. Small valley between East and West Acadia Valleys showing stripped-off morphology on valley walls, debris flow filling floor, and continuity of reflectors beneath the valley floor. (Note this valley crossing is upslope from plate 11.)

Plate 13. Possible buried valley, covered by stratified sediment. Surface sediment has been stripped off on NE side of section. Sediment to SW may be an autochthonous residual mass, or may be a slid block. The valley may be a former downslope continuation of the valley in plate 12.

Plate 14. Irregular surface erosion in small valley between East and West Acadia Valleys.

Plate 15. Section just downslope from bifurcation of small channel B.

Plate 16. Migration of small channel A on backside of large levee of West Acadia Valley.



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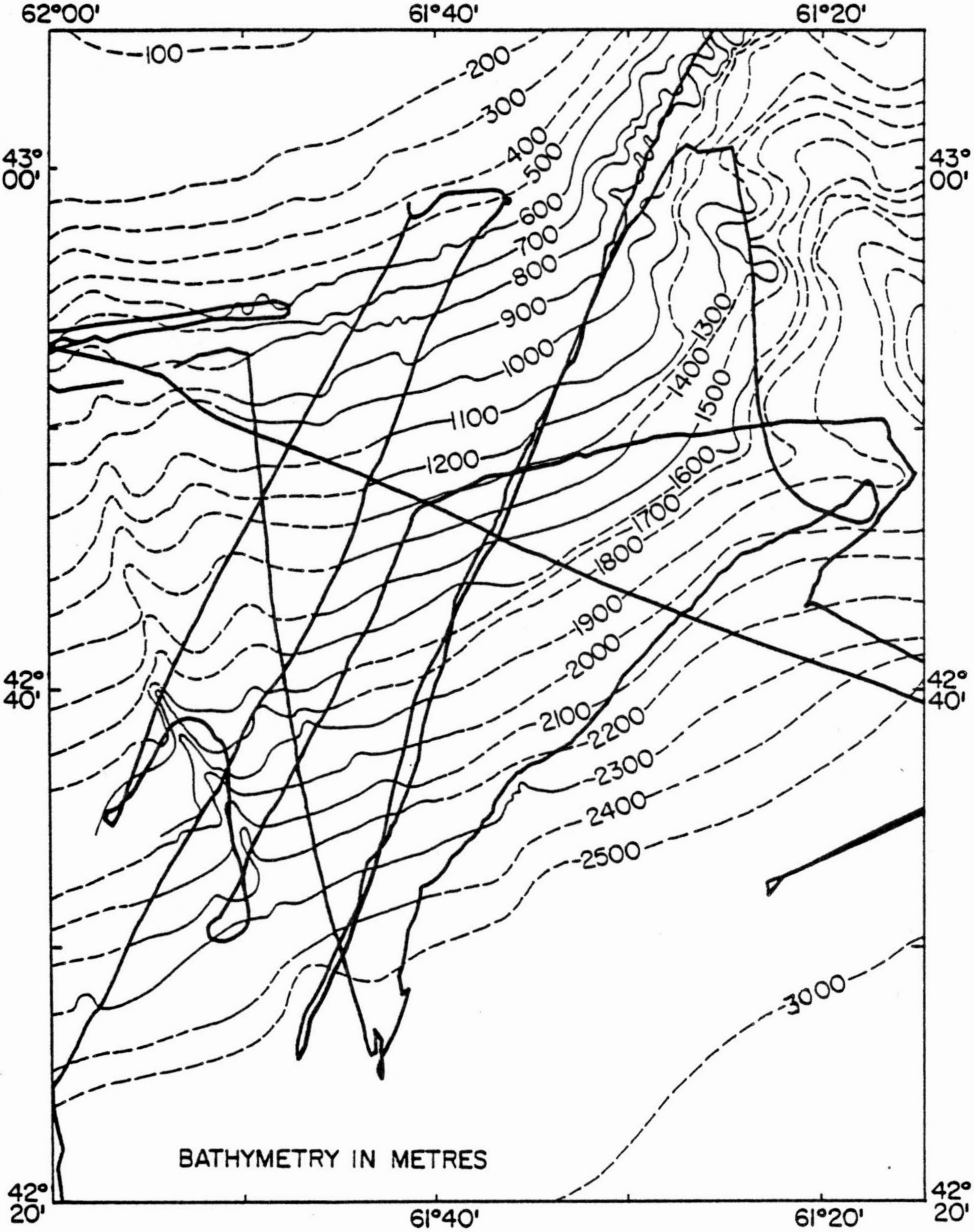

Figure 2. Generalised bathymetric map of survey area showing ship's track for cruise 82-014. Solid lines are contours with good control from side-scan images.

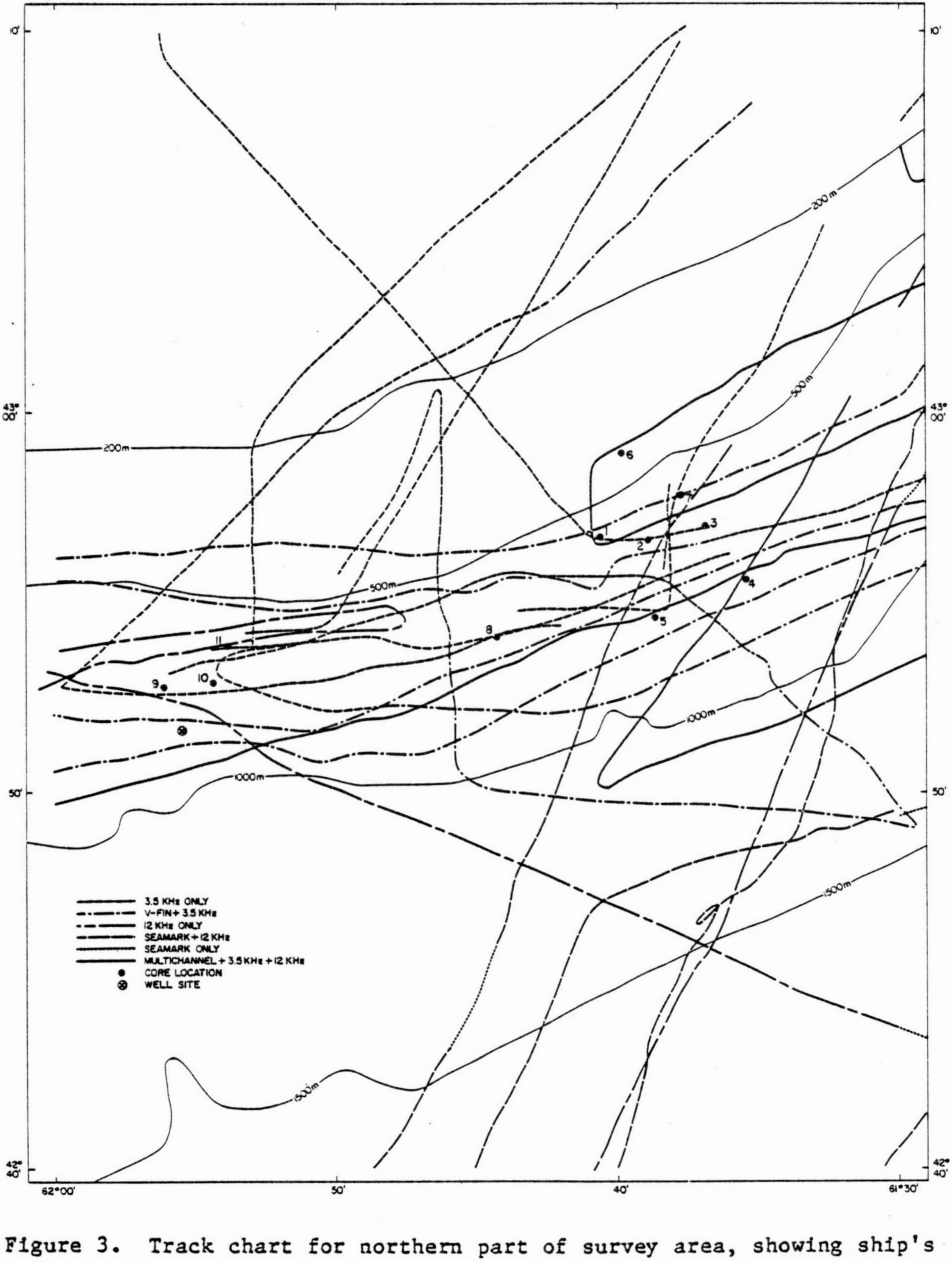

Figure 3. Track chart for northern part of survey area, showing ship's track for Sea MARC survey, other high-frequency seismic lines, high-resolution multichannel seismic lines, and cores. In southern part of survey area, only Sea MARC data (Fig. 2) is available.

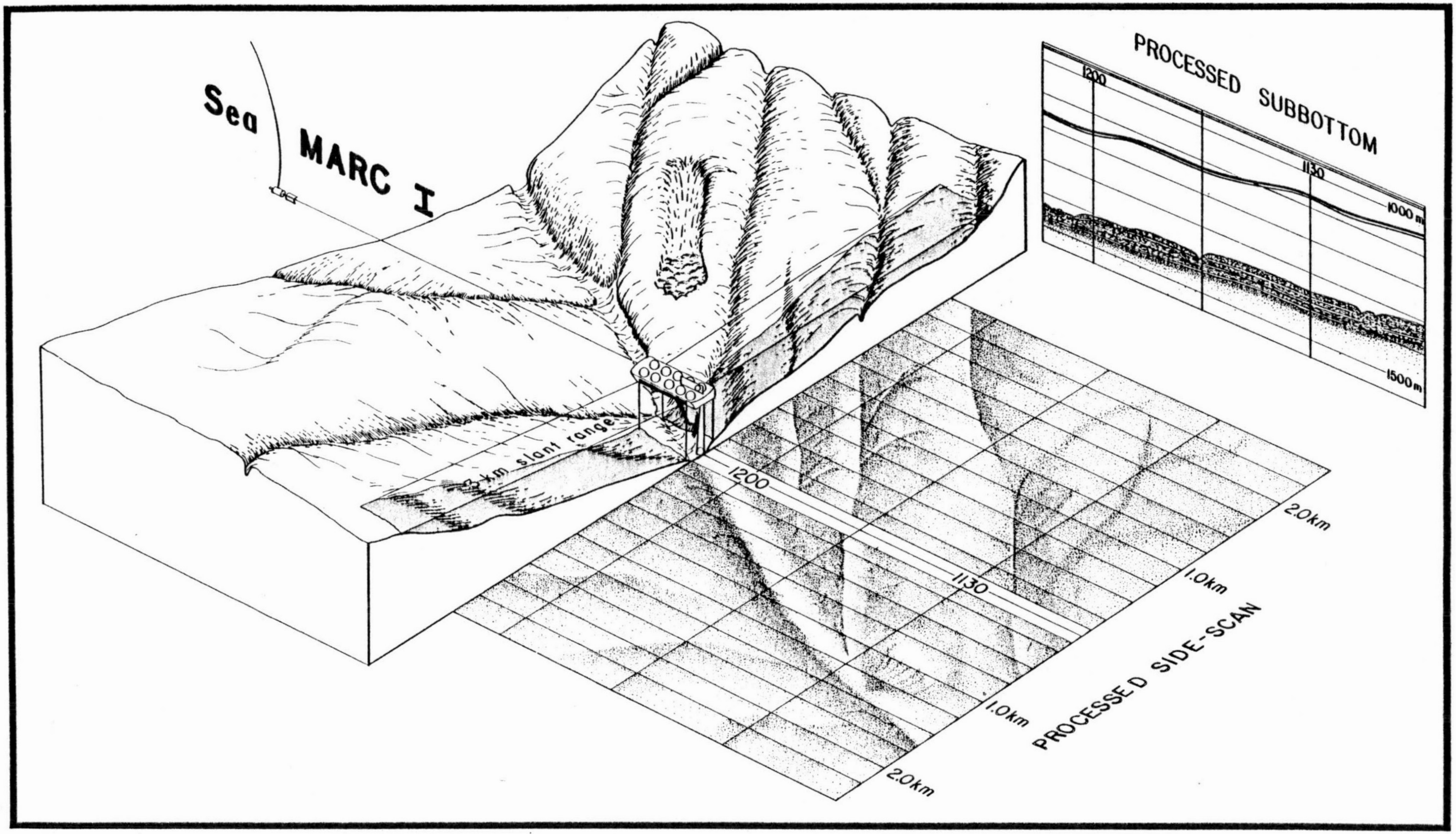

Figure 4. Schematic configuration of Sea MARC I system.

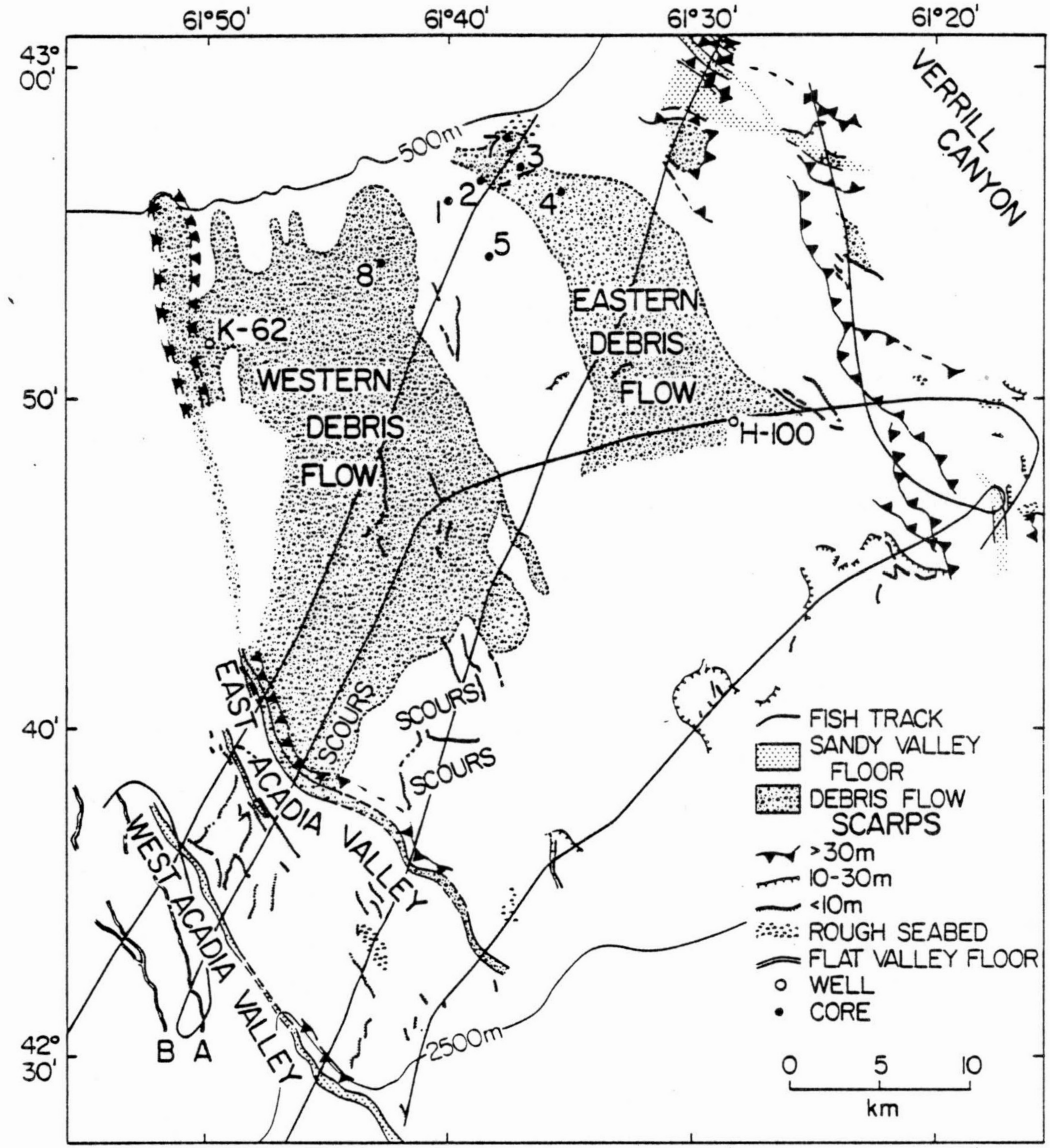

Figure 5. Map showing principal morphologic features of the survey area.

