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Evidence for Slope Instability and Current-Induced Sediment Transport, the RMS *Titanic* Wreck Search Area, Newfoundland Rise

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Abstract

The first map of the sea bed morphology and sedimentary features within the RMS *Titanic* search area is proposed from the interpretation of SAR side-scan sonar images. Downslope sedimentary features such as erosional furrows and crown scarps constitute a 7 km wide instability corridor. A large field (15 km^2) of asymmetrical sediment waves indicating a downslope transport is identified. Current-induced features corresponding to associated sand ribbons and barchan dunes resulting from the Western Boundary Undercurrent action are mapped. The morphology of the *Titanic* Canyon is also precised from the SAR images. Finally, the origin of the sea bed features is discussed in an attempt to link each bed form to a sedimentary process.

Introduction

For twenty-three days, side-scan sonar survey was conducted over a 300 km^2 area of the continental rise of Newfoundland in July 1985 (Cochonat and Ollier 1987), (Fig. 1). Its primary purpose was to search for the wreck of the *Titanic* as part of a cooperative project between IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) and the Woods Hole Oceanographic Institution.

The surveyed area is located at the bottom of a submarine valley near the intersection of two main bathymetric features (Fig. 1): the southeast Newfoundland Ridge and the J anomaly ridge, about 100 km east of the eastern edge of the Laurentian submarine fan. The orientation of the submarine valley is thought to result from a structural control by the J anomaly ridge. Surface cores were collected on the northern flank (Pastouret and others 1974) and on the southern flank (Allam and others 1981, 1987) of the southeast Newfoundland Ridge, but not within the studied area itself. The sediments recovered from the cores consist of biogenic oozes overlying terrigenous sediments interbedded with turbidic sands and gravels, and ice rafted debris.

Three cruises were carried out in 1980, 1981, and 1983 near and in the study area by Ryan (1982, 1983, 1986). Bathymetric and side-scan sonar surveys were completed as well during the three cruises, allowing the identification of a submarine canyon named *Titanic* Canyon, and unstable sedimentary bedforms appearing as "crescent-shaped slump scars and debris flow aprons." SeaMARC I sonar imagery also revealed "a lineated bottom roughness interpreted as erosional furrows and/or the outcrop expression of erosion-resistant bedding" on the west bank of the canyon (Ryan 1982). Ryan (1986) also mentioned the existence of "large asymmetrical giant ripples" (wavelength > 50 m) and "migrating barchan dunes" to the south of the *Titanic* Canyon.

In 1985, the IFREMER SAR device (Systeme Acoustique Remorqué, Deep Towed Acoustic System) was used to investigate the present study area. The SAR system permitted the collection of a mosaic of 1 km wide overlapping contiguous sonar images and 3.5 Khz subbottom profiles. The SAR cruise primarily resulted in focusing the Angus and Argo *Titanic* wreck research (Ballard 1986) outside the SAR survey area and contributed significantly to its subsequent discovery. Also, the 1985 SAR survey brought

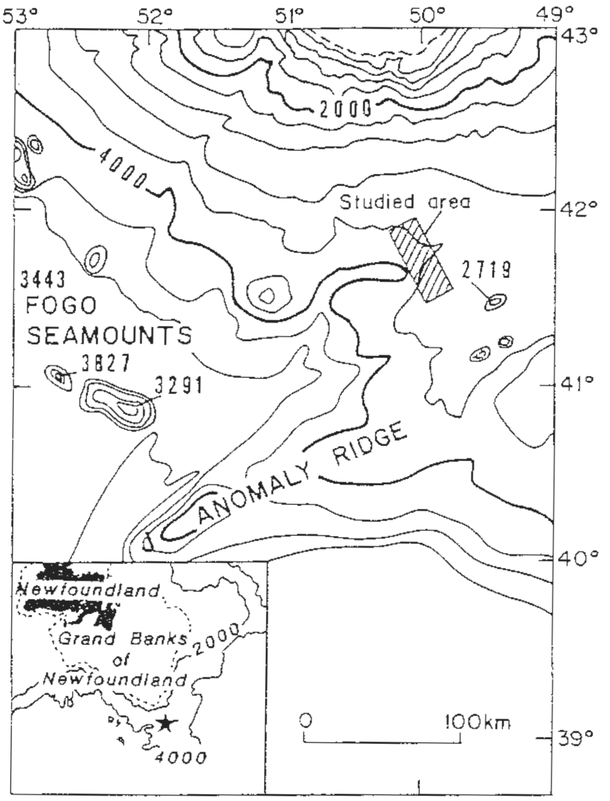

Figure 1. Bathymetric map of the Grand Banks (after Uchupi and Hays, 1981) showing the study area.

data up to date, improving the quality of the sea floor mapping and adding to the geological knowledge of a wide zone around the *Titanic* site. The high resolution SAR images has allowed us to resolve sea bed features of metric scale range accurately, to aid in their identification as sand ribbons or sediment waves, to propose the first map of the sedimentary facies in the area, and suggest the primary sedimentary processes involved on the Newfoundland rise.

