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SHALLOW STRUCTURE AND STRATIGRAPHY OF THE CARBONATE WEST
FLORIDA CONTINENTAL SLOPE AND THEIR IMPLICATIONS TO
SEDIMENTATION AND GEOHAZARDS

by

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ABSTRACT

An 1800-joule sparker survey of the West Florida continental slope between about 26°N and 29°15'N showed a top bed of Pleistocene age forming an irregular drape over a surface that is probably Pliocene. The contact between the top two layers is unconformable in the south and, in some places, shows karst collapse and solution features. Karst topography grades into a more hummocky erosional surface to the north, which in turn smooths out; the contact become conformable still further north. A period of folding, which is widespread over the outer portion of the study area and which may be related to large scale mass wasting, occurred at about the same time represented by the unconformity. Significant subsidence has occurred as late as Pleistocene.

The surface layer thins to a minimum (0 in the south) at about 525-meters water depth and then thickens again dramatically to the west, downslope. This thinning is interpreted to be due to the Loop Current, which flows from north to south in the area and which acts to block deposition and scour the bottom.

Despite the fact that the margin is dominated by carbonates, usually associated with low sedimentation rates, there is widespread evidence of mass wasting affecting ancient and surficial deposits on the outer part of the upper slope.

Three potential groups of geohazards identified are:

1. Potential bottom failure in areas where a thin top layer overlies the karst surface.
2. Potential for sliding and slumping.
3. Scour due to currents which could also affect drilling and engineering activities.

INTRODUCTION

The West Florida continental slope shown in Figure 1 is the only slope of the continental United States that is dominated by active carbonate sedimentation. The carbonate slope is of additional interest because it is juxtaposed against the terrigenous Mississippi Cone. The expansion of petroleum and natural-gas exploration to deeper parts of the west Florida margin, with all its potential economic and environmental ramifications, has provided the impetus to investigate this unique transition zone. This paper presents the results of a high-resolution seismic study (fig. 1a) of the west Florida continental slope between about 26°N and the eastern flank of DeSoto Canyon at about $29^{\circ}15'\text{N}$; the study's goal included determination of shallow stratigraphy and structure of the region and what these parameters can tell us about potential geohazards and sedimentary processes.

The continental margin of western peninsular Florida, the West Florida Platform, is composed of a sequence of carbonates and evaporites more than 4.5 km thick, which ranges in age from Jurassic to Recent and which unconformably overlies Paleozoic crystalline basement. Bryant and others (1969) and Antoine and others (1974) have pointed out that during various phases of the build-up of the Florida Platform, circulation was restricted by shelf edge reef dams. During these periods of restricted circulation, especially during Albian/Aptian and Paleocene times, evaporitic deposition became important. When barriers were not present, open-water limestone deposition was dominant. Mitchum (1976) worked out the stratigraphy and lithology of the major units underlying the West Florida continental slope north of about $26^{\circ}30'\text{N}$, utilizing deep seismic-reflection data that were verified by seven stratigraphic test holes, some of which penetrated to the Cretaceous. He described about 500 meters of Cretaceous shallow-to-deep-water limestones overlain by about 650 meters of Lower Tertiary bathyal carbonates. Crumpled Eocene and Oligocene sequences are the thickest. An erosional unconformity is present at the top of the lower Oligocene section. Carbonate deposition continued through the lower Miocene. Terrigenous fine-grained sediments are important constituents of Middle Miocene strata on the northern slope but decrease to the south, indicating a northern provenance. Upper Miocene-through-Pleistocene lenses of foraminiferal and coccolith sands and silts are built upon prograded Middle Miocene strata. Carbonates still dominate the surficial sediments of the shelf and the slope of the region (Gould and Steward, 1955; Doyle and Sparks, 1980; Doyle and Feldhausen, 1981). Ludwick (1964) named the slope surface sediments, which contain a high percentage of foraminifera and coccolith plates (Doyle and Sparks, 1980), the West Florida Lime Mud Facies.

Uchupi and Emery (1968) described the two major physiographic divisions of the West Florida Slope, the upper portion of which begins at between 60- and 100-meters depth and which has a gradient of less than 2%. The Florida Escarpment, the lower portion, begins between 2200 and 2600 meters water depth and has a gradient of over 20° in places. Like the Patton Escarpment of the California Borderland and the steep slopes between the southeastern Atlantic shelf and the Blake Plateau and deep North Atlantic, the Florida Escarpment is not cut by submarine canyons. Like the Patton Escarpment, the Florida Escarpment does contain some U-shaped gaps, one at about 26°N and several more west of the Dry Tortugas, south of the study area. The gap at the southern end of our study area has some interesting features associated with it which will be discussed in the following sections.

STRATIGRAPHY

Plates 1-3 are isopach maps which show the thickness of the top layer in milliseconds of two-way travel time. The top layer is set off by a distinct reflector which can be recognized over most of the region (e.g., Figs. 2a,b). Based upon 7 drill holes and several reconnaissance deep seismic lines, Mitchum (1976) presented a series of contour maps of the thicknesses of strata of various ages. The thicknesses of the top bed shown in Plates 1-3 generally agree with Mitchum's (1976) interpretation of the Pleistocene of the West Florida Slope, although our more extensive sampling grid yields a correspondingly more detailed picture.

According to Mitchum (1976), Pliocene rocks are present as a lens on the slope above the escarpment. Our first major subbottom reflector, then, is probably of Pliocene Age.

South of about 28°N , our data show that the contact between the top bed and the underlying strata is an erosional unconformity. Two types of morphology are present along the unconformable surface. The most striking is a karst topography (fig. 3), the extent of which is shown in Plates 2 and 3. The karst topography grades into a more rolling surface to the north (fig. 2a), which gradually dies out as the contact apparently becomes conformable (fig. 2b). On the outermost portion of the slope, in localized areas, the strata beneath the top bed are folded and the unconformity is structural.

The top layer (Plates 1-3) forms an irregular drape over the West Florida Slope, has a small basin centered at about $26^{\circ}30'\text{N}$, $84^{\circ}40'\text{W}$; it reaches a thickness of over 130 milliseconds and forms another basin at about $27^{\circ}30'\text{N}$, $84^{\circ}45'\text{W}$ which is over 160 milliseconds thick. Bed thickness generally decreases to zero south of 27°N near the 500-meter contour and then thickens again dramatically to the west. A thin finger of Pleistocene strata continues to about $27^{\circ}15'\text{N}$; thereafter, it thickens gradually to the north and northwest and rapidly to the west to about 300 milliseconds (Plates 1-3). A small window to the underlying strata is present at about $27^{\circ}10'\text{N}$, 85°W .

STRUCTURE

Plates 1-3 show some of the surface features of the West Florida slope. In the southern terminus of the study area, in a re-entrant, is a large deposit which we interpret to be a series of submarine slides (fig. 4). The deposit has been heavily dissected by gullying. For a carbonate slope of suspected low-sedimentation rate, mass-wasting structures in slope sediment are surprisingly common. Plate 3 also shows a field of gullies between about 26°N and $26^{\circ}50'\text{N}$.