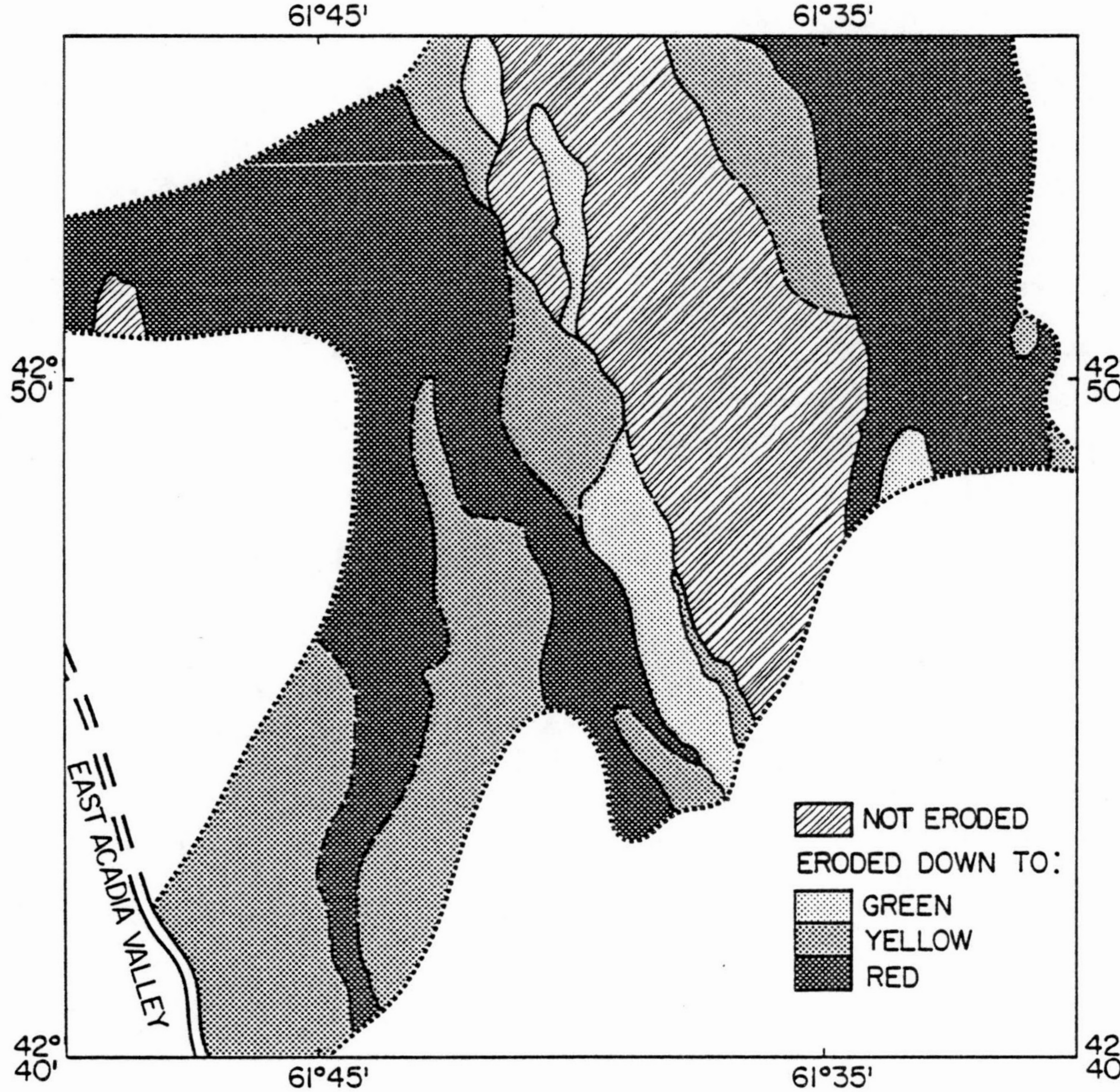

Figure 6. Geologic outcrop map at the sea-floor, north-east of East Acadia Valley.

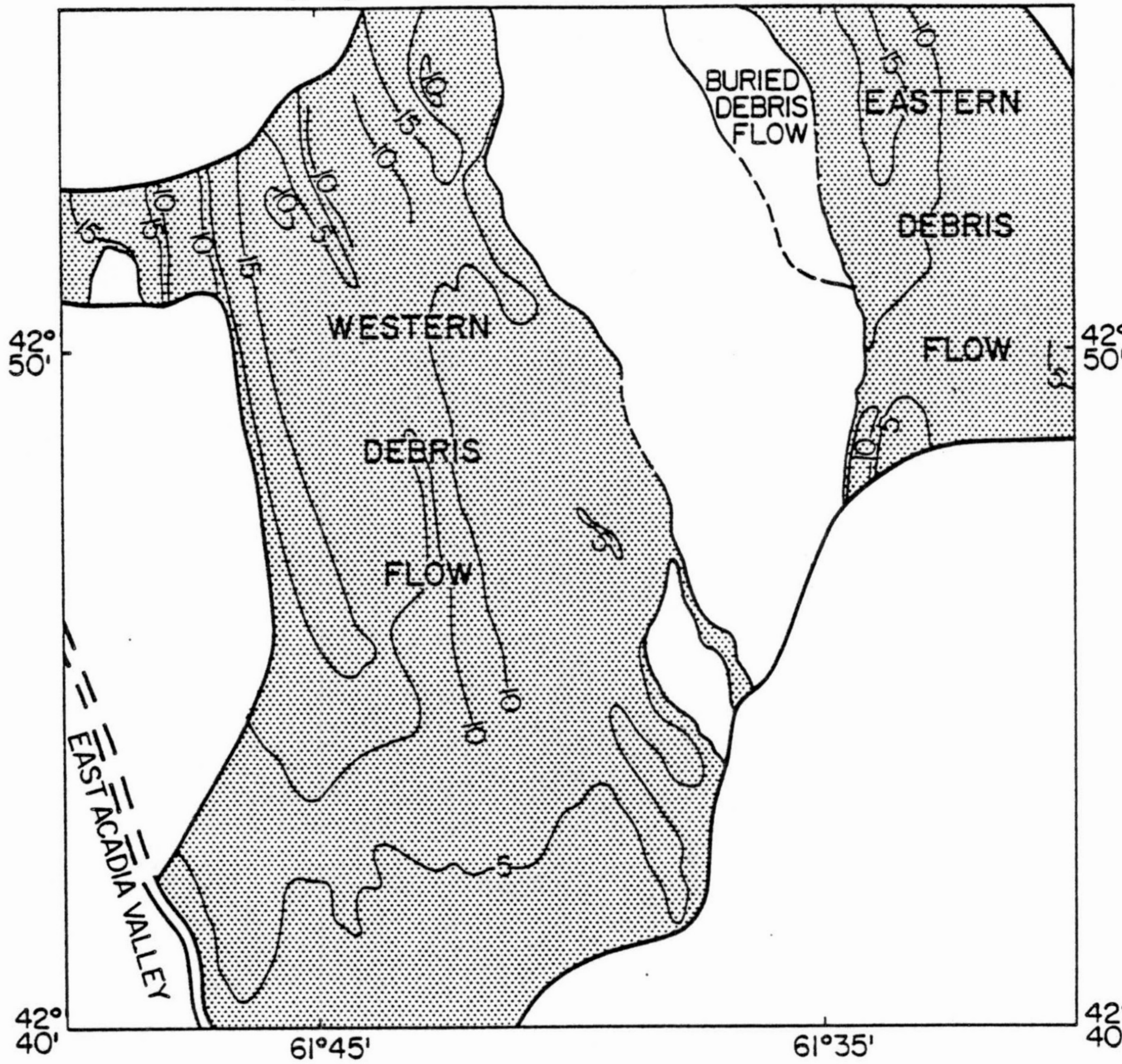

Figure 7. Isopach map of debris flows, north-east of East Acadia Valley.

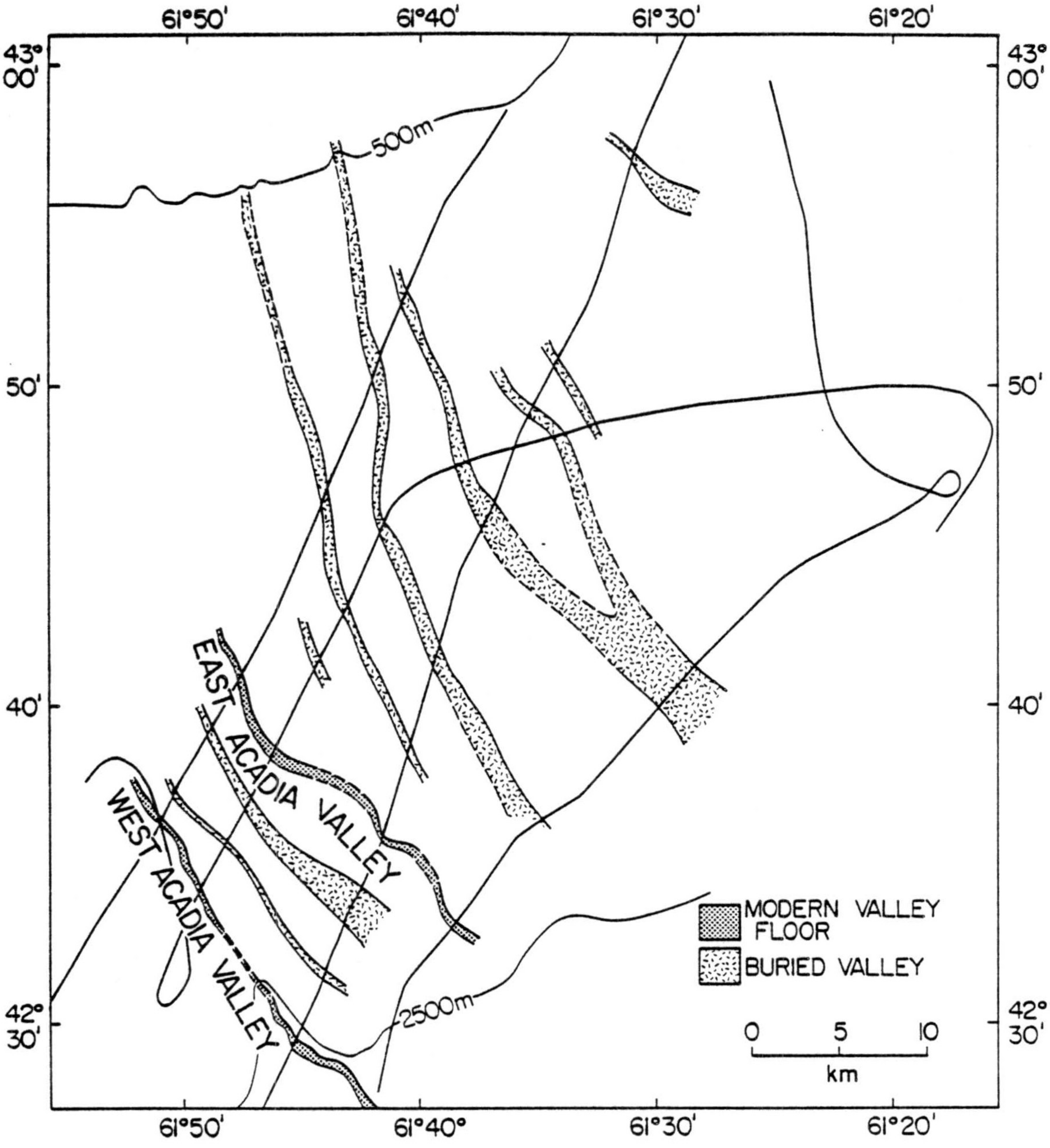

Figure 8. Map showing inferred distribution of gullies at 50-100 msec subbottom.