After the discovery of the *Titanic* wreck, Uchupi and others (1988) looked at the photographs and video data from a restricted area in the southern part of the present study zone. They described several sea bed features like "sand ribbons, continuous rippled sand sheets, barchan dunes, mud waves, mud ripples, moats, comets and shadows." In the present report, these data were compared to the SAR images to interpret the sedimentary structures located at the southeastern part of the SAR survey area.

Data Acquisition and Processing

The SAR is a deep-towed (up to 6,000 m) sidescan sonar equipped with 170 (port) and 190 kHz (starboard) tranducers and a 3.5 kHz subbottom profiler (Farcy and Voisset 1985). At the time of the cruise, the system was able to produce one-kilometer wide swaths of the sea floor with a pixel size corresponding to a 30 cm field patch (today, the range has been increased up to 750 m). In soft sediments, subbottom profiles penetrate the sea floor to a depth of up to 80 m with a vertical resolution of about 0.75 m. The SAR is towed near the bottom at a height of about 70 meters and a speed of 2 knots. All the data are digitized and stored on magnetic tapes for reprocessing onshore. The navigation during the *Titanic* survey used *Loran C* for the ship, whereas acoustic transponders were used to navigate the SAR. All the data were processed using IFREMER TRIAS software ("Traitement des Images Acoustiques Sous-marines") which offers powerful capabilities previously described by Augustin (1986).

The Mosaic

The SAR side-scan sonar mosaic aids the identification of three physiographic regions (Fig. 2):

1. The *Titanic* canyon which traverses the entire mosaic from northeast to southwest (N220);
2. A gentle slope east of the submarine canyon consisting of an eastern striped facies and sediment patches zone, and a western sediment wave field;
3. An area west of the canyon having an irregular topography where side-scan sonar images show scars and pronounced lineations oriented downslope. The western area is referred as the "instability corridor."

The Titanic Canyon

A 15 km long section of the *Titanic* Canyon crosses through the SAR mosaic with a slightly curved path, except at latitude 41°42′ where the strike of the canyon changes abruptly from 230° to 195°. The upslope continuation of the *Titanic* Canyon still remains uncertain. Uchupi and others (1988) think it is directly connected to the Cameron Canyon on the upper slope of the Grands Banks. On the other hand, recent bathymetric compilations (Canadian Hydrographic Service 1987) do not show clear evidence for the continuation of the *Titanic* Canyon up to the Grands Banks upper slope.

The 3.5 kHz SAR sea floor cross-sections show that the canyon has a very distinct U shape. Going downslope, the canyon tends to widen from 300 m in the northern section to about 1,000 m in the southern section. The canyon depth remains constant (50 m) in the surveyed area. The mean slope value of the can-

