SHALLOW SEDIMENT INSTABILITY IN THE CENTRAL PART OF FLEMISH PASS, EAST OF THE GRAND BANKS OF NEWFOUNDLAND

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Preface

This report consists of a description and interpretation of seismic reflection profiles from the western margin of Flemish Pass, accompanied by a series of illustrations of seismic profiles.

Abstract

High resolution seismic profiles from the area south of the Gabriel C-60 well show three distinct horizons of sediment failure and debris flow in the upper few tens of metres of the geologic section, inferred to be of Wisconsinan age. Some of the failure may have been seismically triggered. The debris flows were probably transported through valleys and spread out on the floor of the Pass. Diapir-like structures extend to the seabed from these acoustically transparent horizons.

Forty cubic inch airgun seismic reflection profiles suggest that the Late Neogene to Quaternary seismostratigraphy of the western slope of Flemish Pass is similar to that seen on the Scotian Slope. A Miocene (?-Early Pliocene) phase of uniform deep water sedimentation is followed by a phase of slope progradation associated with shallow slope valleys (?fluvial activity in Late Pliocene and Early Pleistocene). Finally, glacial progradation of the slope in later Pleistocene times is associated with till deposition on the upper slope, widespread gullying downslope, and the accumulation of debris flows on the floor of the Pass.

Introduction

In 1984, the Atlantic Geoscience Centre carried out a SeaMARC mid-range sidescan sonar survey of a small area in the west-central part of Flemish Pass (Pereira et al., 1985), where a study is being undertaken by C-CORE and the Department of Earth Sciences of Memorial University of Newfoundland and the Atlantic Geoscience Centre (Fig. 1). The survey showed that there were few recent seabed morphological features that might indicate near-surface sediment instability, but that there was evidence for buried debris flows and diapir-like features (Pereira et al., 1985).

In November 1985, C.S.S. Hudson cruise 85-044 of the Atlantic Geoscience Centre obtained additional Huntec deep-towed high-resolution seismic reflection (DTS) profiles and two piston cores in the study area (Fig. 2). A 40 cu. in. airgun seismic reflector system was run simultaneously with the Huntec DTS system. This report describes initial interpretatiion of the high-resolution and airgun seismic data. The Huntec DTS profiles allow a detailed stratigraphic sequence to be defined and correlated in the upper 50 m of the sediment column. The resolution of the airgun seismic reflection profiles is much less, but three key reflecting horizons can be defined: the deepest, at over 500 m sub-bottom, can be tied to the Gabriel C-60 well. Lithologic, biostratigraphic, and geotechnical information from the two cores will be presented in a second report.

Geological Setting

The study area is situated on the western slope Flemish Pass, in water depths of 800 to 1150 m between 47° 00′N 47° 25′N (Fig. 1). The western slope of the Pass has a gradient of about 3°, flattening off below approximately 1000 m to the floor of the Pass. Although no large valleys incise the flanks of the Pass, small gullies 20-50 m deep and up to 1 km wide have been mapped from both echosounder profiles and sidescan sonographs.

Alam (1979), who examined and described three cores from the western flank of Flemish Pass (Esso cores 3-1; 4-1; 4-2), recognized three sedimentary facies. Olive-grey, silty mud characterised late Holocene sedimentation, probably dominated by the Western Boundary Under current. The early Holocene, and possibly other warm interstadials, were characterized by carbonate-rich sandy mud, with substantial ice-rafted debris, and higher abundances of sub-arctic foraminifera and coccoliths. Muds with thin sandy turbidites, presumably derived from the margin of the Grand Banks of Newfoundland, characterize glacial maxima when sea level was low. Core 3-1 is located on the floor of Flemish Pass within the study area and has a sedimentation rate about half of that in cores 4-1 and 4-2 which are located in 850 m of water, 25 km north of the study area. Alam (1979) suggested that turbidites at depths varying between 2 and 6 m from the top of the cores represent the late Wisconsinan maximum lowering of sea level. This chronology has not been substantiated directly by either radiocarbon dates or oxygen isotope stratigraphy, but is consistent with the recent stratigraphic work of Schafer et al. (1985).

Interpretation of Huntec DTS Seismic Profiles

Recognition of Facies

Most of the interpretation of seabed instability in the study area is based on Huntec DTS profiles. The new data consists of a Huntec DTS seismic profile of a 100 km long section along the western lower slope of Flemish Pass in water depths of 1100 to 1150 m, and a series of shorter profiles collected obliquely up the western slopes of Flemish Pass to water depths of 500 m (Fig. 2). Typical maximum penetration is 40 to 50 msecs (Figs. 3 and 4).