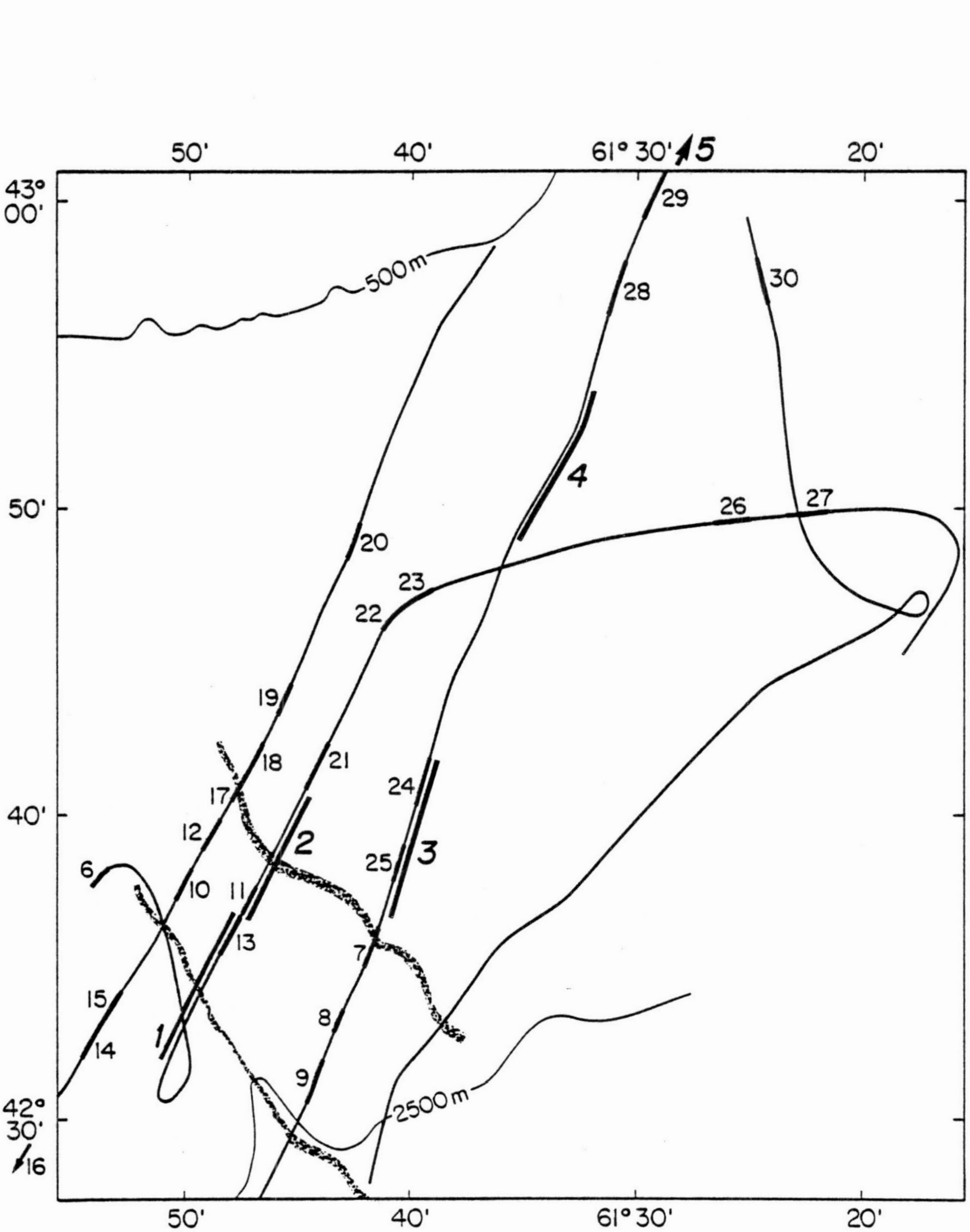

Figure 9. Key to location of plates.

Plate Captions

Plates 1-5 are selected processed orthorectified sidescan sonar images.

Scale in km.

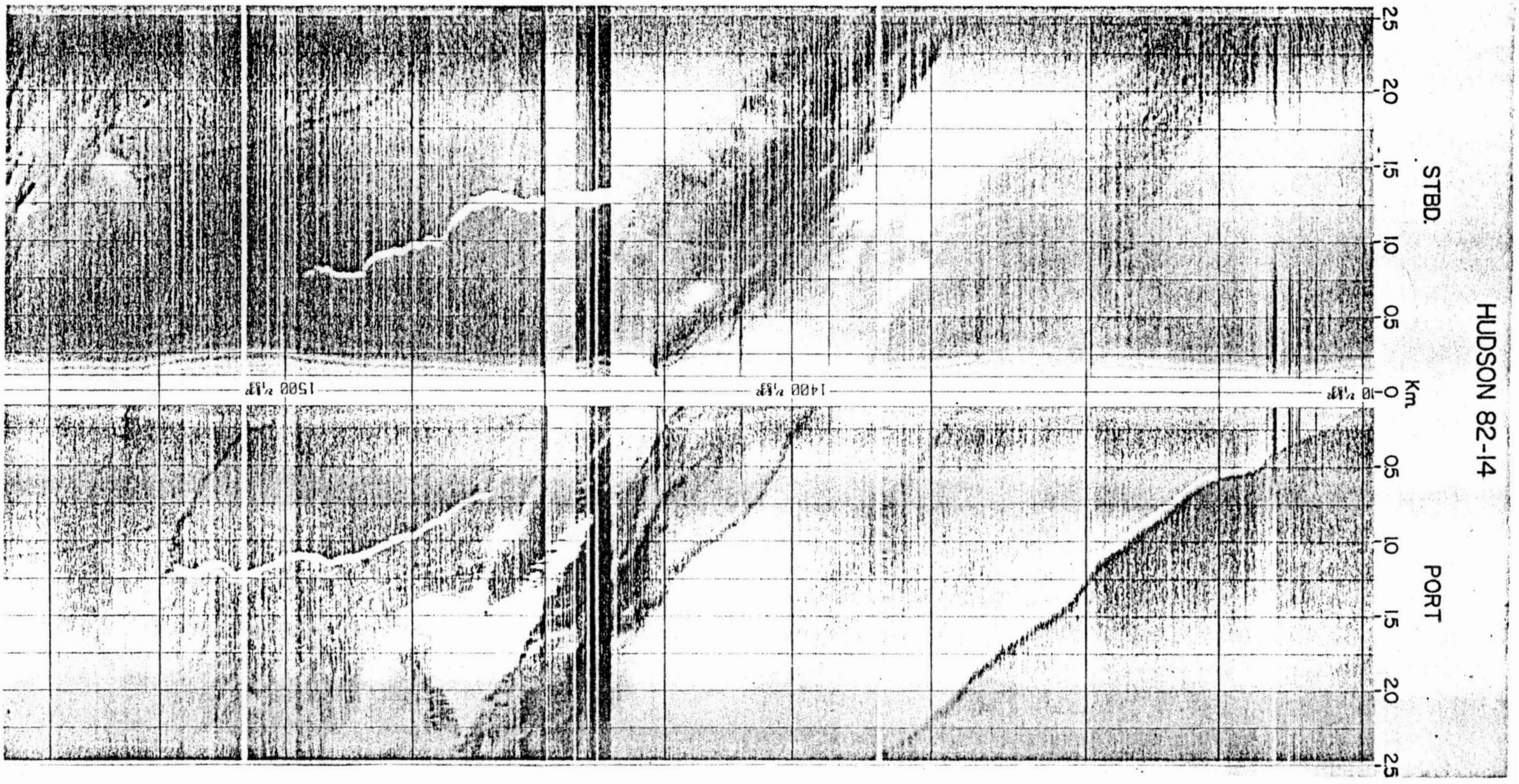

Plate 1. Small channel A; West Acadia valley and west levee; and large feature that is either a slide block, or a residual area surrounded by slide scars.

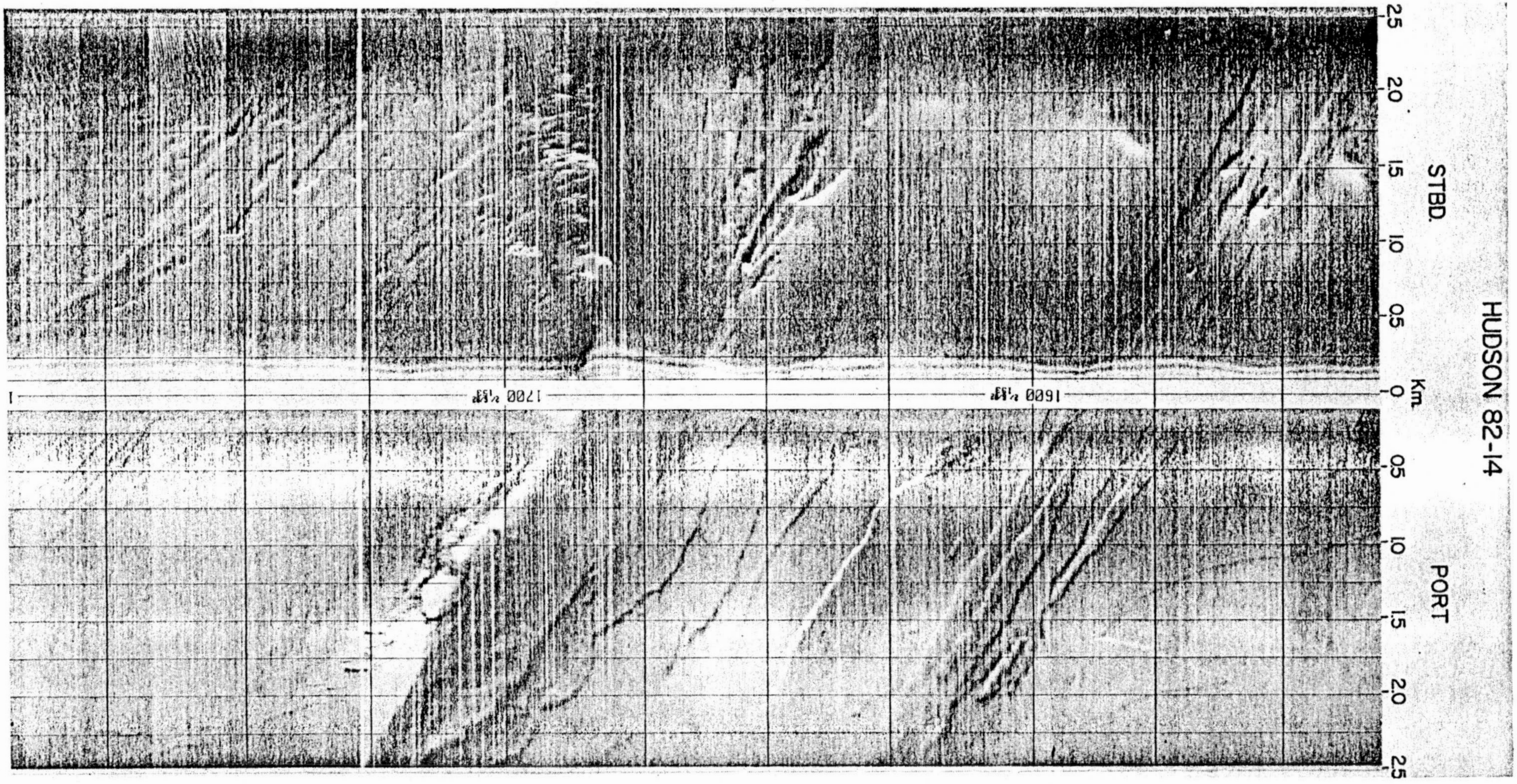

Plate 2. Slide scars in area of stripped off sediment with streamlined erosional depressions in shallow valley; East Acadia Valley; and downslope edge of western debris flow, showing flow into valley and streamlined erosional depressions.

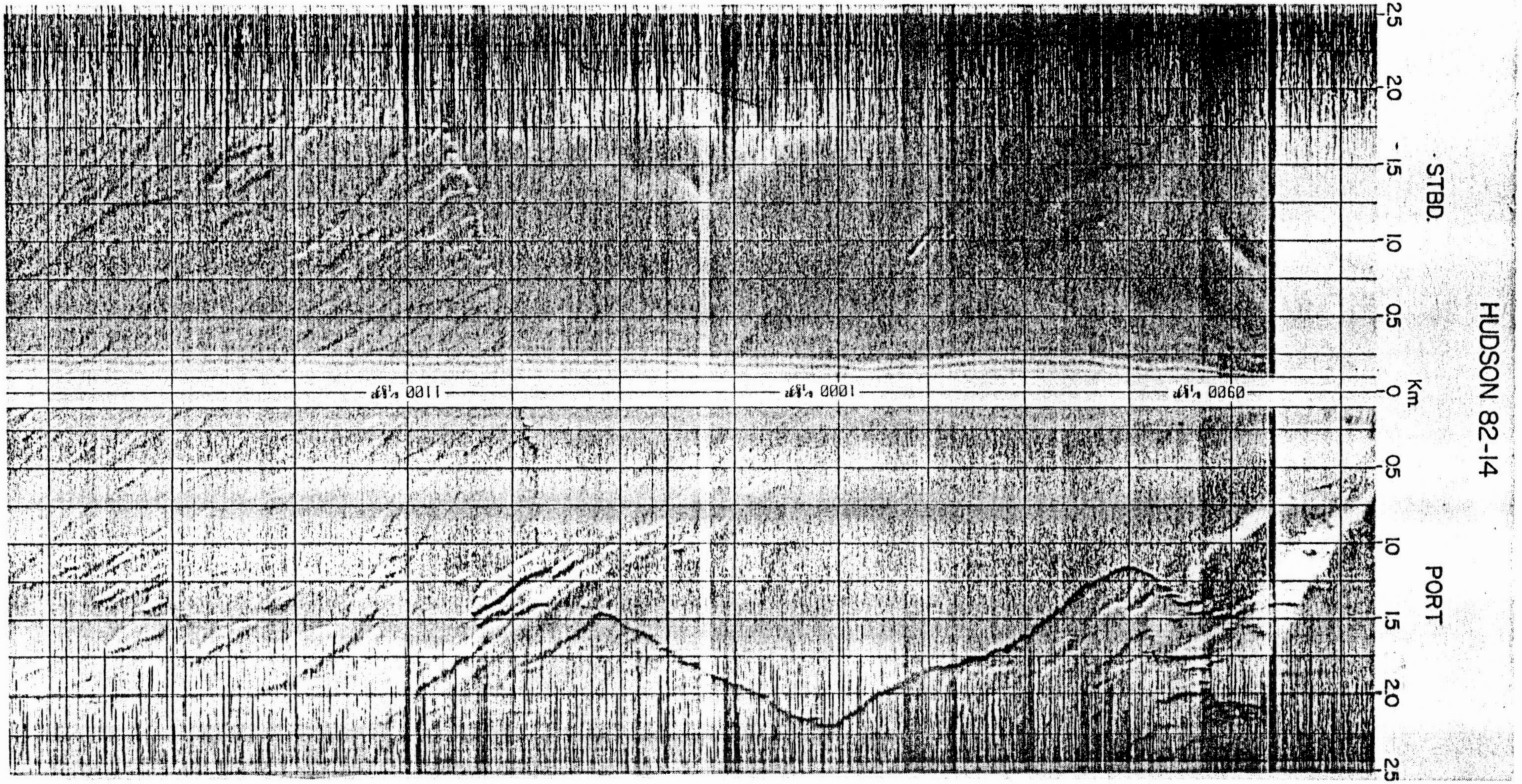

Plate 3. Slide scar in area of stripped off sediment, just south of down-slope edge of western debris flow, and streamlined erosional depressions.