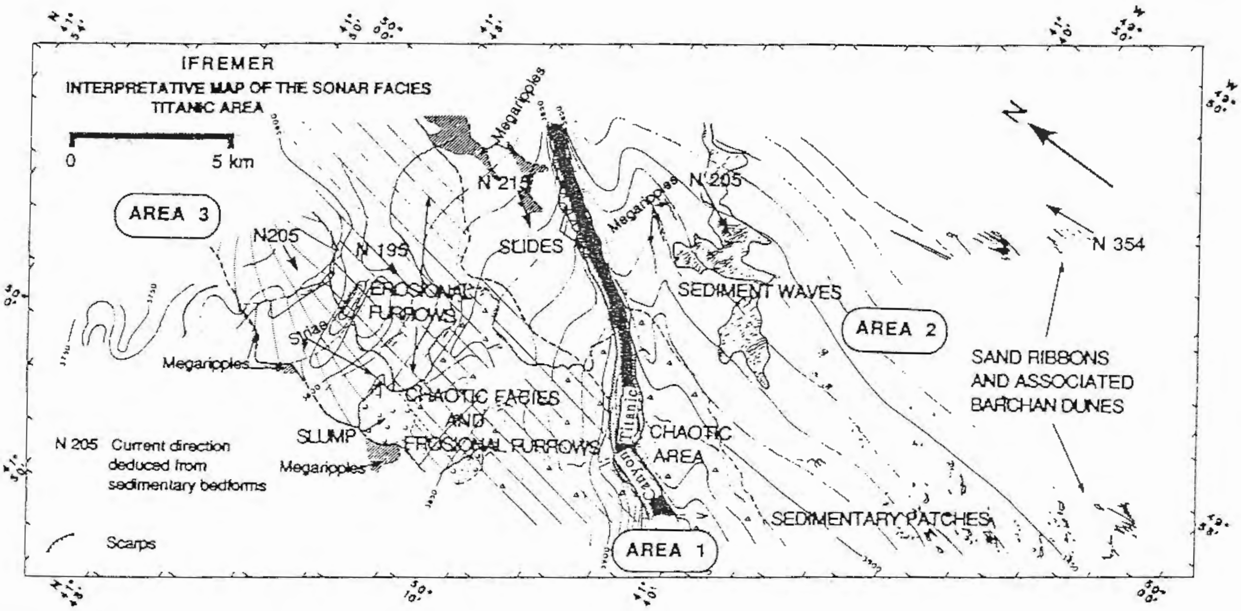

Figure 2. Map interpretation of the side-scan sonar mosaic showing the three different physiographic regions: area 1—the canyon; area 2—a south east region with gentle slope and specific sedimentary features; area 3—a northward region having more irregular topography where side-scan sonar images show pronounced lineations oriented downslope.

yon floor is 0.85 percent (0.5°); in the northern section, the slope value is only 0.4 percent (0.2°) whereas in the southern section the slope value is increasing up to 1.55 percent (0.9°). Several hundred meter long sections of the canyon banks are affected by slides which accumulate at the foot of the canyon walls (Fig. 3). The wall slides appear to be overlaped with the sediments filling the canyon giving a very flat topography at the canyon floor.

East Section of the SAR Mosaic

Sediment Waves. A field of sediment waves was mapped over an area of about 15 km^2 east of the submarine canyon (Fig. 2). The crests of the bed forms are oriented perpendicularly to the regional slope. The crests are about 400 m to 500 m long with anastomosed undulating shapes. The wavelength of the bedforms (crest to crest) is about 60 m. The height of the waves calculated from the acoustic shadow length of the flanks and from the images of the sea floor profiles (Fig. 4) is of the order of 3 m.

Differences in the sonar responses of the two flanks of the waves indicate that they are strongly asymmetrical, with their steep sides facing downslope and their gently dipping sides facing upslope (Fig. 4). The asymmetrical shape and size of the sediment waves are confirmed by the sea floor profiles (Fig. 4).

Poor penetration suggests that the waves are composed of coarse material. This coarse material appears as high reflectivity patches at the top of the sediment waves. These waves are similar in scale to the gravel waves previously described by Piper (1985) on the Laurentian fan and are thought to result from unusual downslope flow conditions.

The Striped Facies. To the east and south of the sediment wave field, the sea floor is crossed by numerous streaks of low reflectivity, termed "the striped facies." These spectacular streaks are typically 10 to 100 meters wide and up to several kilometers long (Fig. 5). They are sub-parallel to the isobaths which run north-south on the east side of the valley. The profiles do not exhibit any relief, thus, the striped facies are due to subtle surficial textural variations.

The striped facies are thought to correspond to fine material resedimentation along current lines on a substratum consisting of coarse material of sandy to gravel type as described by Uchupi and others (1988). The description and the size of striped facies are in good agreement with the description of the sand ribbons by Kenyon (1970). The accuracy of the SAR images allows one to see that the streaks are in some places associated with 15 to 50 m wide perpendicular arcuated bedforms (Fig. 5).

The crescentic shape bedforms have the same size and are deposited in the same place (Fig. 1) as the barchan dunes observed and described by Uchupi (1988) from the Angus photographs and video trac-