In the southern portion of the area, two reef trends, one at about 250-meters and the second at 225-meters water depth, are exposed at the surface but cease at about $26^{\circ}40'\text{N}$ and $26^{\circ}30'\text{N}$ for the deeper and shallower members, respectively (fig. 5). A band of isolated pinnacles and rubble lies seaward of the deeper reef. In addition to those reefs exposed at the surface, and as expected on a carbonate platform's flanks, buried reefal structures like that shown in Figure 6 are quite common. Sometimes sediment appears to be ponded behind the reefs. Buried reefs cannot be followed for long distances through our seismic net, suggesting that they were patchy when active.

One of the more surprising aspects of the data is that they show some rather tight folding (fig. 7), behind which sediments have ponded in places.

When not associated with karst and mass-wasting phenomena, faulting is not common on the slope. A few examples are present, however, like that shown in the outer portions of line 191 (fig. 8). There, the fault cuts the surface sediments and can be followed into the second layer. This feature and the sag at the surface may also be the result of slow mass wasting as the upper layers pull away and begin to move down slope.

DISCUSSION

Folds and Subsidence

Although the West Florida Margin has been considered to be tectonically stable since Jurassic time, Mitchum (1976) reported crumpled beds of Eocene and Oligocene age, indicating that because the beds beneath are undeformed, the folds are the result of gravity-induced sliding. Two additional events are suggested by our data, the first by some folding on the outer portion of the upper slope near the juncture with the Florida Escarpment (fig. 7). This folding affects the second layer but not the top bed, suggesting that it is Middle or Late Pliocene age. If the undeformed sediment shown ponded behind the innermost fold (line 186, fig. 7) is Late Pliocene, then the folding is probably Middle Pliocene. Folding is probably the result of largescale sliding, possibly occurring before sediments were consolidated. Over 225 meters of strata are involved. Folds seem to be piled behind an indistinct submerged feature which does not show internal structure, probably a reef. Considerable subsidence is suggested by our data.

The erosional unconformity present over much of the study area, which is expressed as a karst surface in some places and as an irregular erosional surface in others (fig. 2b and 3), lies as much as 450 meters below present-day sea level. This surface separates layer 1 from layer 2 and, like the folding, is probably Pliocene in age. The two drowned reef trends exposed at the surface lie in 225-250 meters of water, respectively. Based upon Mitchum's (1976) work, they must be Pleistocene. Recent estimates of low stands of sea level for the Wisconsin are less than 100 meters (Dillon and Oldale, 1978; Blackwelder and others, 1979). The Florida Middle Ground is a living deep-water reef on the outer West Florida Shelf whose maximum depth is about 40 meters. If 40 meters is considered as an upper depth limit, then there must have been about 100 meters of subsidence since the now-drowned slope reefs were active.

Sedimentary Processes

Seismic profiles suggest that several interesting processes may be occurring on the West Florida Slope. The thinning (pinching out in the south) of the top bed (Plates 2 and 3) and the rapid thickening to the west, downslope, may represent a sedimentologic boundary on each side of which different processes are dominant. Pinch out or maximum thinning occurs at about 525-meters water depth. The Loop Current flows from north to south along the West Florida continental slope. The thinning of the top layer may be the result of the scouring and depositional blocking action of this current system, which has surface velocities of over 1 knot.

Further scouring, this time roughly perpendicular to the isobaths, is indicated by the gullies shown in Plate 3 and figure 9. Current systems or frequent gravity flows responsible for this scouring are not understood on this margin.

Although carbonate sedimentation rates are considered to be low compared with clastic rates, build-up of sediment on the outer West Florida Slope has been rapid enough to cause rather extensive mass-wasting phenomena to occur. Massive slide deposits as well as creep and smallscale buckling of sediment are found. The ages of these events are not known with certainty, but the phenomena are present in deeper beds as well as in the surface layers so they have been common to this margin for relatively long periods of time.

Geohazards

Three types of potential geohazards germane to exploration and production of oil and gas on the West Florida Continental Slope have been pointed out by the seismic survey. The first is potential collapse of cave roofs in areas where the karst surface lies beneath a thin top unit. Enplacement of any structures in the karst area shown in Plates 2 and 3 should take this potential hazard into account.

The second major type of geohazard is the whole gamut of mass-wasting phenomena, ranging from largescale slope failure and major sliding through smallscale slumping to creep.

The third potential geohazard is the Loop Current. Its relatively high velocities will cause problems in the water column similar to those envisioned for the Gulf Stream on the southeastern Atlantic margin. Bottom scouring and gullying will also be factors to be dealt with.

SUMMARY

The West Florida Continental Slope is physiographically complex. Its two major divisions, the West Florida Escarpment and a gentler upper portion, have long been recognized. The upper portion, in turn, is divided into several parts by changes in gradient.

Seismic-reflection profiles reveal that the Pleistocene horizon forms an irregular drape over the second layer, probably Pliocene in age. An erosional unconformity lies between the two in the southern portion of the study area. The unconformity is represented over a broad swath by karst morphology which grades into an irregular surface to the north and, finally, into what may be a conformable contact still further north.

The surface layer thins at around 525-meters water depth, perhaps as the result of scouring or blocking of deposition by the Loop Current. Seaward of the thinnest portion, the top layer thickens rapidly downslope.