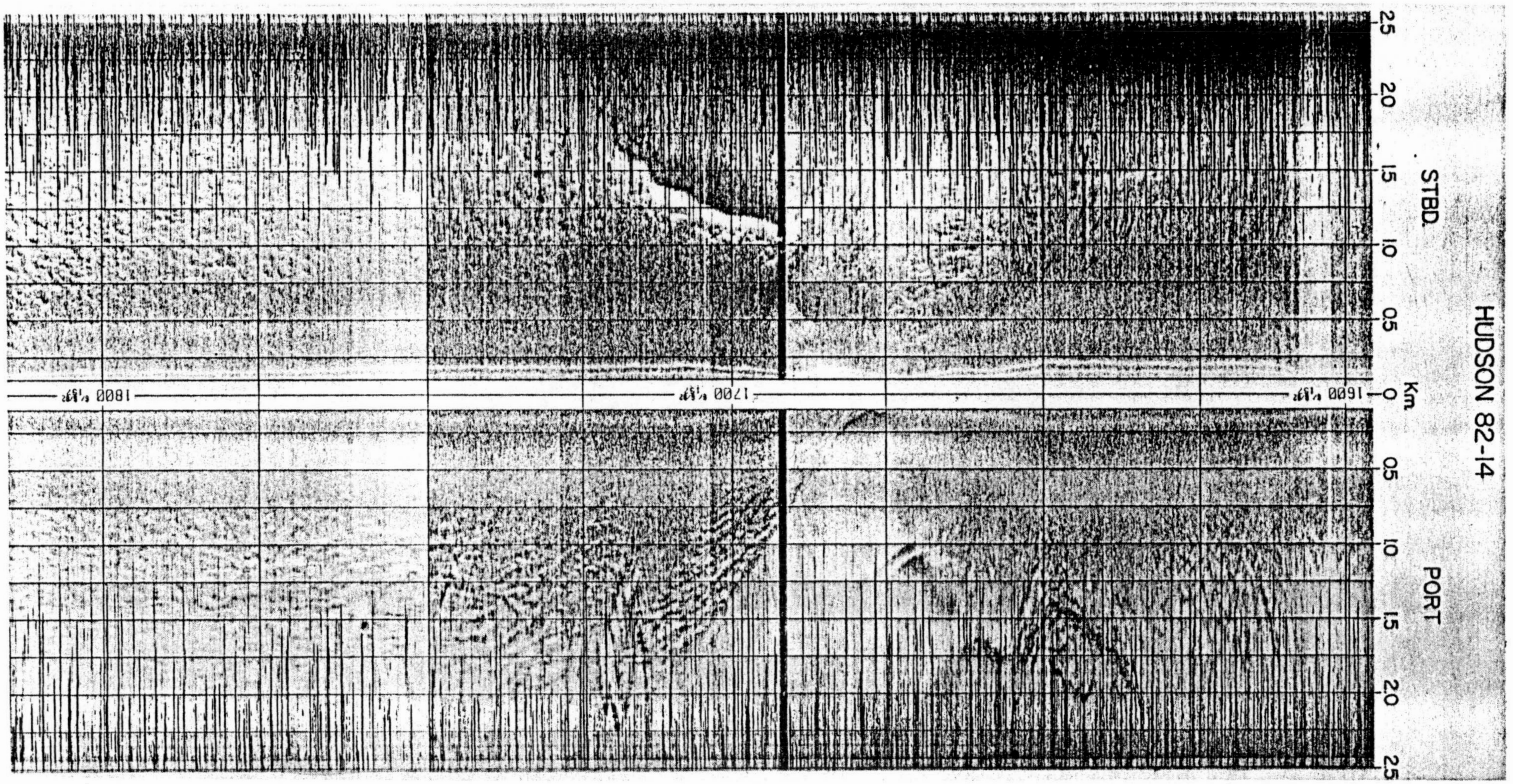

Plate 4. Area of undisturbed sediment, cut by unidentified scars; edge of eastern debris flow showing orientation of surface ridges parallel to edge; main part of eastern debris flow with transverse ridge pattern.

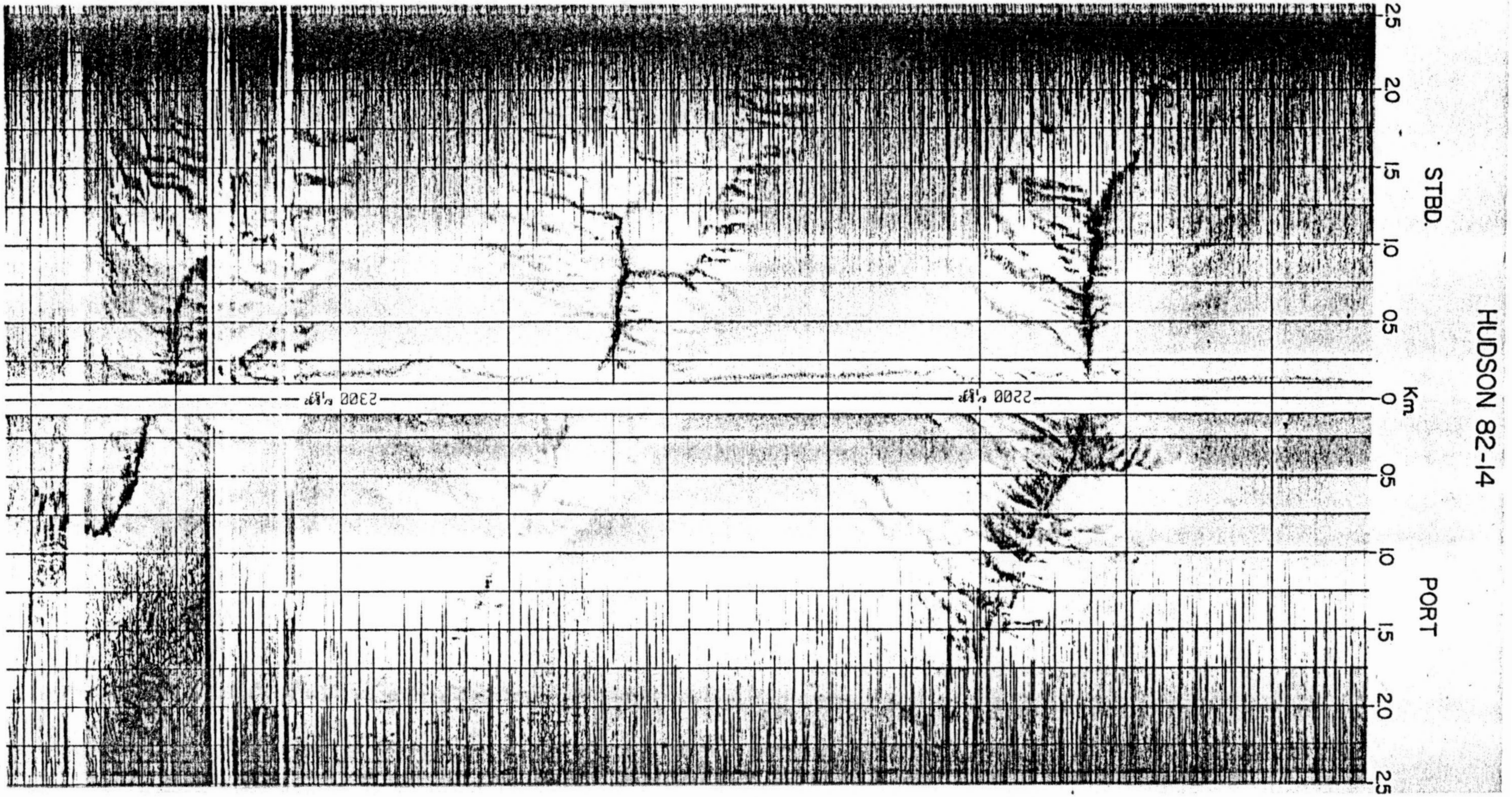

Plate 5. Series of flat-floored valleys separated by steep, sharp-crested ridges dissected by gullies.

Plates 6-33 are selected sub-bottom profiles. Horizontal scale lines are at 10 m intervals. Vertical 15-minute time lines have an average spacing of 750 m.

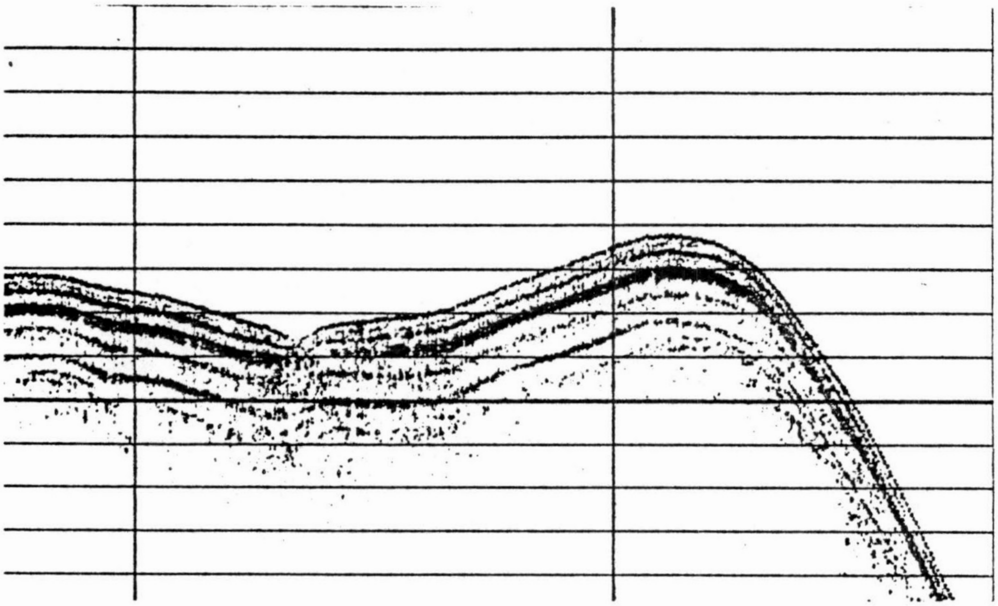

Plate 6. Small valley A, showing small dimensions and lack of disruption of underlying reflectors. On the right is the western levee of West Acadia Valley.

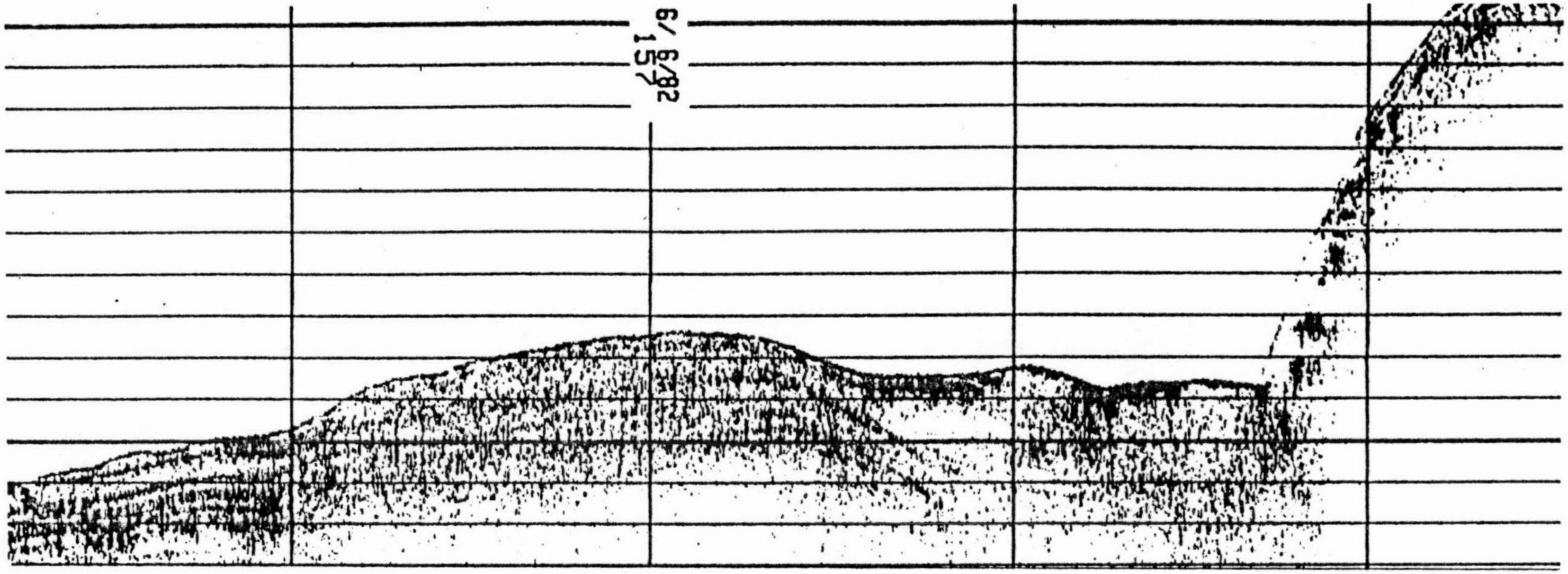

Plate 7. East Acadia Valley showing steep east wall with outcropping strata, valley floor filled with debris flow deposits, low west levee, and stripped-off morphology with strealined erosional depressions beyond levee.

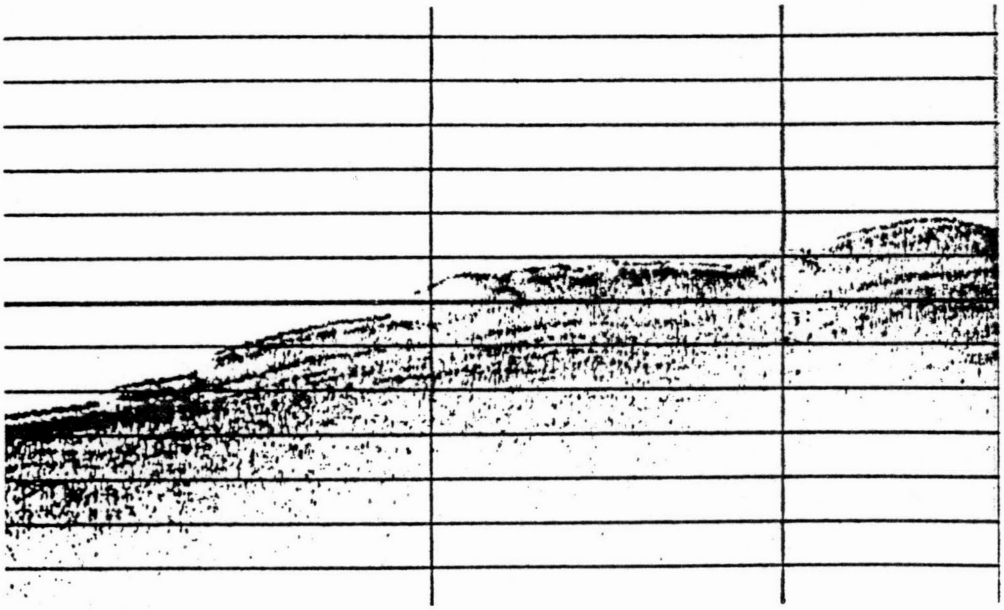

Plate 8. Area between East and West Acadia showing stripped off morphology and possible debris flow deposit.