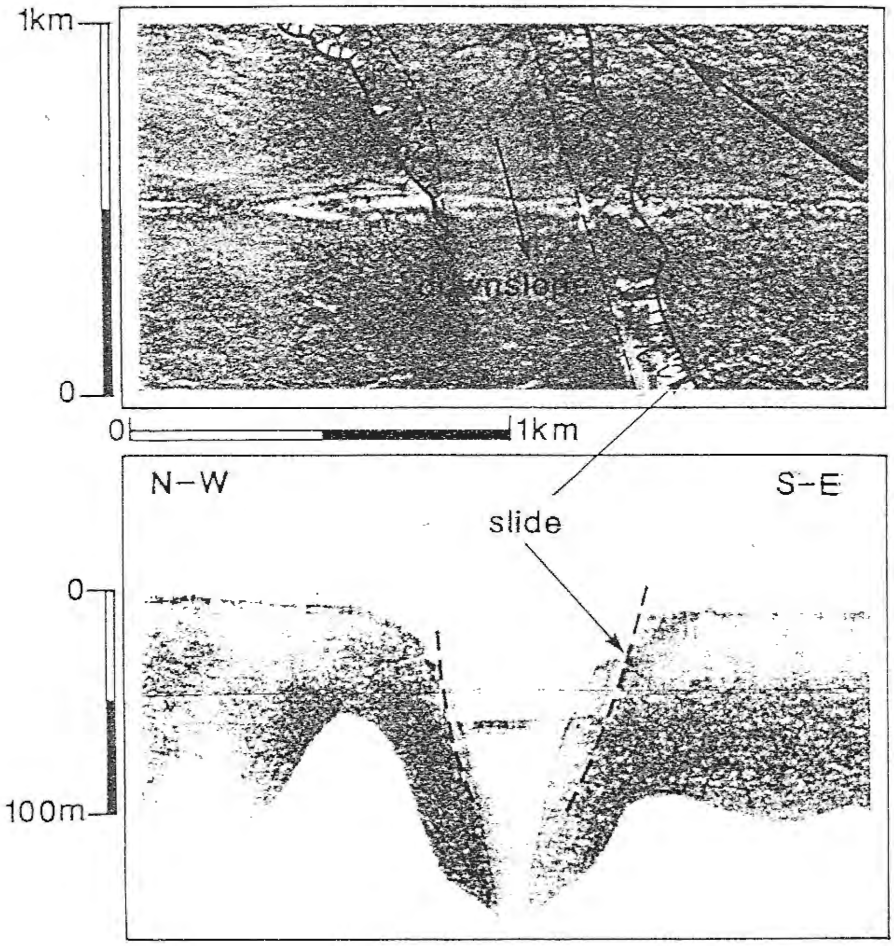

Figure 3. Side-scan sonar sonograph and 3.5 kHz subbottom profile of the box-shaped submarine canyon shown on Figure 2. Many closely-spaced slope failures occur along the canyon walls.

ings. On the SAR images the barchan dunes are either isolated or organized in group; they usually are isolated when there is very little low reflectivity material on the sea floor and grouped when there is more low reflectivity material. According to their morphology, the associated sand ribbons and barchan dunes would correspond to an intermediate type between b and c of Kenyon's sand ribbons classification (1970). Images of a deep field of sand ribbons and associated barchan dunes (3,800 m) have not previously been published.

West Section of the SAR Mosaic

To the northwest of the study area, on the right bank of the canyon, a seven kilometer wide corridor of complex topography was studied. This may be the result of large sedimentary instability events on the rise which leads to the canyon at the bottom of the regional valley.

The sediments in this area appear to have been removed along numerous parallel, rectilinear furrows (Fig. 6). The furrows are 15 meters wide and several kilometers long with a downslope orientation. The furrows show no appearance of significant sediment filling (Fig. 6). According to Flood (1983) such furrows could be eroded by the coarse fraction of a sedimentary flow. Several scarps facing downslope, interpreted to be mass movement scars, occur in this area and truncate strata crossed by the erosional furrows (Fig. 6).

At the bottom of the corridor the topography is highly irregular, showing chaotic facies on the sonar images (Fig. 2). The irregular topography is thought to result from the accumulation of the sediments at the bottom of the valley after movement along the instability corridor. The characteristics described above, and in particular the general direction oriented N200, suggest that the instability corridor was initiated independently from canyon formation processes.