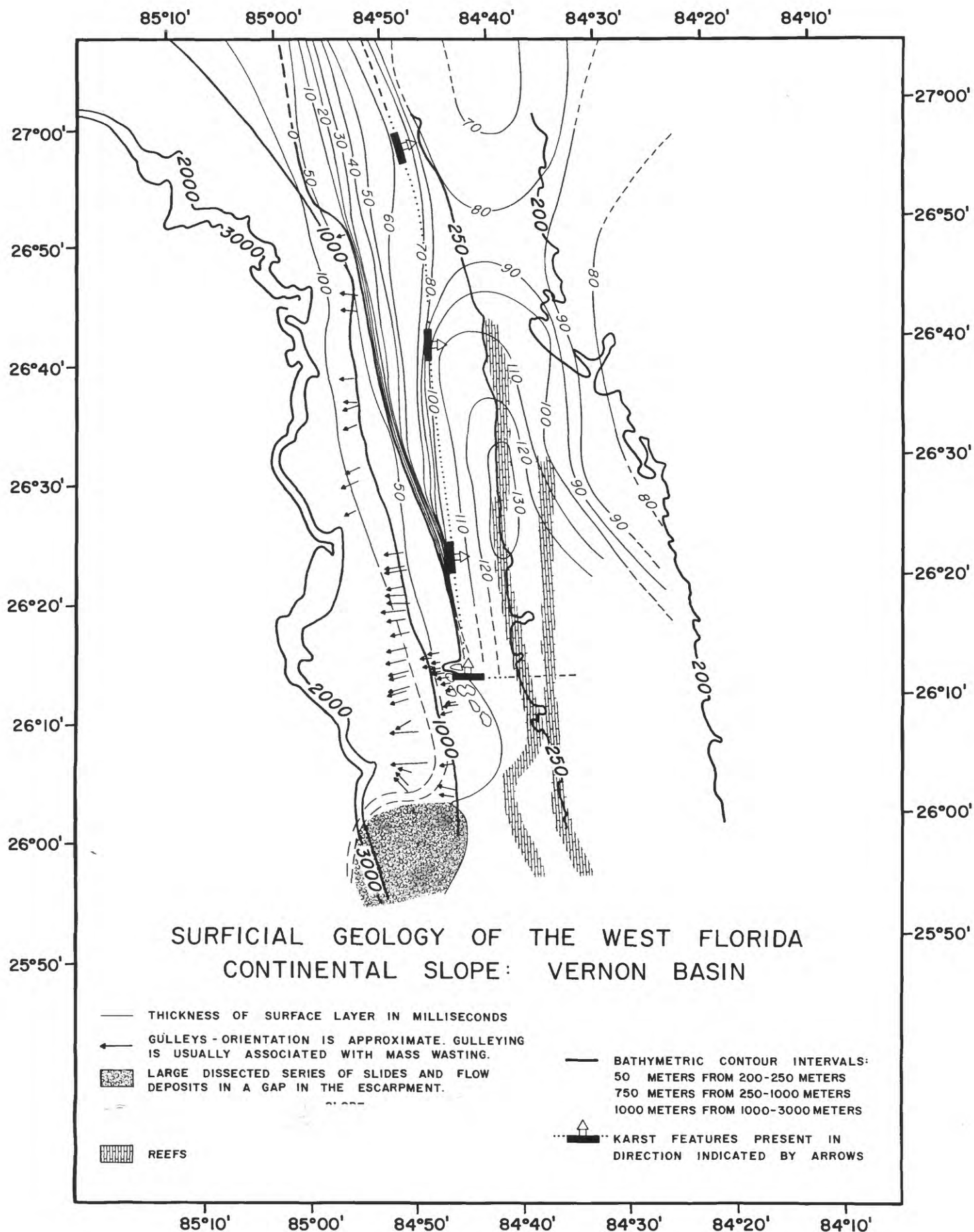
The full range of mass-wasting phenomena, from massive slumps to crumpling probably associated with creep are represented in the slope. Although the ages of these events are not known, they are known to have affected both the surface sediments and those located well into the subbottom.

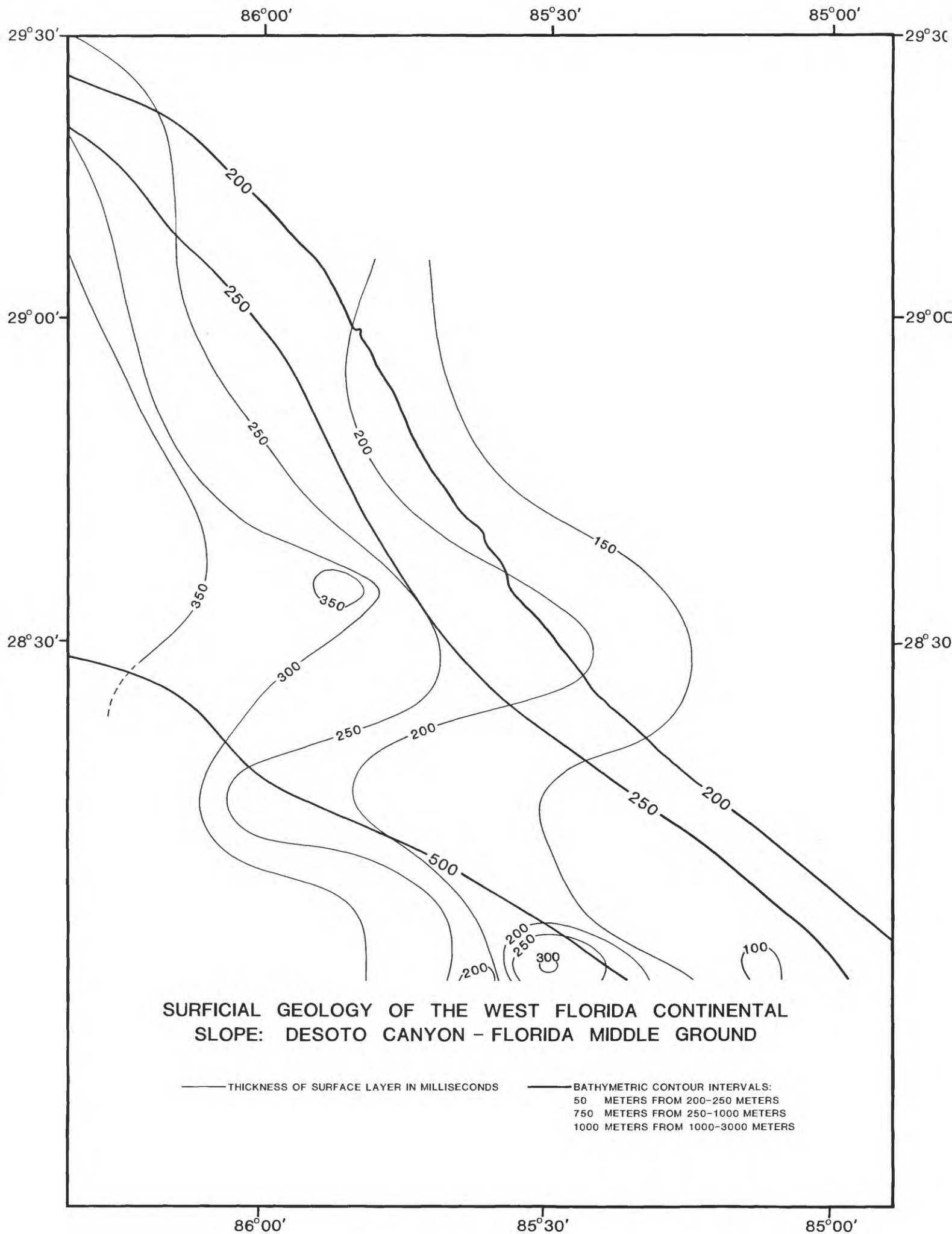