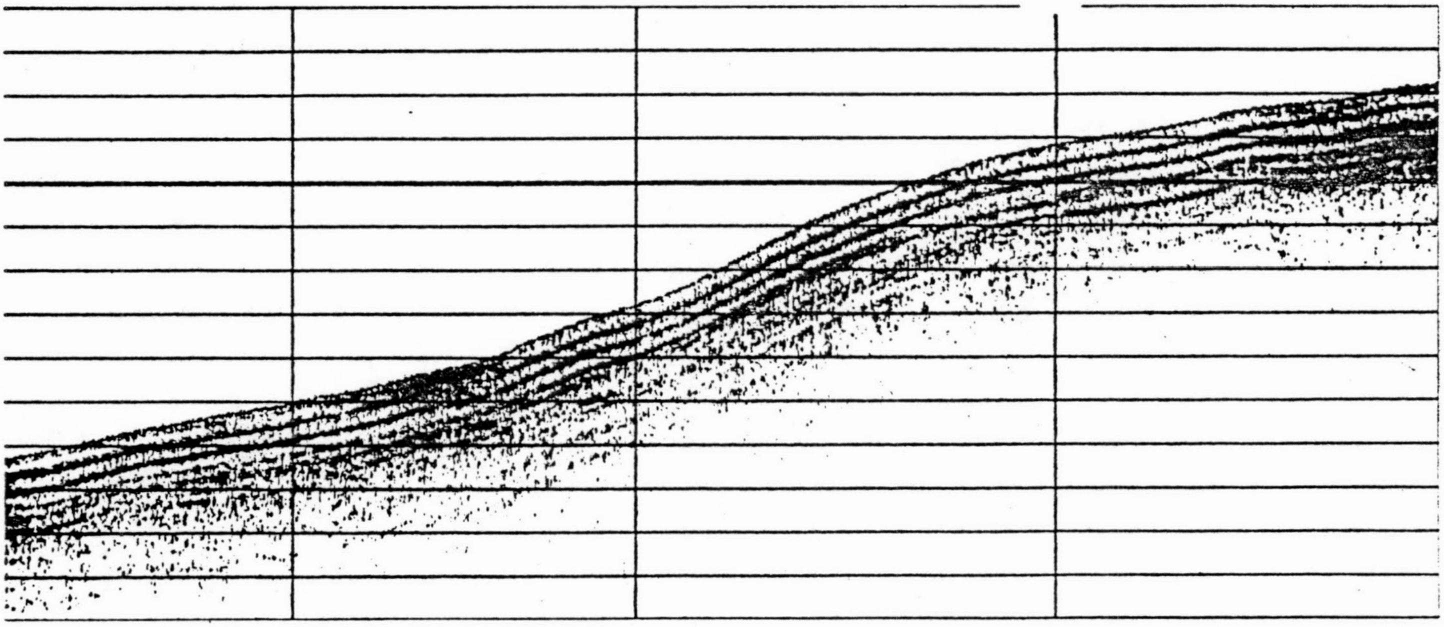

Plate 9. Area of undisturbed stratified sediment showing draped character and the occurrence of "steps" or changes in gradient.

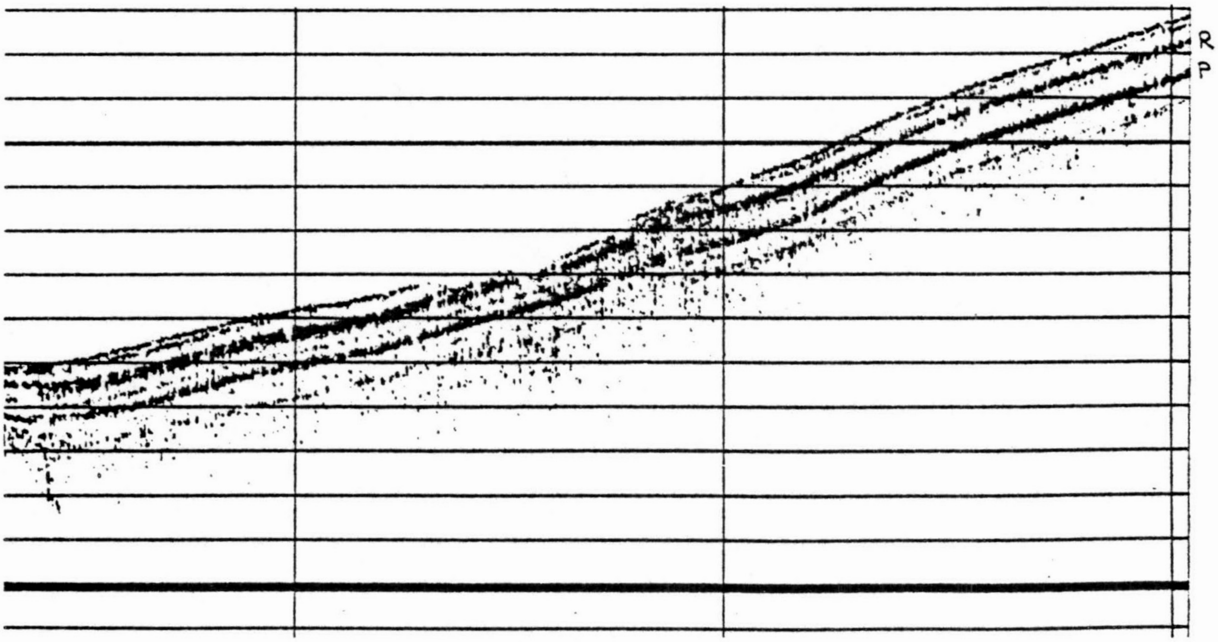

Plate 10. Irregular surface erosion in area showing streamlined erosional depressions in sidescan sonar records, downslope from edge of debris flow.

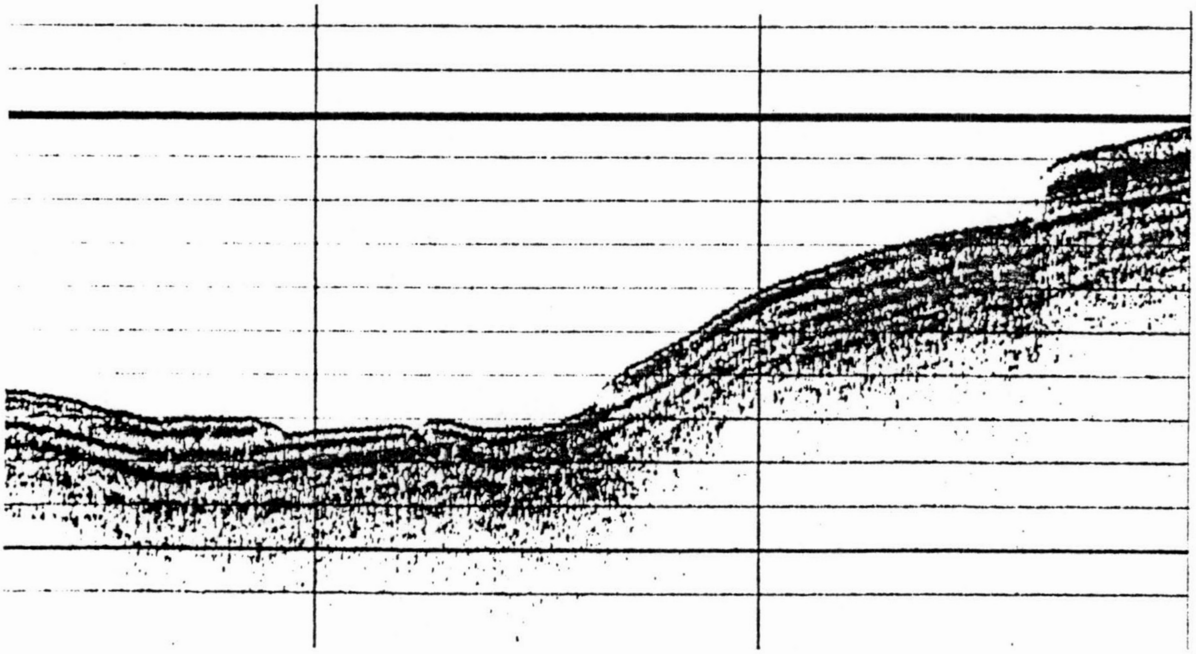

Plate 11. Crossing of small valley, showing stripped-off morphology. Compare with plate 12.

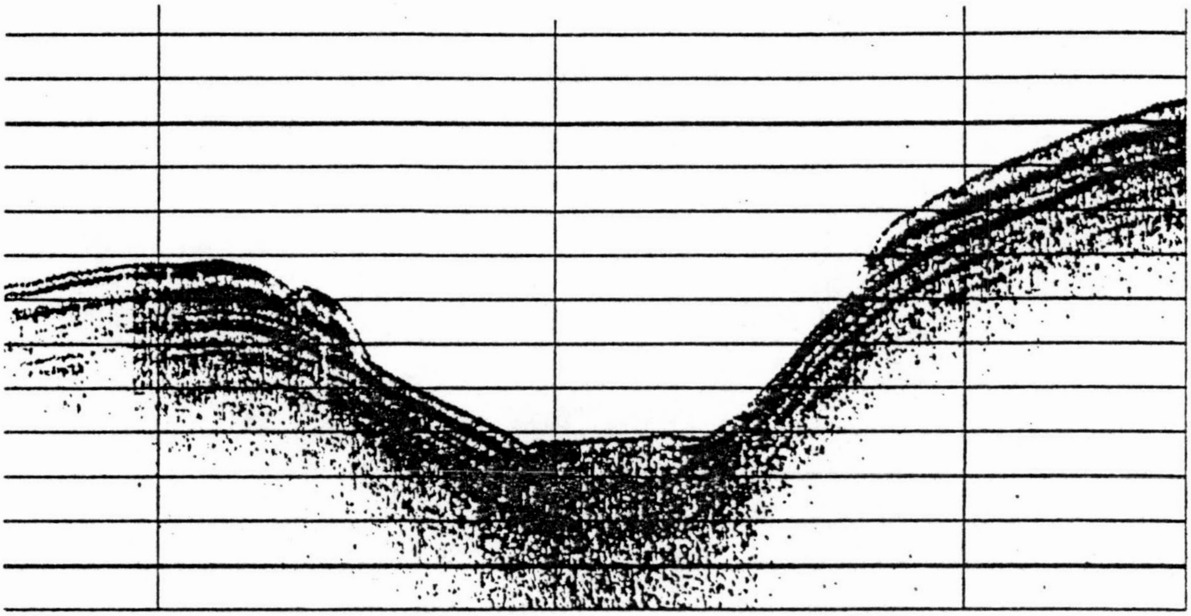

Plate 12. Small valley between East and West Acadia Valleys showing stripped-off morphology on valley walls, debris flow filling floor, and continuity of reflectors beneath the valley floor. (Note this valley crossing is upslope from plate 11.)

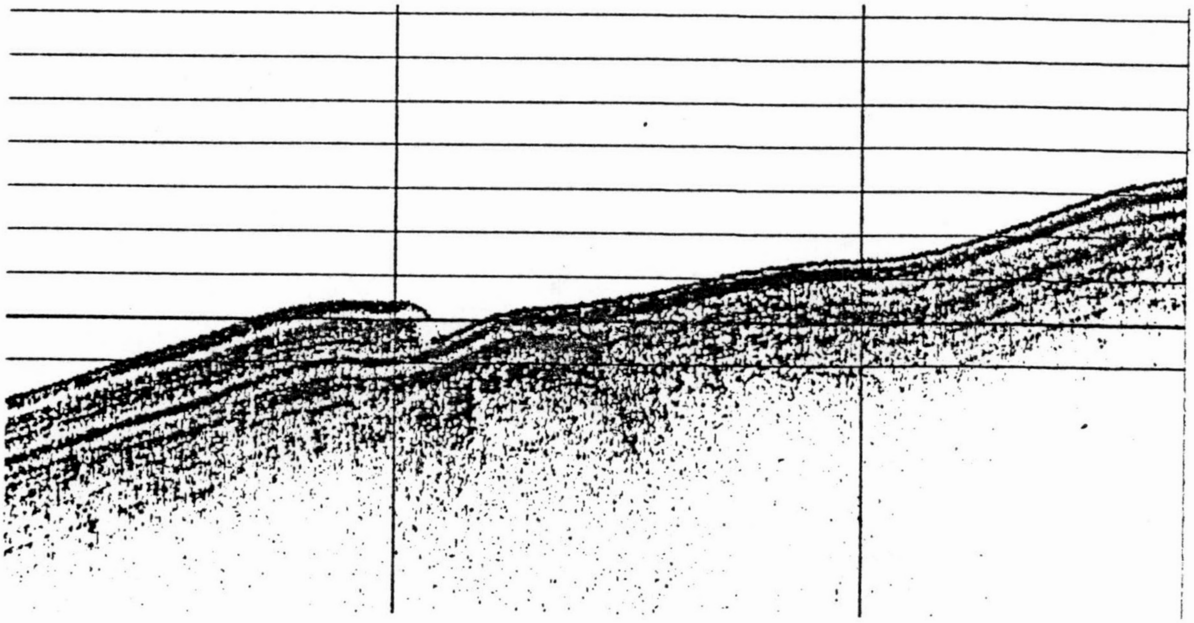

Plate 13. Possible buried valley, covered by stratified sediment. Surface sediment has been stripped off on NE side of section. Sediment to SW may be an autochthonous residual mass, or may be a slid block. The valley may be a former downslope continuation of the valley in plate 12.

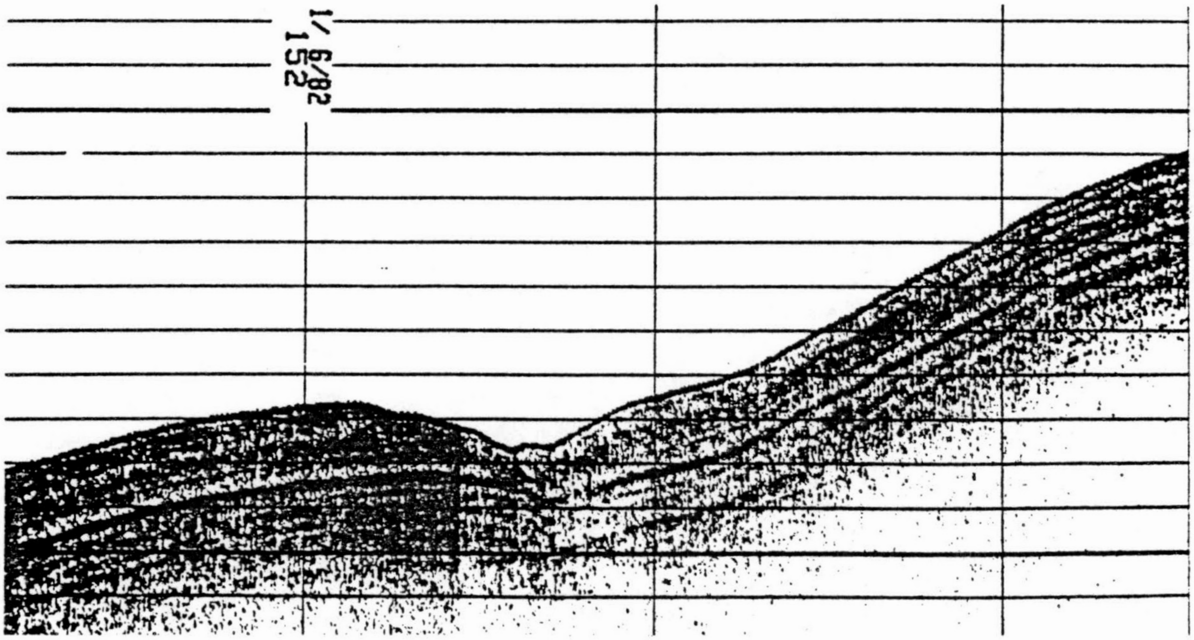

Plate 14. Irregular surface erosion in small valley between East and West Acadia Valleys.