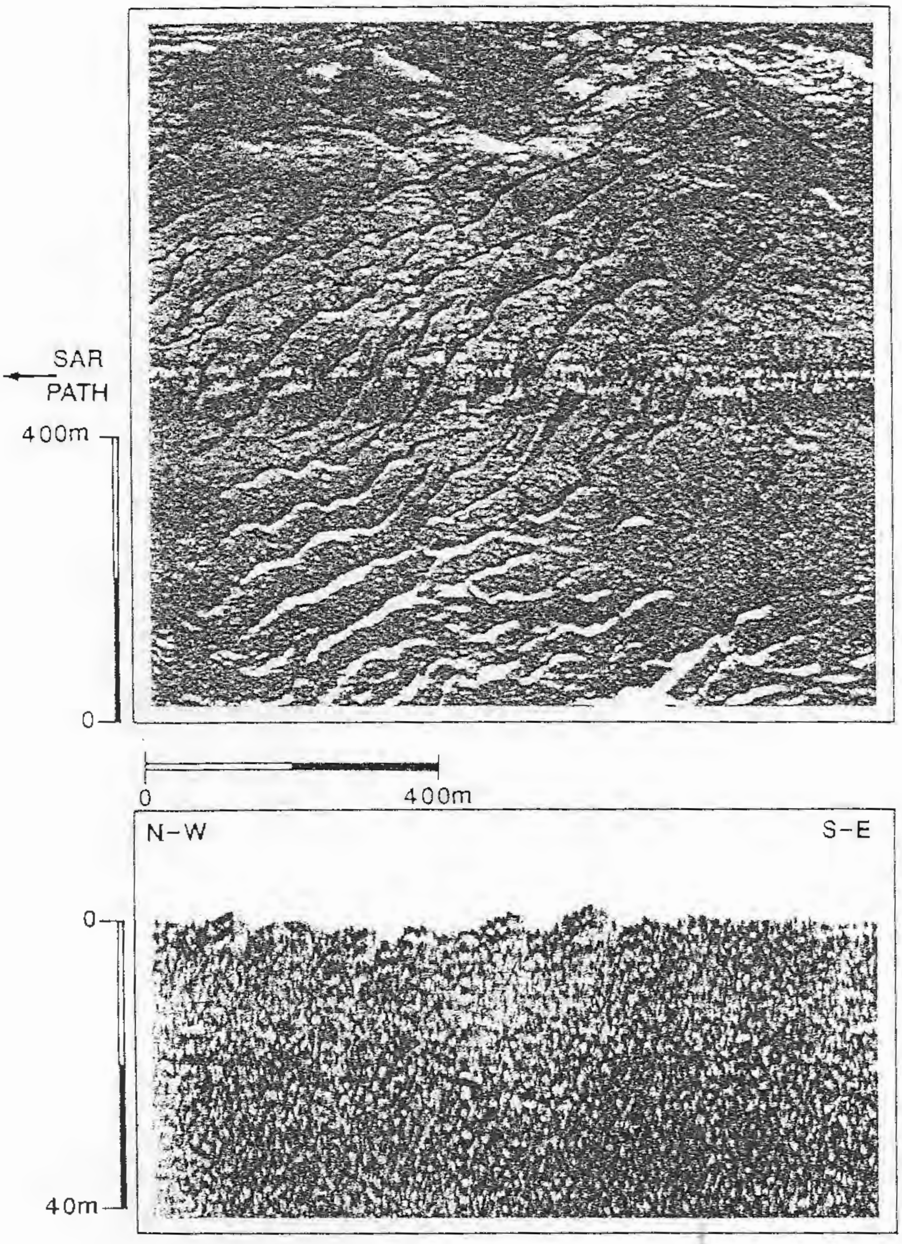

Figure 4. Side-scan sonar sonograph and 3.5 kHz subbottom profile showing a part of a field of asymmetrical sediment waves shown on Figure 2 with their steep sides facing downslope towards base of the figure.

Discussion

Two kinds of sedimentary transport are suggested on the basis of the SAR images descriptions. The first type is related to the "mass movement process" including the instability corridor of the west bank of the canyon, the sediment waves of the east side, and the canyon itself. The second type of sedimentary transport is related to "current induced processes" on the eastern section of the SAR mosaic with the sand ribbon area.

Directions of sedimentary transport can be inferred from the study of the sedimentary bedforms and the bottom topography in the area:

- Mass transport processes: A N195 direction given by the lineations of the instability corridor indicating a downslope transport along the west flank of the submarine valley. The N205 direction of transport is perpendicular to the sediments waves crests; A N220 direction given by the canyon indicating a transport slightly oblique to the regional slope.
- Bottom current induced features: The sand rib-