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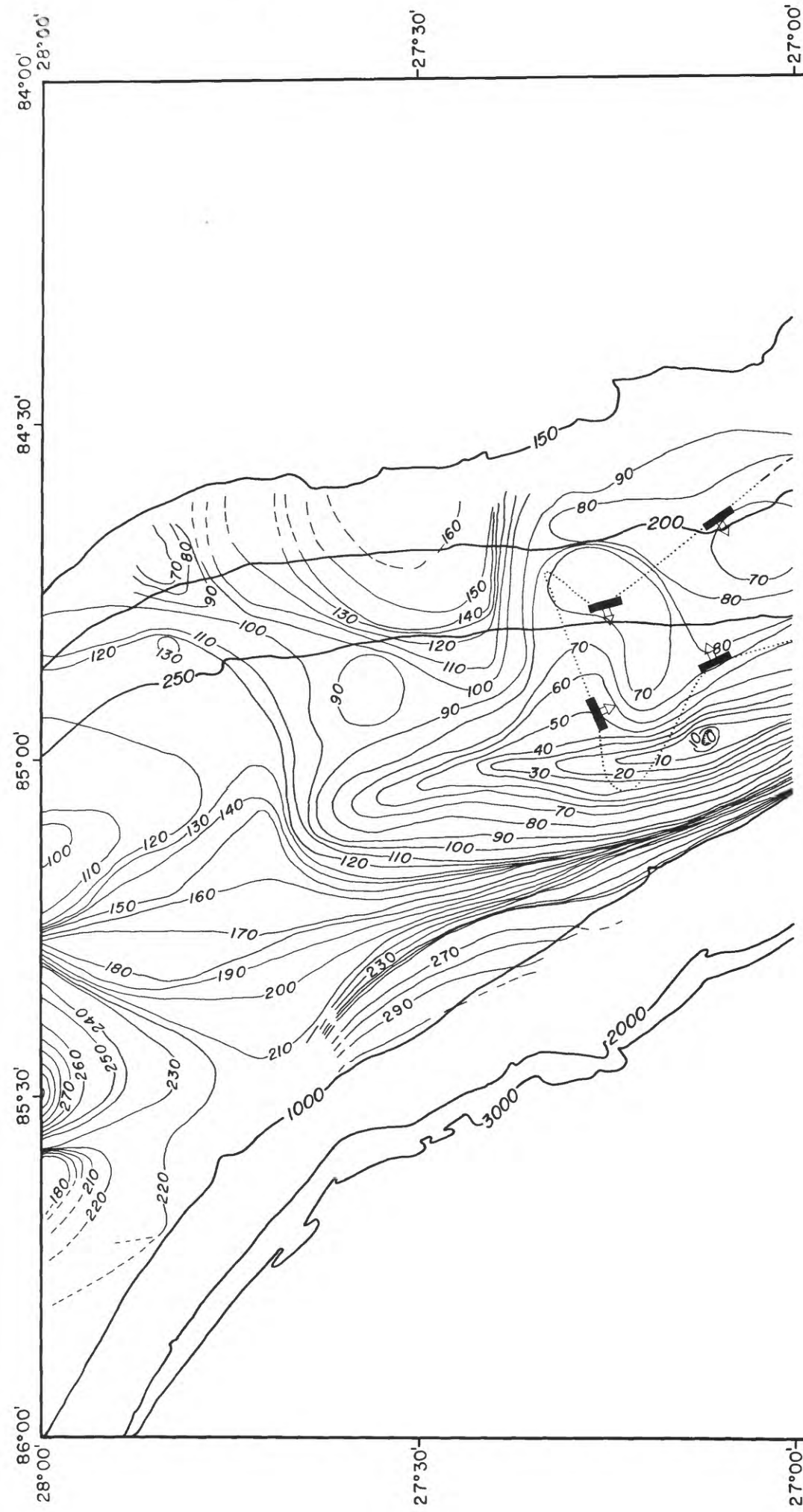
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Both the deeply drowned reef trends exposed at the surface in the southern portion of the study area and the erosional unconformity suggest that considerable subsidence of the outer portion of the West Florida margin has occurred during the late Tertiary and even the Pleistocene.