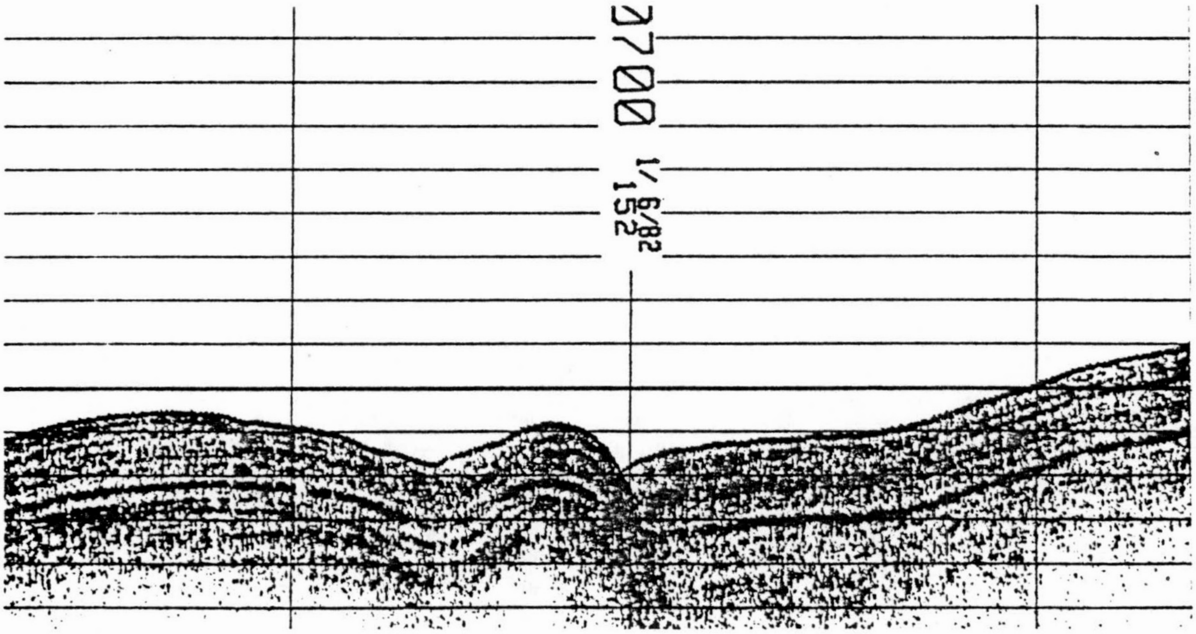

Plate 15. Section just downslope from bifurcation of small channel B.

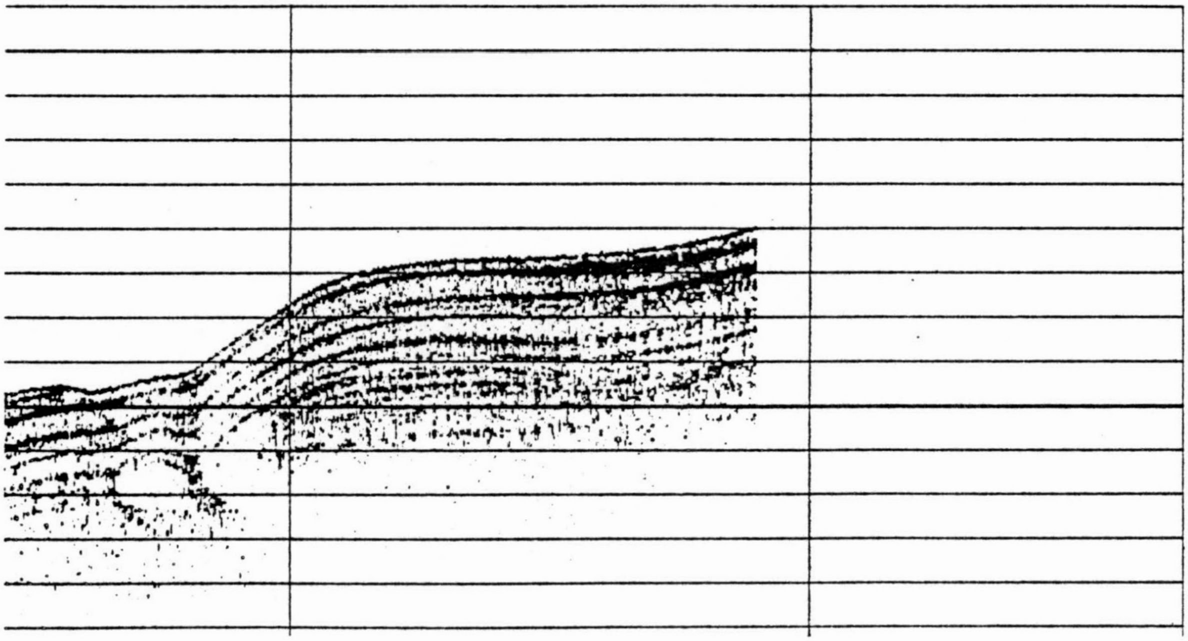

Plate 16. Migration of small channel A on backside of large levee of West Acadia Valley.

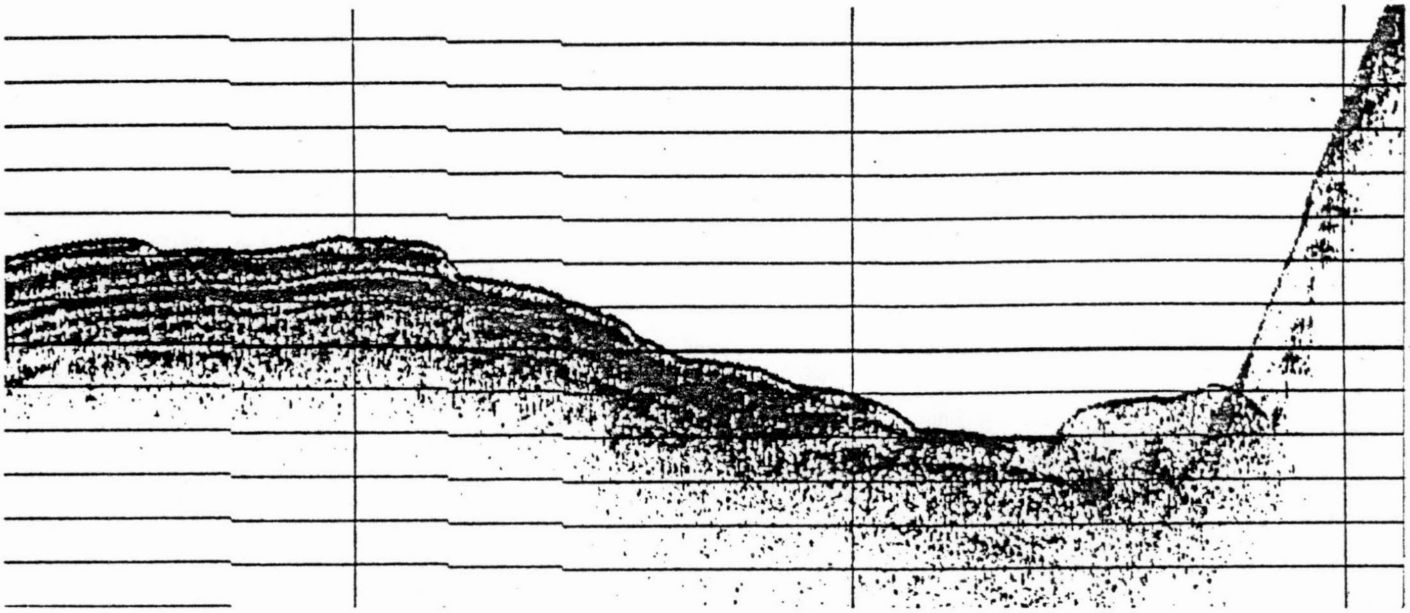

Plate 17. Stripped-off morphology on western wall of East Acadia Valley, truncated strata on eastern wall, and debris flow filling valley floor.

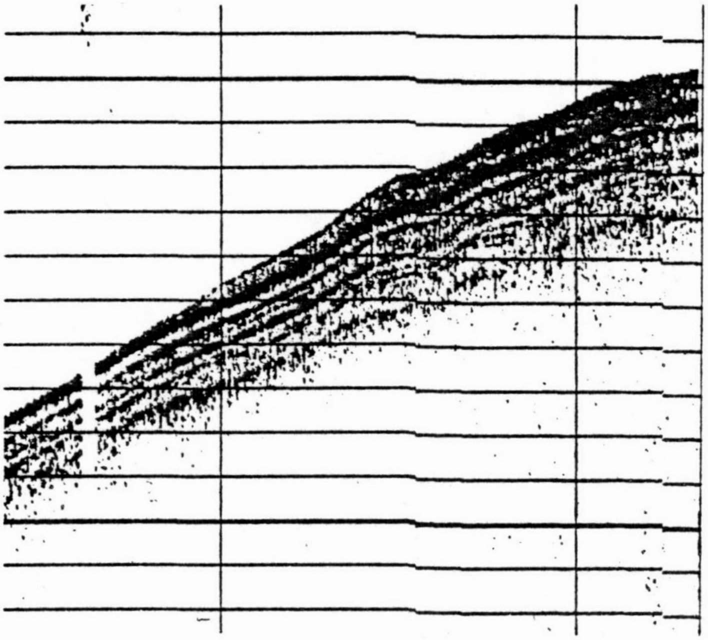

Plate 18. Thin margin of western debris flow above East Acadia Valley.

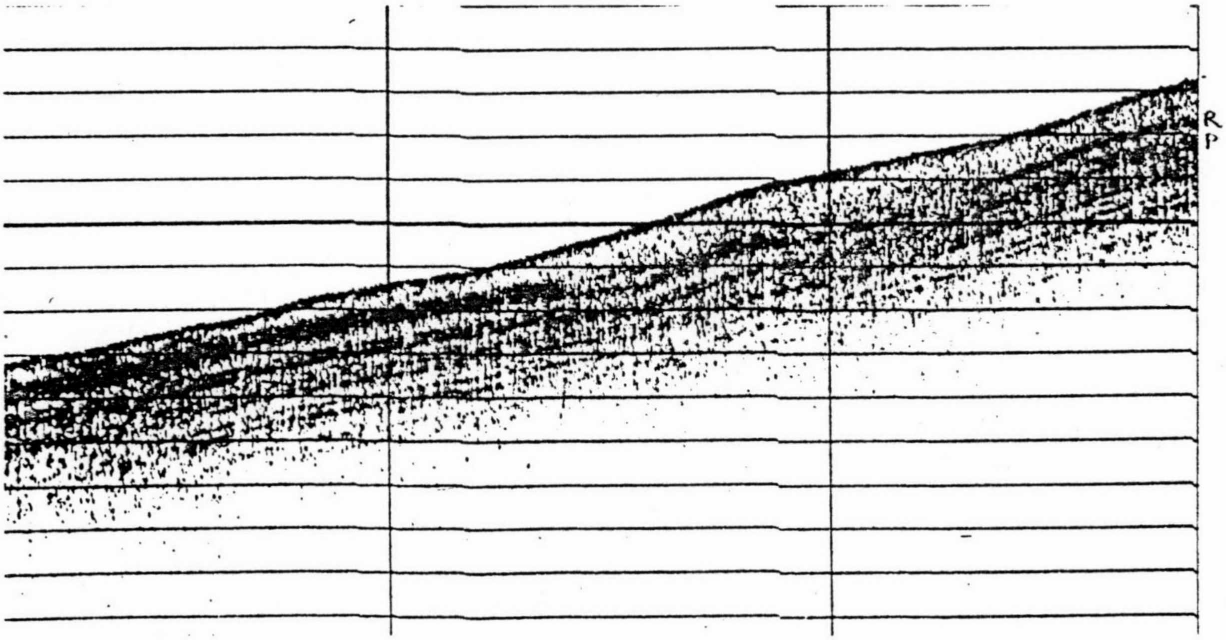

Plate 19. General thinning of western debris flow.

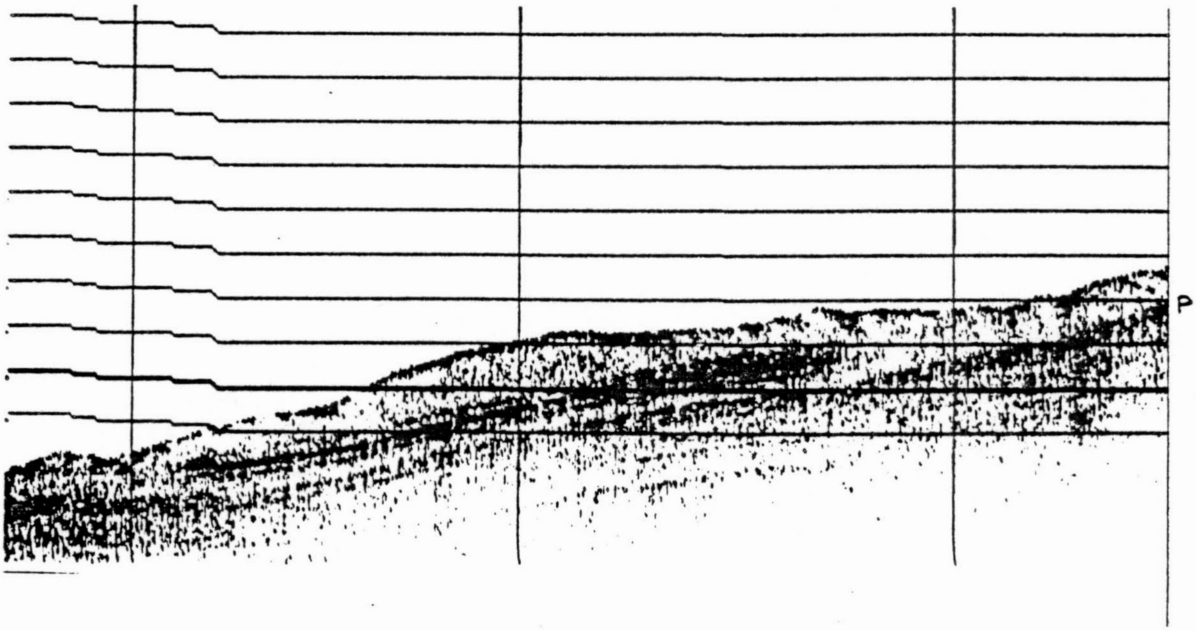

Plate 20. Debris flow overlying steps in stripped-off topography.