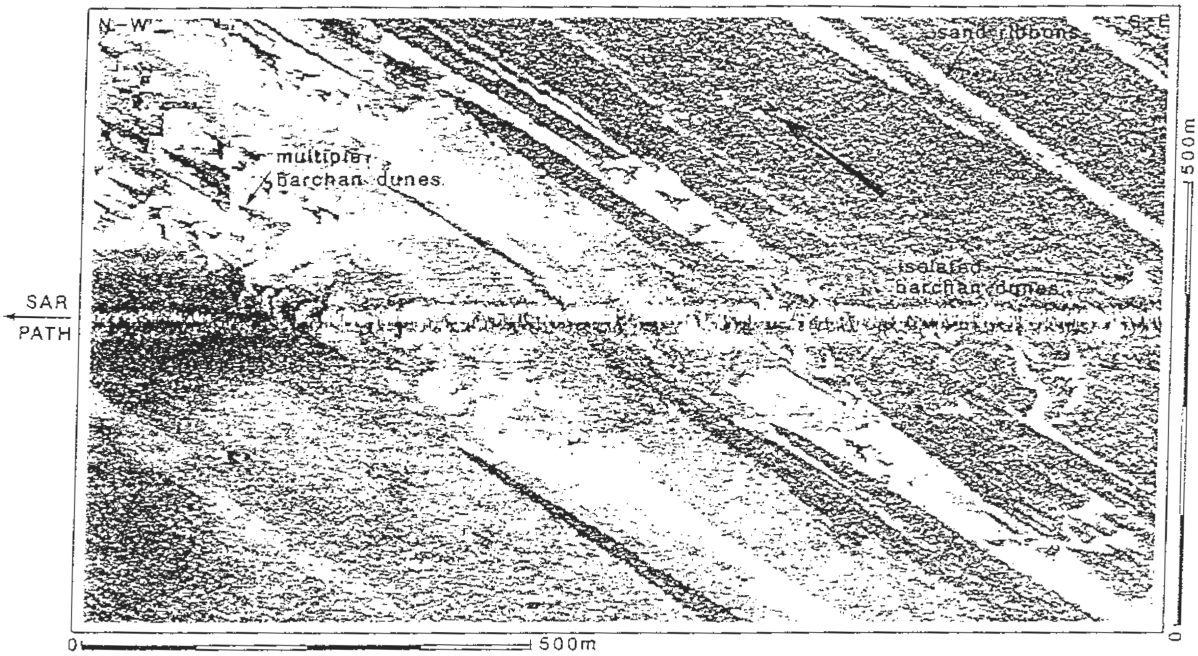

Figure 5. Sonar image of a field of sand ribbons and associated barchans dunes that have been removed and deposited by the Western Boundary Undercurrent (WBU) which is parallel to the isobaths.

bons and associated barchan dunes indicate a subbottom current from south to north.

Mass Transport Processes

The morphologic features such as mass movement scars and erosional furrows constituting the "instability corridor" result from one or several gravity events occuring on the local slope. The erosional furrows appear to extend upslope beyond the boundaries of the SAR mosaic suggesting gravity events with a transport efficiency of the order of tens of kilometers. On the other hand the slides related to the scarps correspond only to a maximum downslope transport of kil-