Folding, perhaps associated with gravity tectonics, affected the outer portion of the slope during the late Tertiary, probably in Late Pliocene time. Hydrocarbon exploration and development projects should take three potential geohazards into account: (1) potential for bottom failure in areas of shallowly buried karst surfaces, (2) possible surface slope failure due to mass-wasting phenomena, and (3) the high velocities of the Loop Current which will affect operations in the water column, with concomitant potential for severe bottom scouring.







SURFICIAL GEOLOGY OF THE WEST FLORIDA CONTINENTAL SLOPE: THE ELBOW

- THICKNESS OF SURFACE LAYER IN MILLISECONDS
- BATHYMETRIC CONTOUR INTERVALS:
50 METERS FROM 200-250 METERS
750 METERS FROM 250-1000 METERS
1000 METERS FROM 1000-3000 METERS
- △ KARST FEATURES PRESENT IN DIRECTION INDICATED BY ARROWS

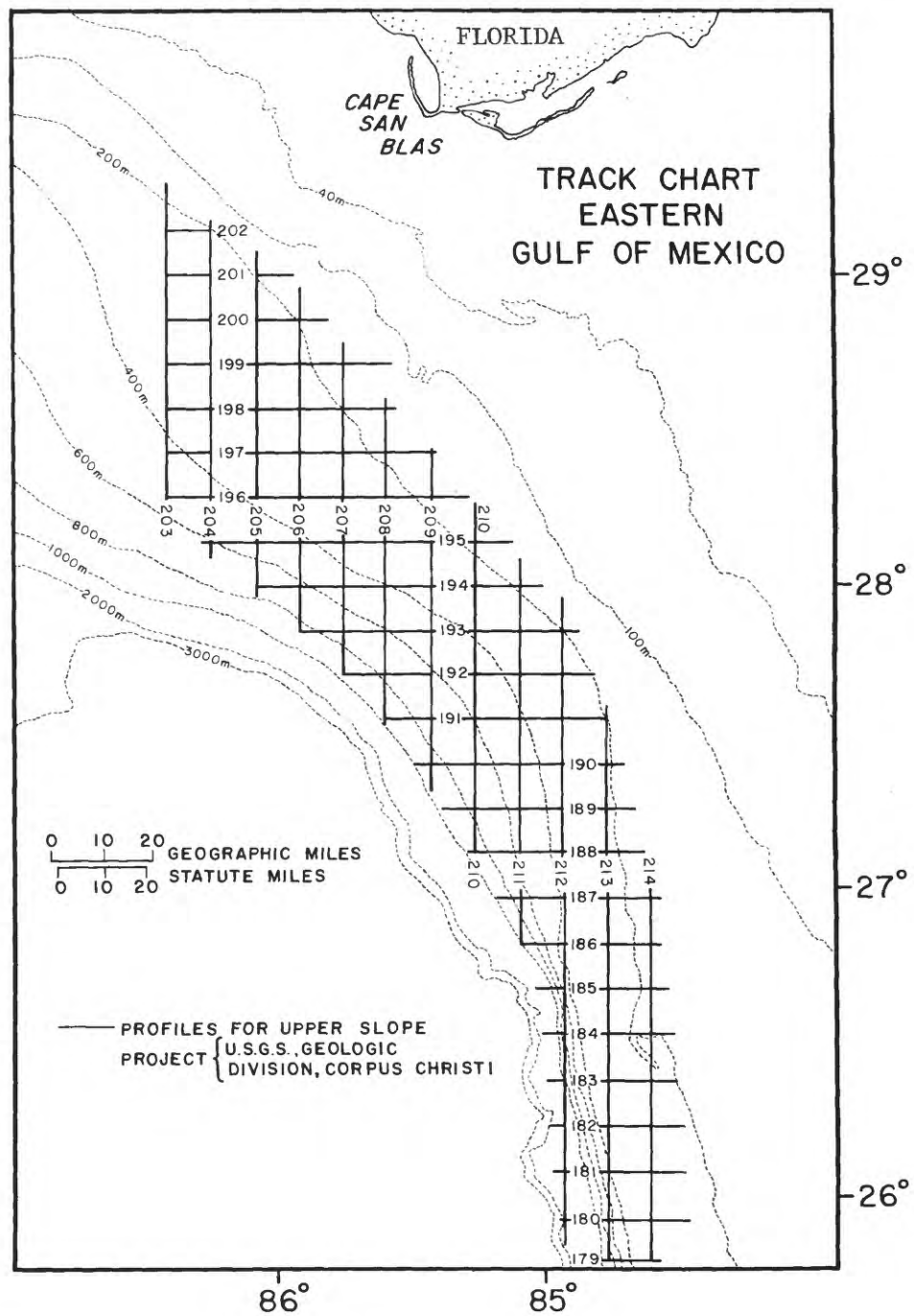


Figure 1a: Study area and general seismic net.

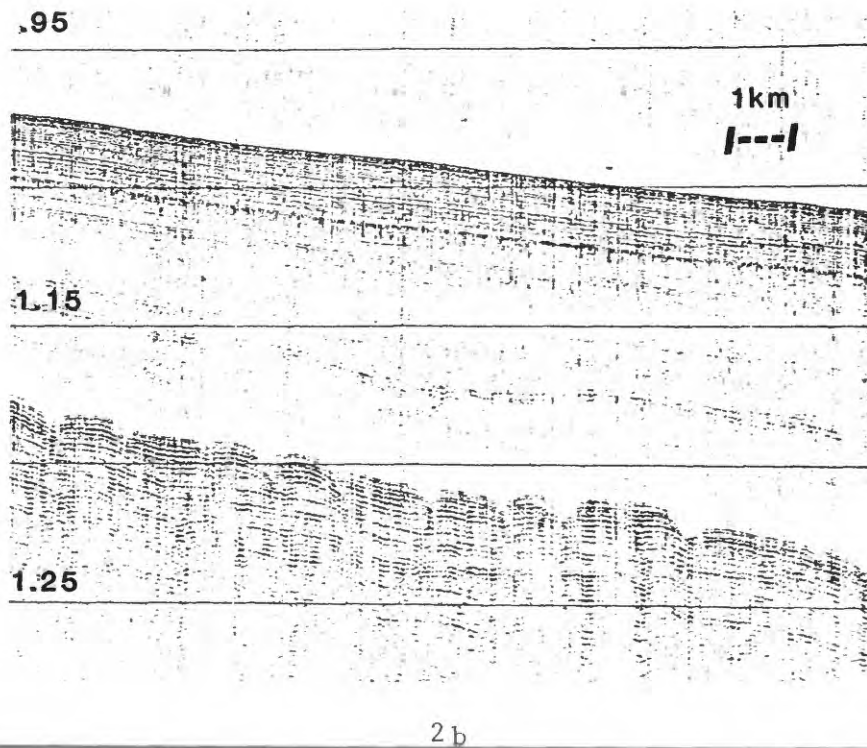
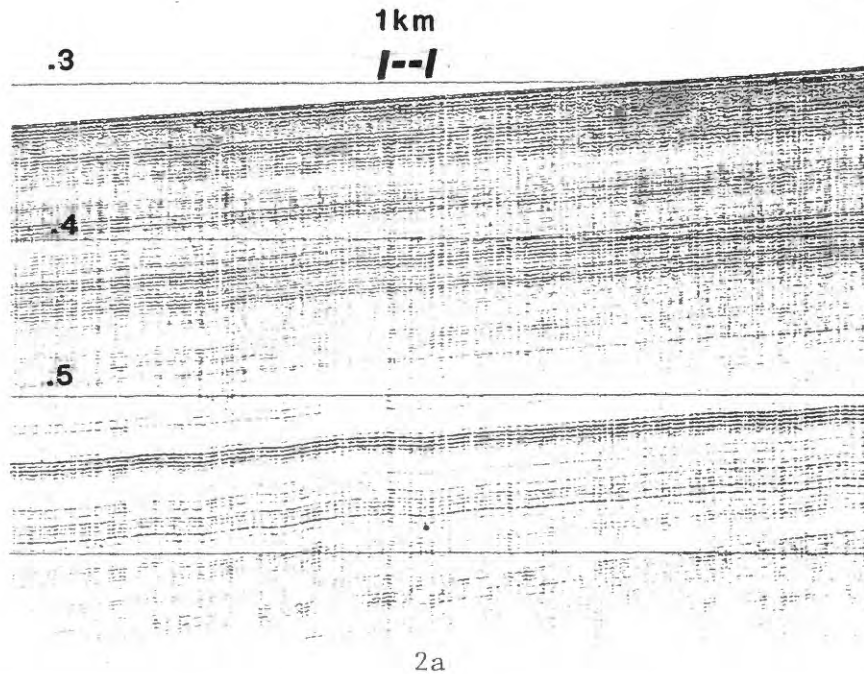


Figure 2: The stratigraphic relationship between the top layer and the first major subbottom reflector that is present throughout much of the study area. Based upon Mitchum's (1976) core data, this surface is interpreted as Pliocene. In Fig. 2a (Line 210), the contact appears unconformable, while in 2b (Line 200), it appears to be conformable.