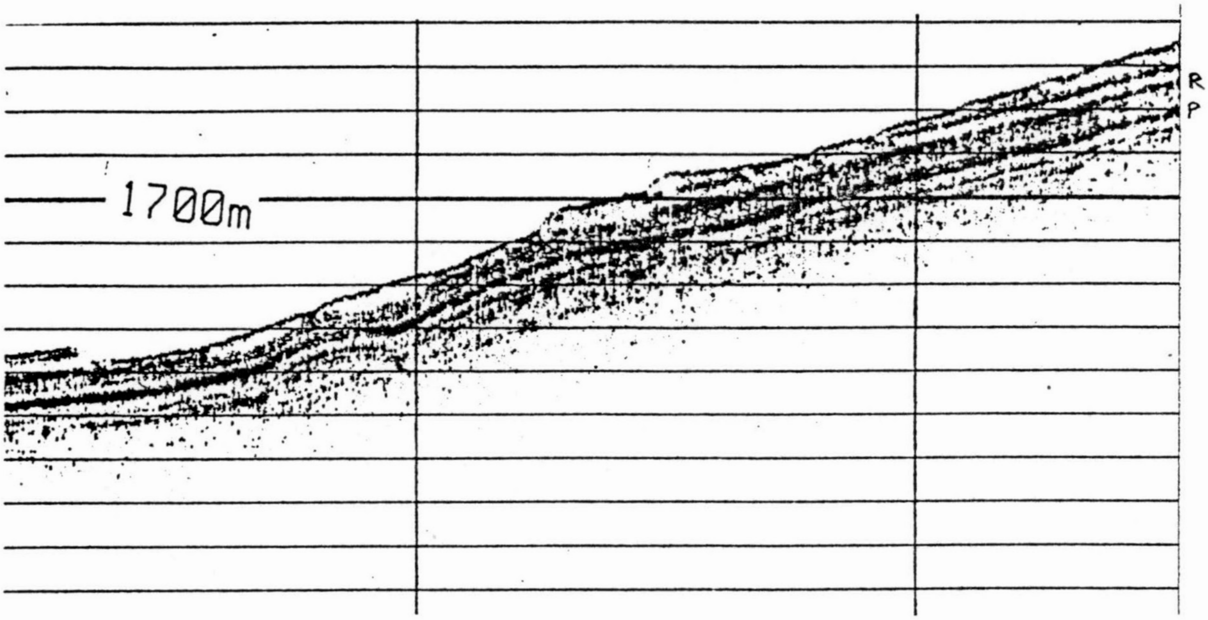

Plate 21. Piled-up edge of debris flow overlying stripped off morphology.

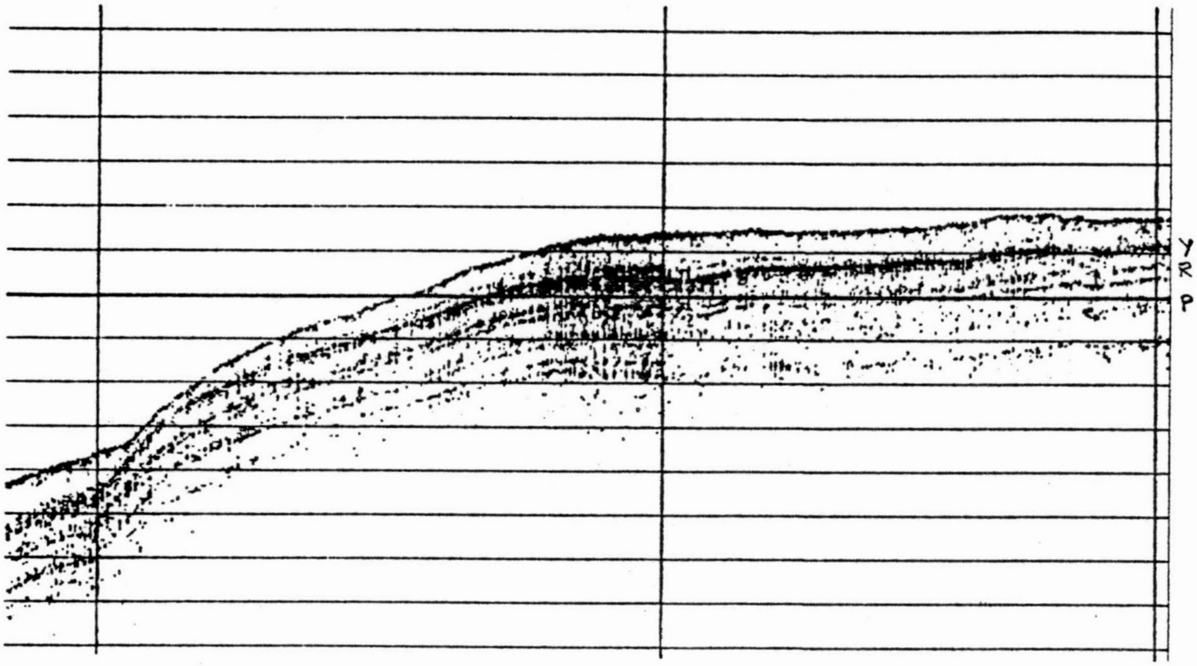

Plate 22. Debris flow showing thinning over steepening of sub-bottom gradient.

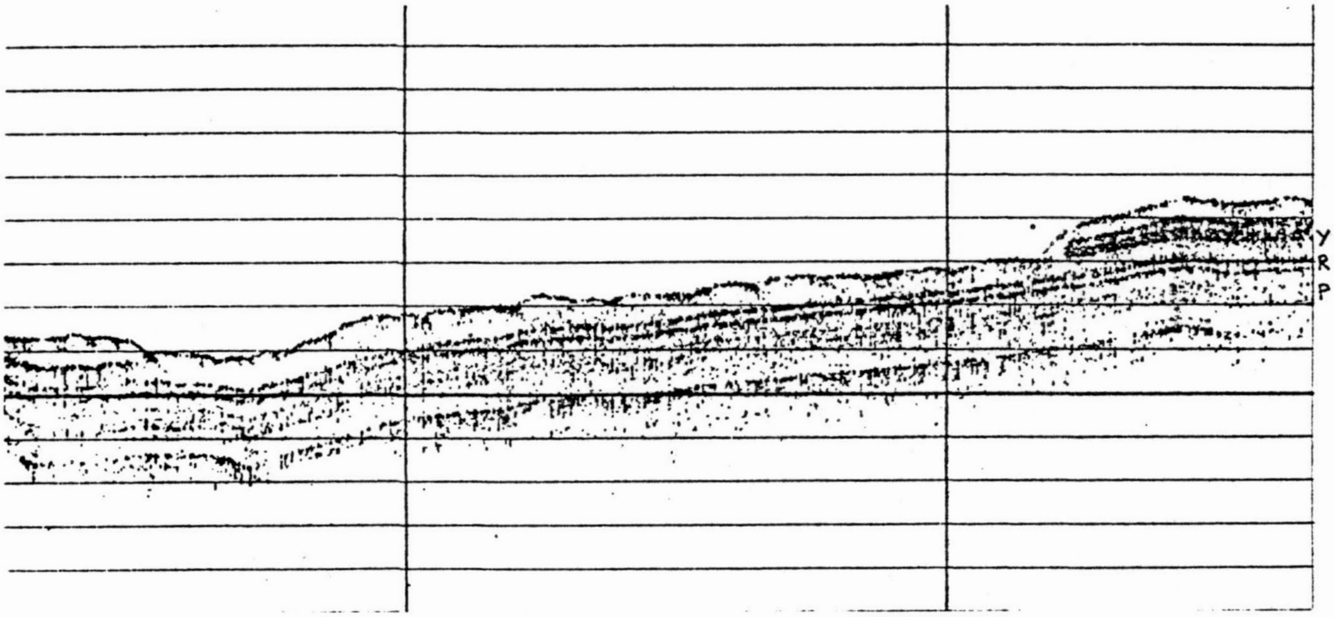

Plate 23. Debris flow overlying stripped-off steps.

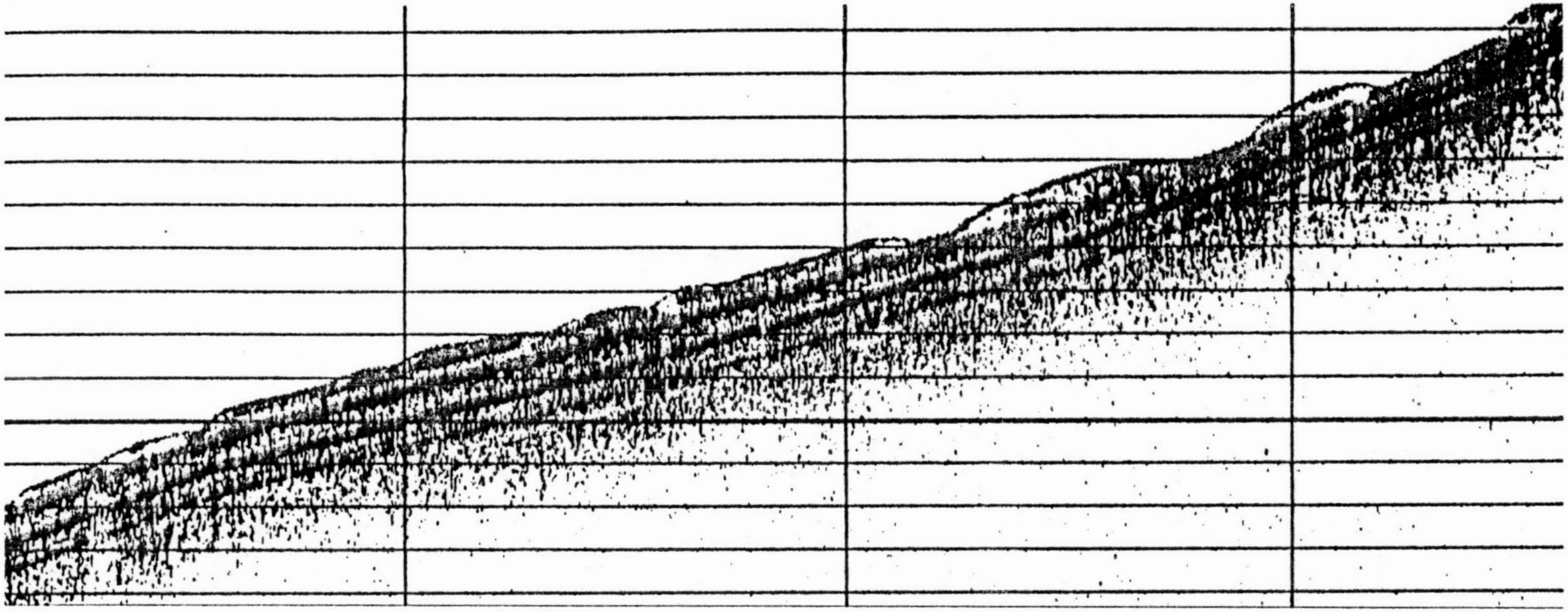

Plate 24. Streamlined erosional depressions developed in thin debris flow.

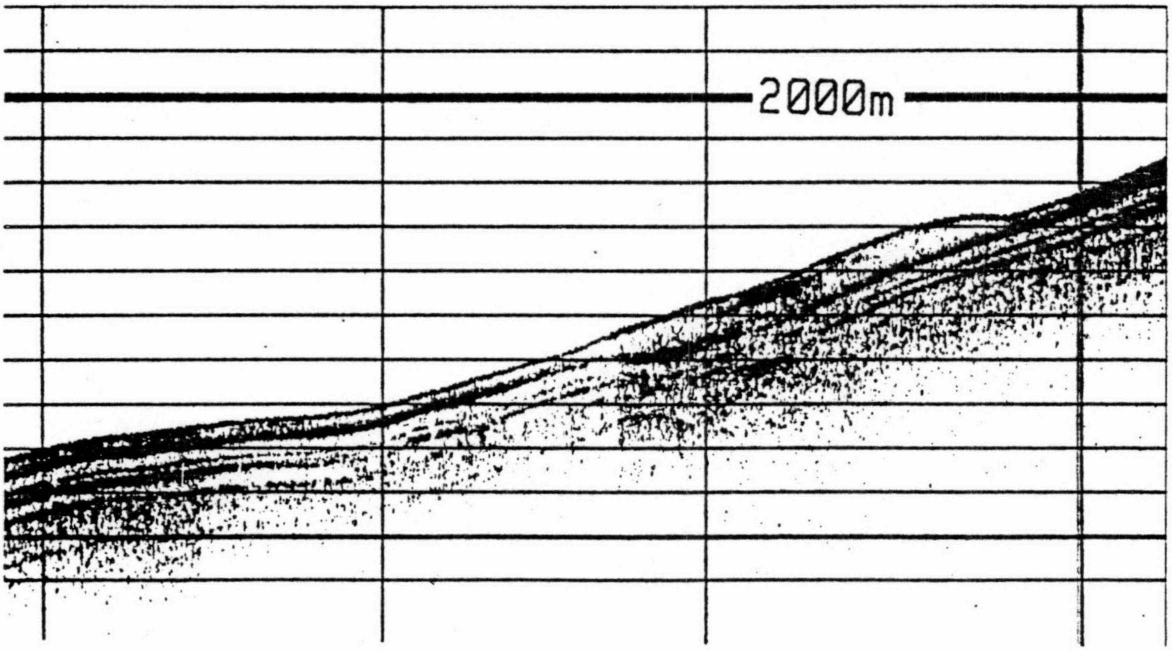

Plate 25. Possible buried valley, covered by stratified sediment of variable thickness, in area of erosional scours.