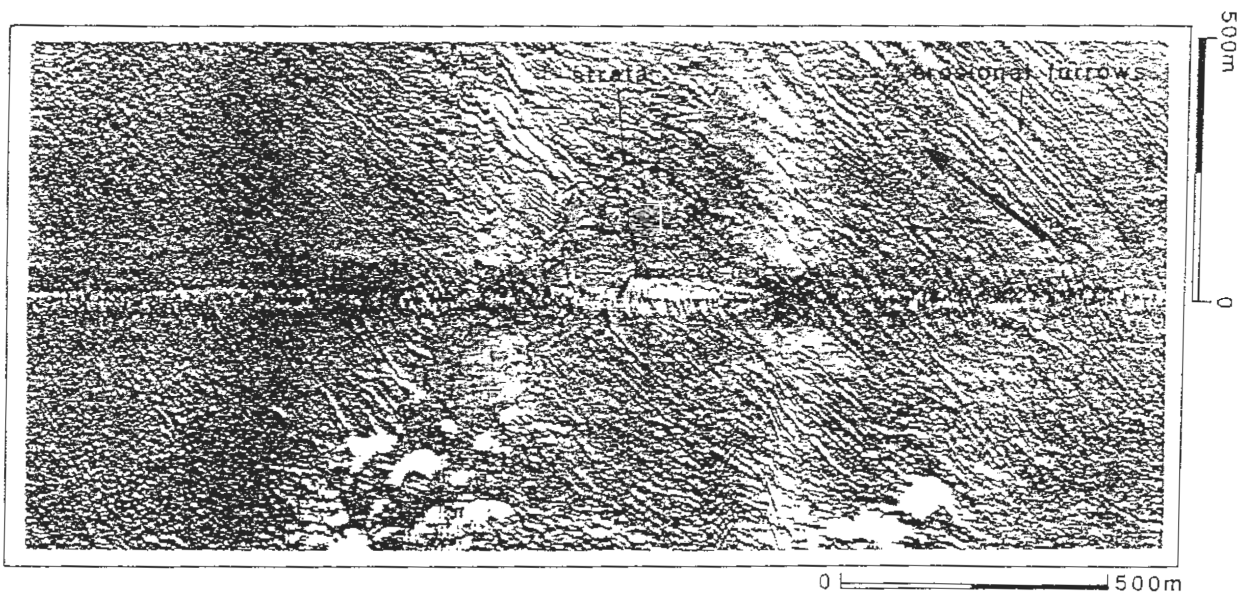

Figure 6. Sonograph of a part of the instability corridor. The straight erosional furrows, oriented downslope, dissect ancient slides scarps showing truncated strata.

ometric scale range. Although no sampling was possible within the surveyed area, the regional geological setting suggests that coarse material such as pebbles and ice rafted debris can be present in the recent sediments. Gravity events with a transport efficiency up to tens of kilometers (like those related to the erosional furrows) and involving coarse materials are usually interpreted as debris flow (Stow 1985). The instability corridor is thus a complex area where mass movement processes of different scales such as debris flow and local slides or slumps can occur. Although slumps or slides can trigger large scale events of debris flow type, we do not know if both kinds of gravity events were originally related or occurred independantly.

The kind of downslope transport which initiated the sediment wave field east of the *Titanic* Canyon still has to be explained. By comparison with morphologically similar bedforms described by Piper (1985) on the nearby Laurentian fan, the *Titanic* submarine sediment waves are thought to result from strong downslope current of at least 10 m/sec. As the velocity is decreasing the sediments are deposited and reworked into large-scale waves by tractional phenomena. The bathymetric setting of the *Titanic* area could explain the slowing of a downslope current particularly with the decreasing slope on the rise.

The existence of the *Titanic* Canyon with its relative sharp walls is a morphological evidence that strong erosional currents were funelled along the northwestern flank of the J anomaly ridge. The path change of the canyon at latitude 41°42′ is probably due to the damming effect of the slides coming from the instability corridor area. According to D'heilly's calculations (1987)—who studied a submarine furrow comparable in size to the Titanic canyon—only turbidity currents with velocities of the order of some meters s-1 would be able to erode such a structure. The largest sediment gravity flow events probably occured during the Pleistocene age when there was a low stand of sea level and strong currents coming from the upper slope (Stow 1979, Shanmugan, and Moiola 1982). The lack of levees at the edges of the canyon and the presence of sediments tending to fill it up suggest that the canyon is no longer active today.

Current-Induced Transport

According to the concave side of the barchan dunes facing to the north, the barchan dunes and associated sand ribbons are thought to result from the action of a northward current. A northward bottom current direction is in good agreement with the circulation of the Western Boundary Undercurrent (WBU) in the studied area. After Schnitker (1979), Stow (1979), and Fofonoff (1985), the WBU is following the isobaths of the lower slope of the north-west Atlantic. From the bottom photographs obtained during the 1984 Woods Hole cruise, Uchupi (1988) indicates a northward bottom circulation within the studied area. The 1986 Alvin dives (Ryan PR, 1986) confirmed the northern direction and gave a current velocity of 30 cm/sec. To the west the sand ribbons progressively turn into shapeless sand patches until they finally disappear.

Conclusion

The SAR images from the *Titanic* wreck area allowed to highlight the submarine landscape of the lower continental rise of Newfoundland. Deep-imaging demonstrates the occurrence of a topography inherited from Pleistocene erosional activity, such as the *Titanic* Canyon itself. Today, induced-bottom current bedforms like sand ribbons and associated barchan dunes are prograding over this ancient topography. The age of the gravity events related to the instability corridor and to the sediment waves remains poorly understood; it is not known whether they result from the same event, even though inferred transport directions are quite similar in both cases. Further seismic and cores investigations will probably clarify the geometric organization and the chronology of these gravity events.