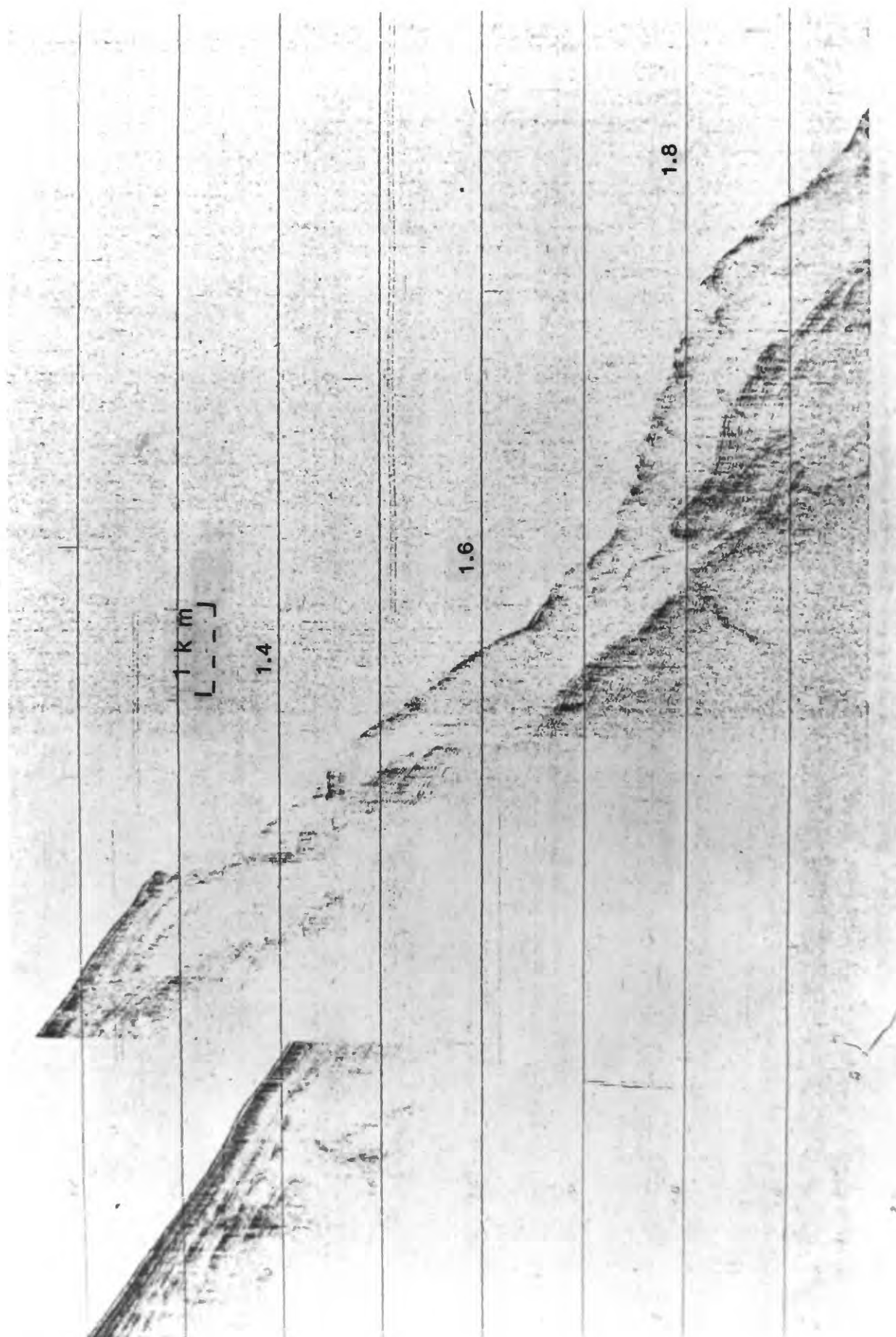


Figure 4. Mass wasting deposits partially filling the re-entrant at the southern end of the area of investigation.

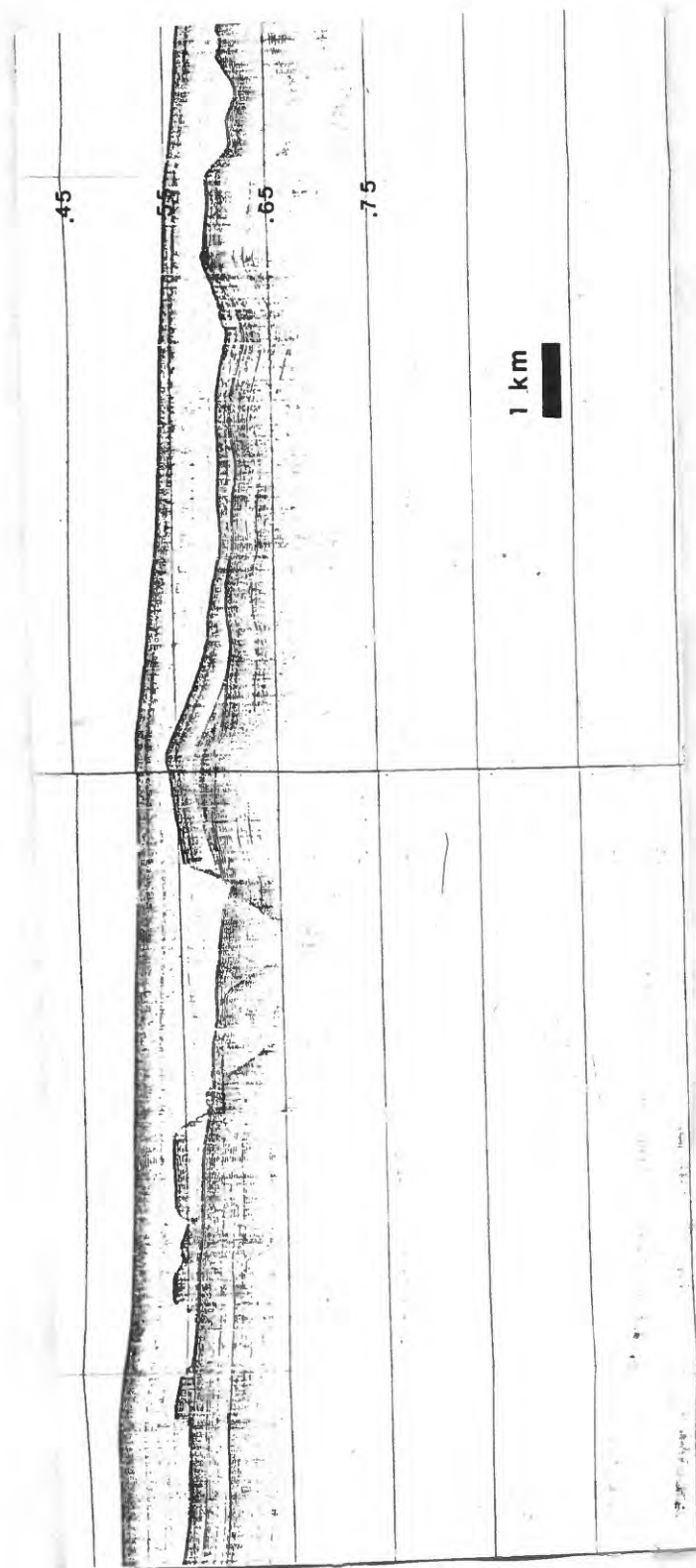


Figure 3. Features on the upper slope interpreted as karst (Line 212).