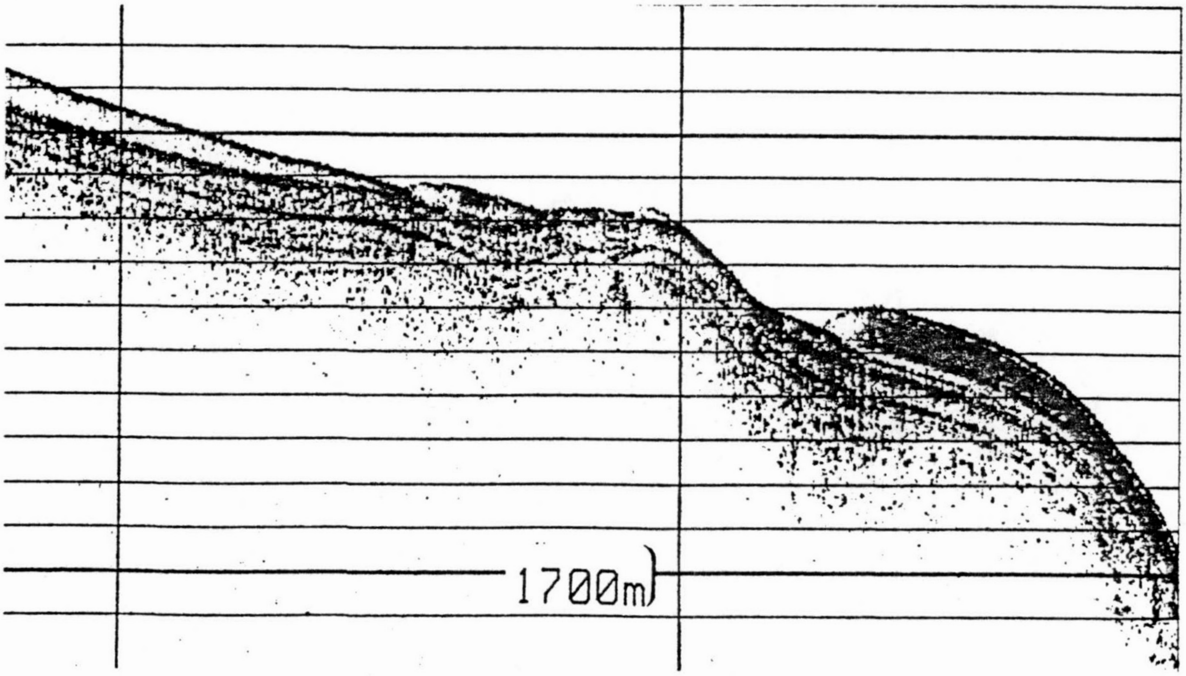

Plate 26. Eastern margin of eastern debris flow, and steep slope with stripped off or slid block morphology.

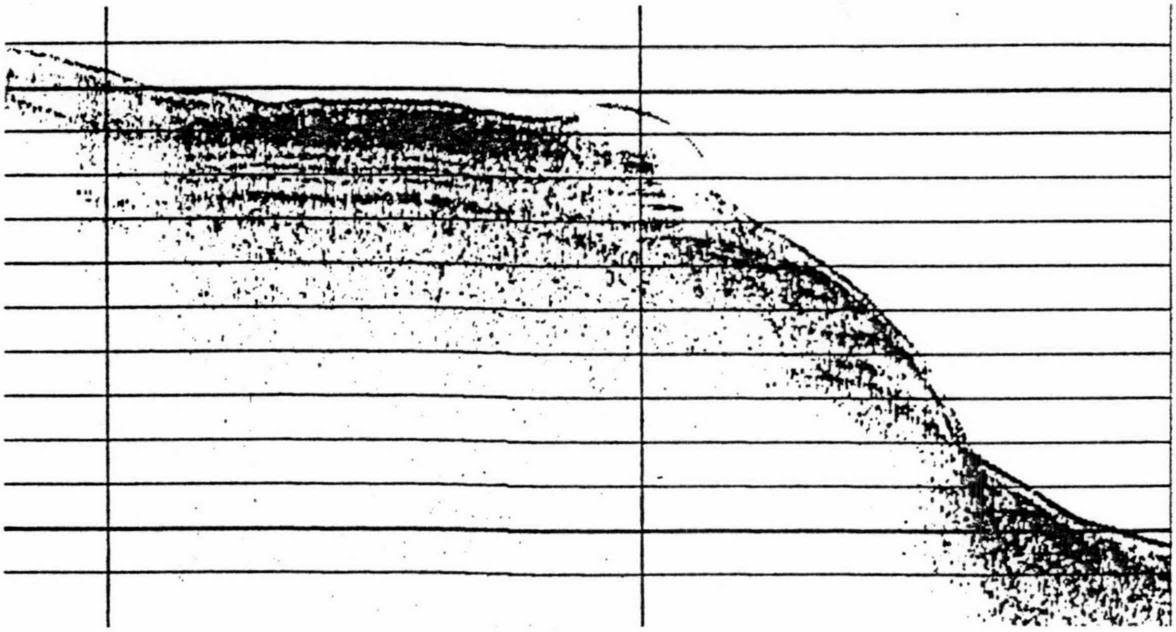

Plate 27. Major slump scar at eastern margin of survey area.

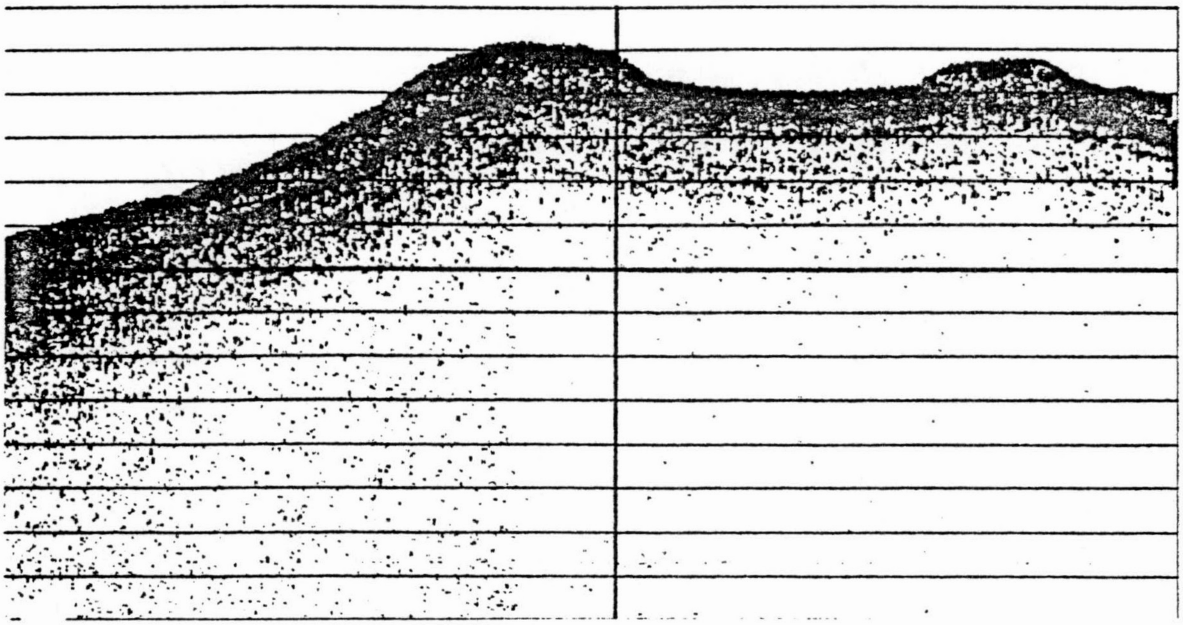

Plate 28. Eastern debris flow filling pre-existing small valley.

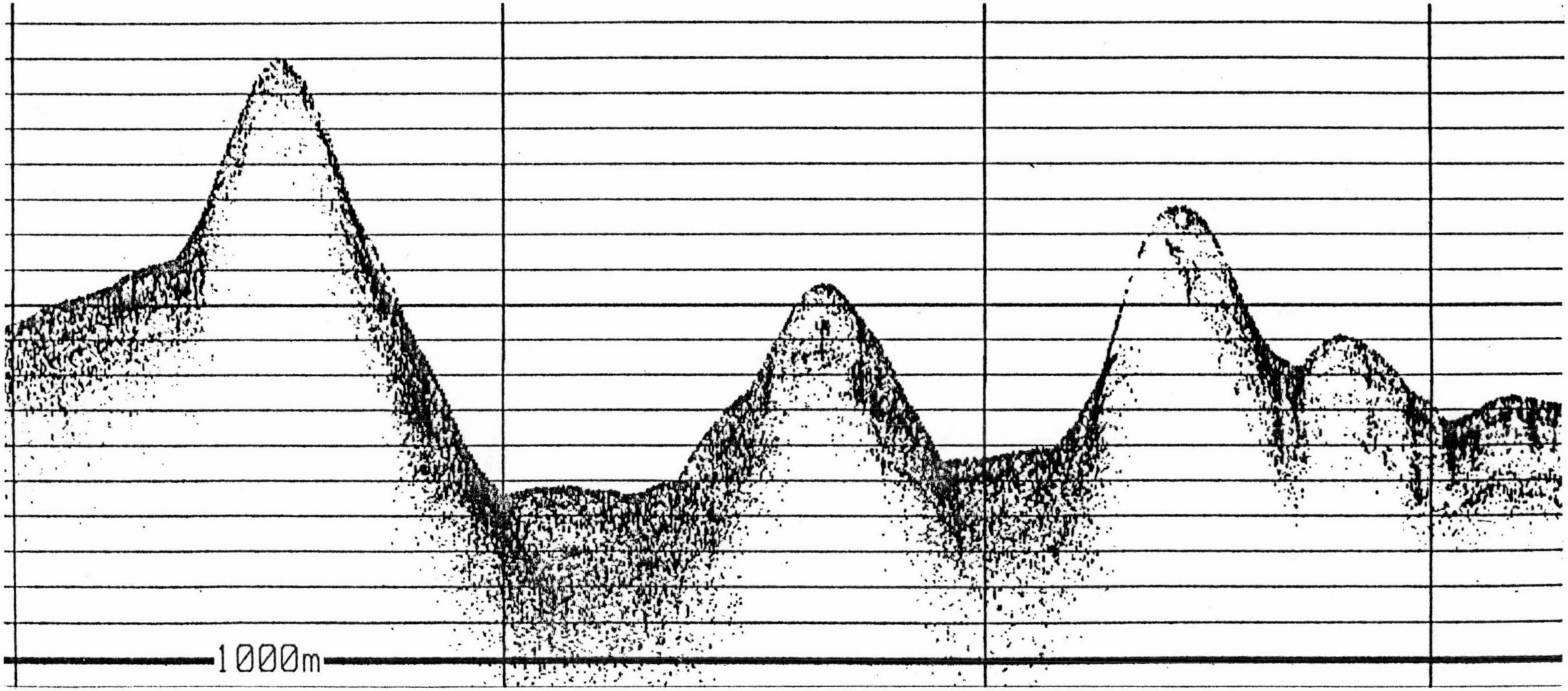

Plate 29. Valleys with gullied slopes and flat floors in northeast of survey area.

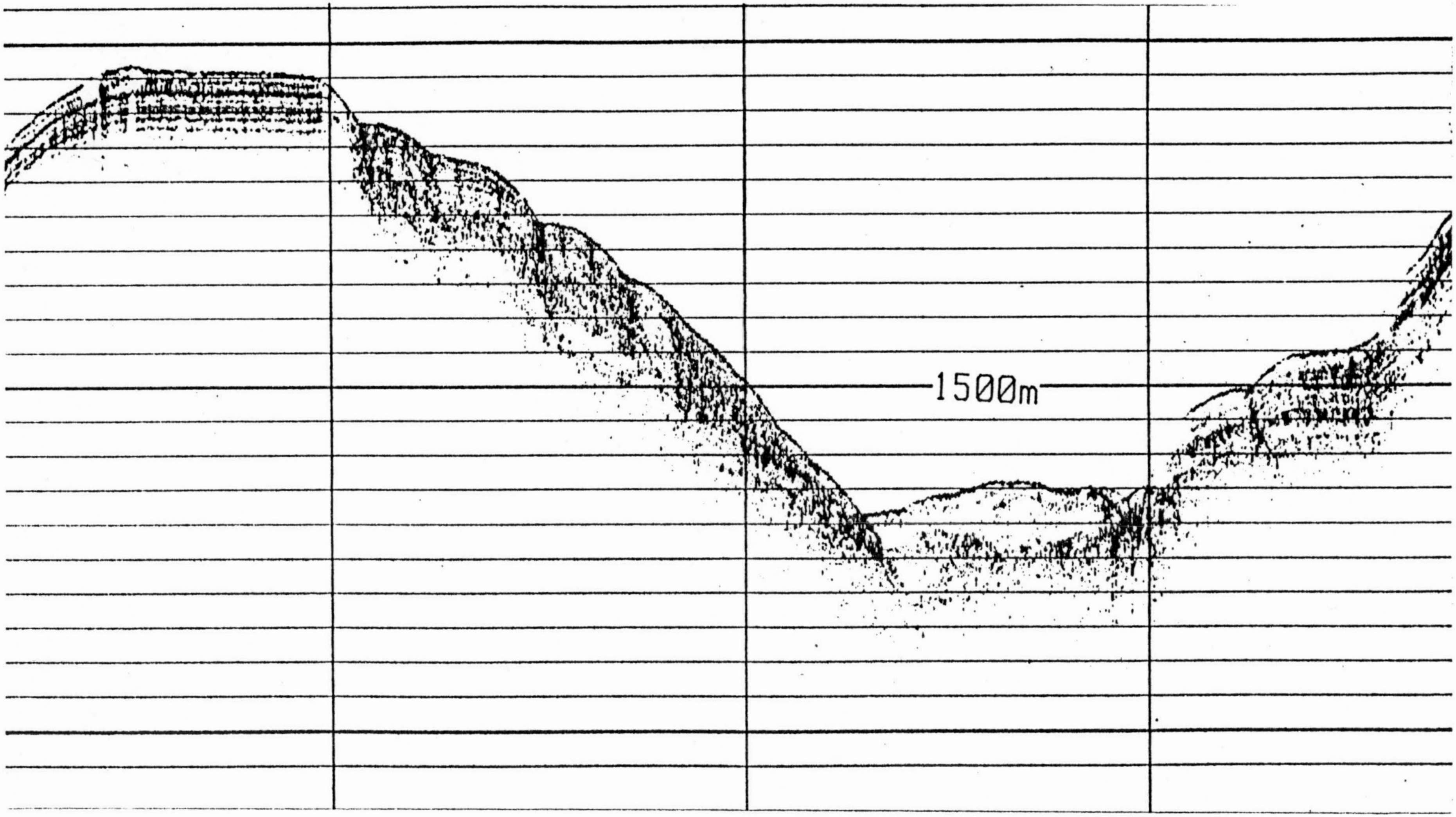

Plate 30. Creep on slope leading to valley filled with debris flow, eastern part of survey area.