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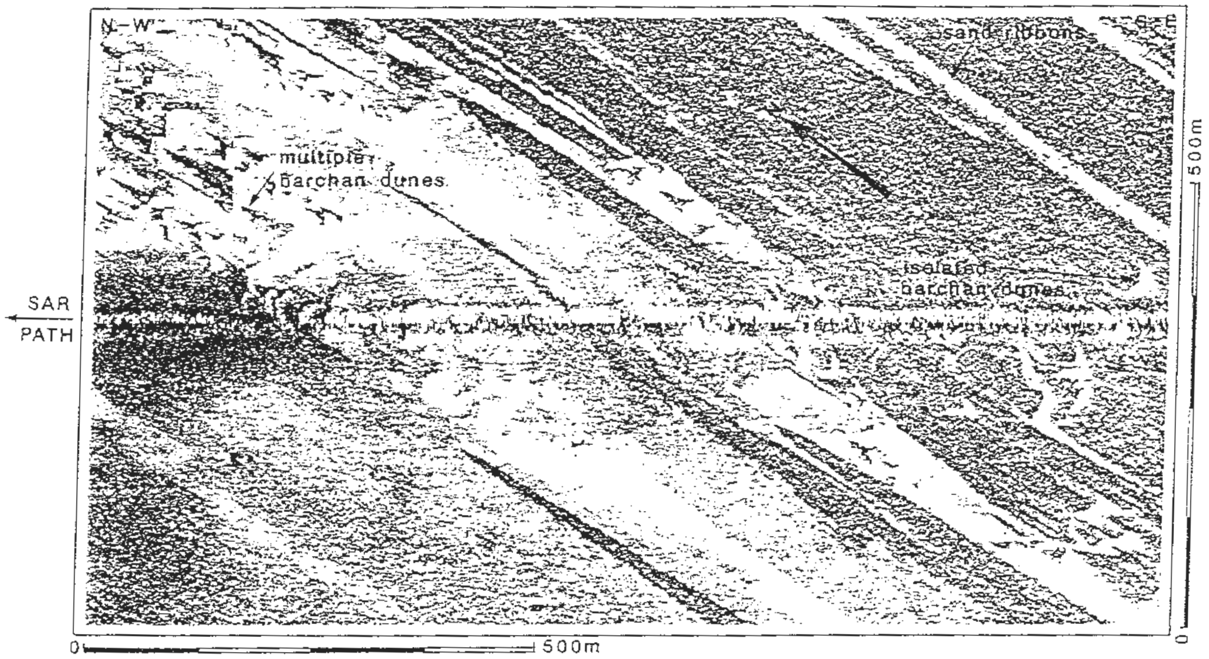

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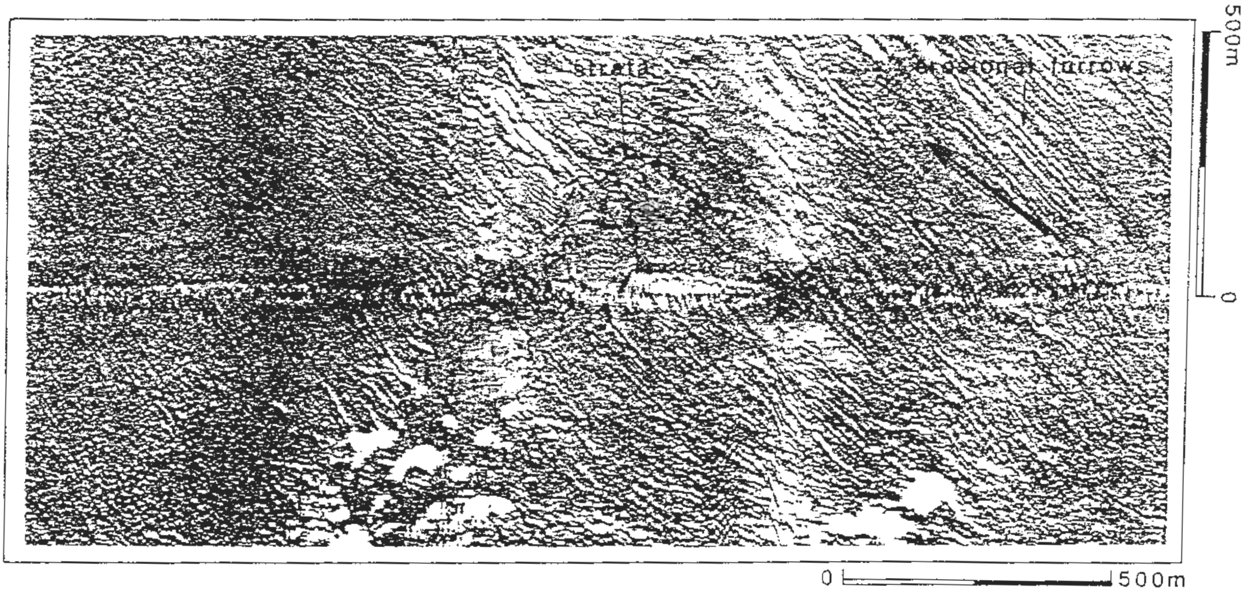

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