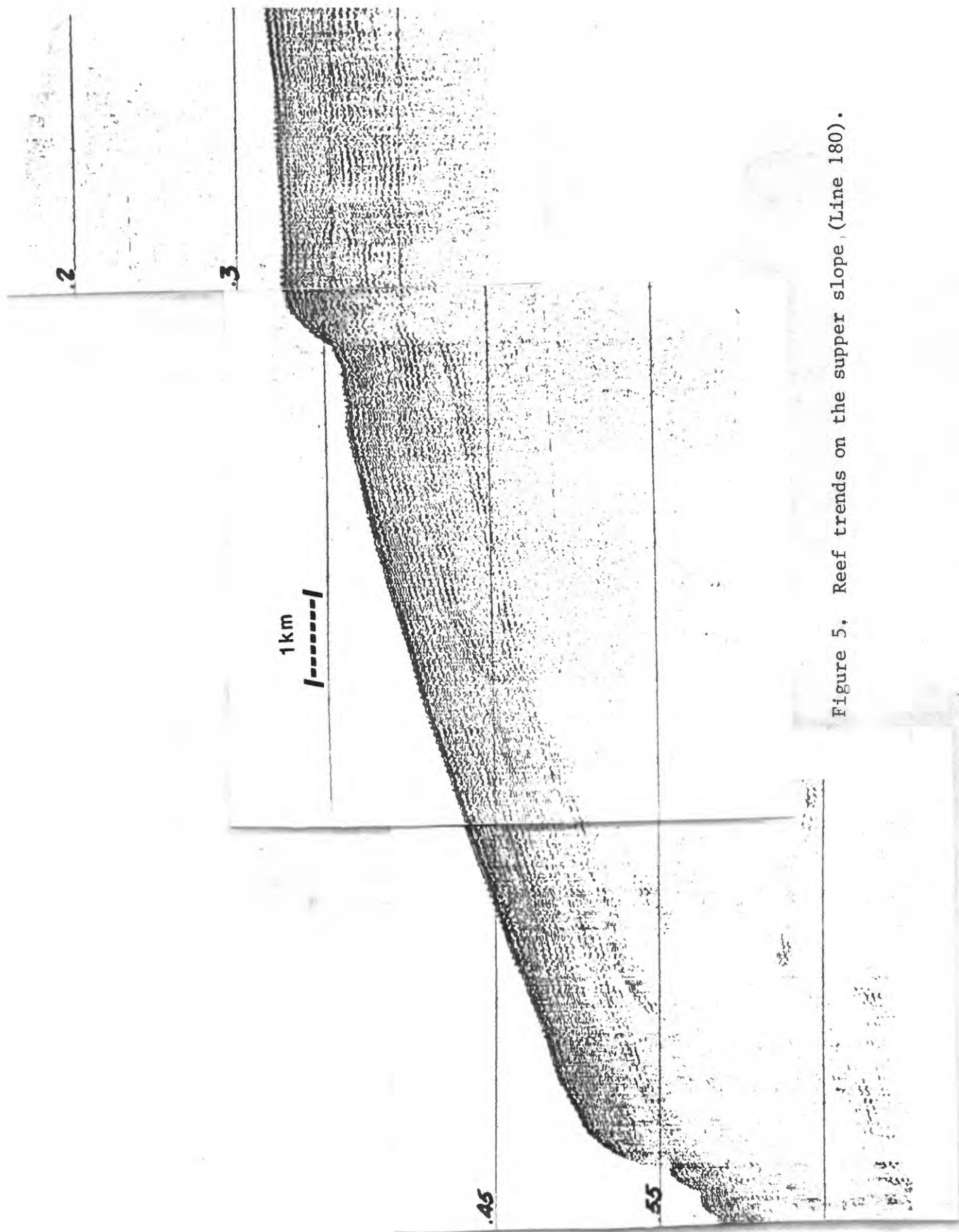


Figure 5. Reef trends on the supper slope (Line 180).

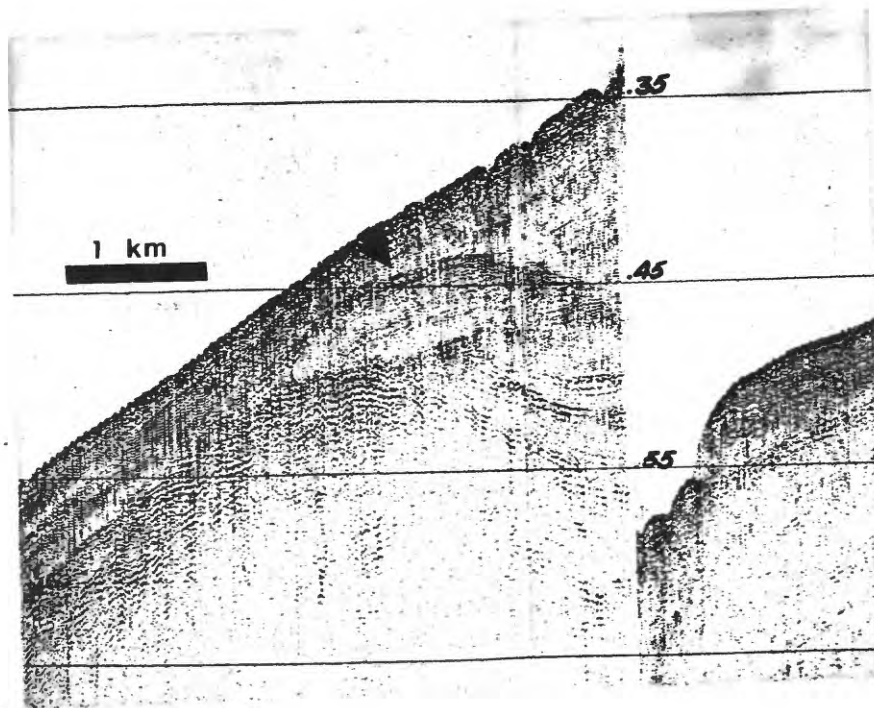


Figure 6. Buried reef on the upper slope (Line 180).

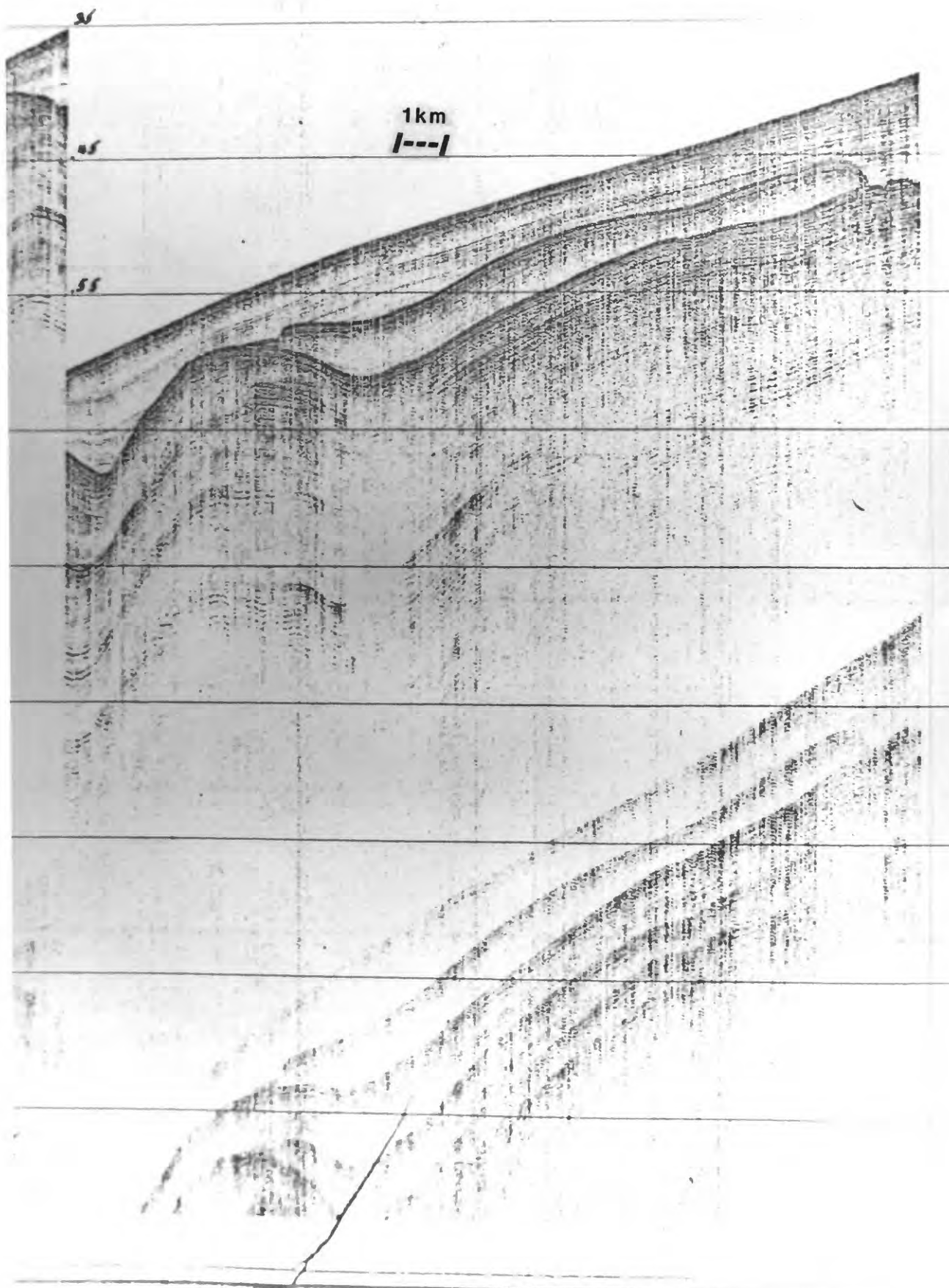


Figure 7. Folds on the upper slope which are interpreted to be the result of gravity-induced sliding (Line 186).

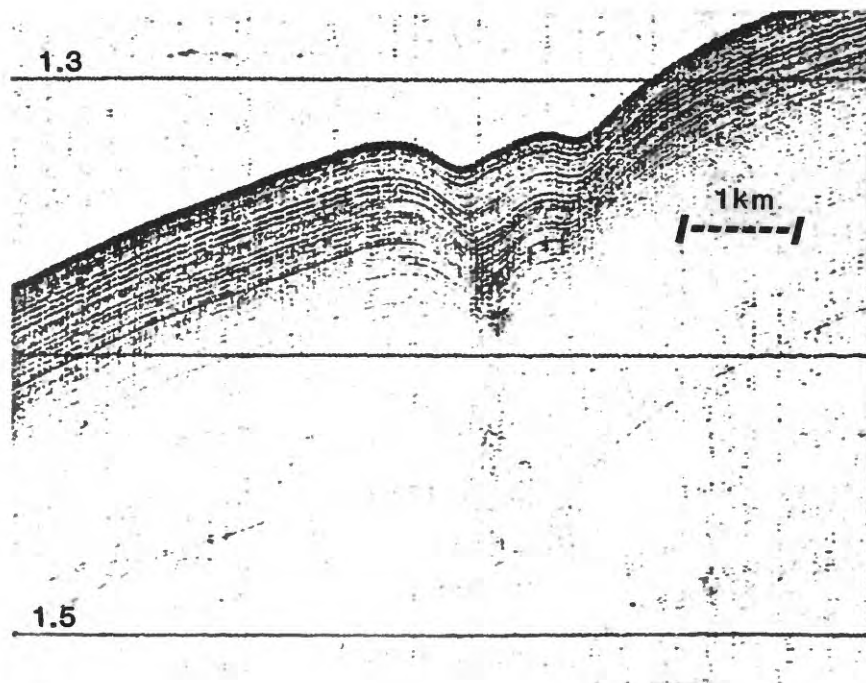


Figure 8. Fault at the surface that probably marks the line of detachment of a mass-wasting event (Line 191).

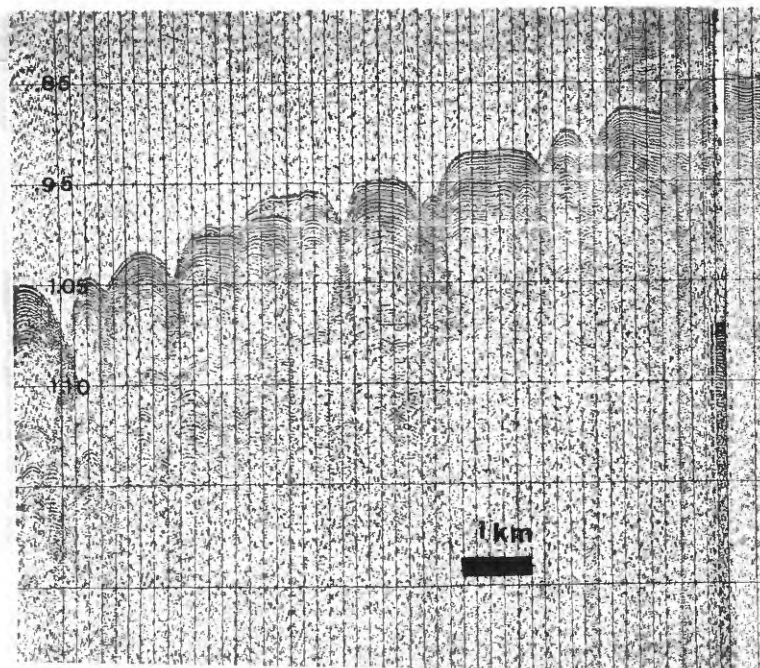


Figure 9. Gullying on the slope. Gullies are roughly perpendicular to the isobaths (Line I-10).