Two principal acoustic facies are distinguished. Throughout most of the area, the bottom sediment is characterized by closely spaced continuous, coherent, parallel reflections that generally mimic underlying topography (Fig. 3). In places, thin (<3 m) sequences of this stratified unit show much less distinct reflections which, may appear discontinuous and locally inclined, but are bounded by parallel, high amplitude, continuous reflectors. The second facies occurs in subbottom units, generally up to 20 msec thick, that appear transparent and almost reflector free (Figs. 3-6). Locally, indistinct, discontinuous internal reflections occur within this facies. The bounding surfaces of this facies are rarely parallel, and there is often considerable relief on the upper surface (Figs. 3, 4).

Seismostratigraphy

The large number of crossovers in the area from 46° 50'N to 47° 30'N allows a reasonable stratigraphic correlation to be made. A type section is defined within the area illustrated in Figure 3. Here a surface unit 12 msec in thickness of stratified facies overlies 19 msec of transparent facies (transparent unit B), which in turn rests on a further 5 msec of stratified facies and a further 12 msec of transparent facies (transparent unit C). This overlies stratified sediments at the limit of penetration of the Huntec DTS system.

North of the type section, the seabed rises abruptly by about 18 m to an elevated area called the "Gabriel high" (Fig. 3). The surface stratified unit thins to about 7 msecs, and is underlain by transparent facies to the limit of penetration. The two transparent units (B and C) in the type section thicken towards this high area and the stratified units terminate, with only an extremely faint continuation of occasional reflectors at the margin of the thick mass of transparent facies (Fig. 3). There is also a tongue like body of transparent facies (transparent unit A in Fig. 3) developed at the margin of the high that pinches out at a horizon about 8 msec subbottom within the surface stratified unit. A widespread correlatable reflector termed alpha, is defined just at the base of transparent unit A.

Transparent unit C thins out about 7 km south of the edge of the"Gabriel high". Stratigraphic correlation at this subbottom depth is difficult, so that the exact stratigraphic position of the edge of transparent unit C within the stratified sequence that occurs regionally beneath transparent unit B is uncertain.

Transparent unit B thins to about 10 msec 5 km south of the "Gabriel high" (Fig. 4) and can then be traced as far south as 46° 57'N, a distance of 35 km, over which the unit varies irregularly in thickness from 3 to 10 msecs (Figs. 6, 7). South of this, the sedimentary succession thins southwards, so that at latitude 46° 52'N (Fig. 8), the alpha horizon is only 2.5 msec subbottom. In this area, there is a clear gulley cutting event below transparent unit B (Fig. 8). At 47° 03'N, transparent unit B overlies two apparent "blocks" of well stratified sediments about 8 msec thick with abrupt lateral terminations (indicated by arrows in Fig. 4). Each of these blocks shows identical internal stratigraphy, and the northern block shows undulations that mimic irregularities deeper in the stratigraphic sequence (y in Fig. 4). For these reasons, we interpret the blocks as autochthonous. The abrupt lateral transitions to the transparent facies probably represent a boundary of the type recognised at the margins of in-situ sediment failures on the Scotian Slope by Piper et al. (1985).

South of the relict blocks illustrated in Figure 4, an upper transparent unit (A) is developed just above the alpha reflector (Fig. 5). This occurs at approximately the same stratigraphic level as unit A at the "Gabriel high", with which it is correlated. The transparent unit occupies a regional depression about 6 km across, and has maximum thicknesses of 6 msecs within this depression, there is a diapir-like feature of acoustically transparent sediment, 1200 m wide, which appears to grow out of transparent unit B and extends to the surface, penetrating both the alpha reflector and transparent unit a (Fig. 5). Adjacent reflectors appear to be bent up against this diapiric feature. This is the only diapir-like structure on this seismic profile, although other similar features may be present on the "Gabriel high" (Fig. 3).

Five km to the south, lenticular bodies of transparent unit A are developed (Fig. 6). These lenses in part appear to have erosional draped margins, and in part to pass laterally into the stratified sediment facies.

The seismic profile across the western slope of Flemish Pass west of the diapir-like feature (322/0730-0930 in Fig. 2) shows that the stratigraphic units described above can be traced upslope to 700 m water depth. (From 700 to 650 m the Huntec DTS system malfunctioned; stratigraphic correlation in shallow water is hampered by widespread iceberg scouring to depths of 650 m: Pereira et al., 1985). The sequence above the alpha reflector thins upslope to 750 m water depth to about 50% of its thickness on the floor of the pass. Transparent unit A can be traced upslope to a break in slope near the 1000 m iso bath, where it rapidly wedges out. Transparent unit B can be traced to at least the 950 m isobath, where some continuous coherent reflectors first appear within this stratigraphic interval. The continuity of reflectors on the lower slope is interrupted in places where the profile appears to obliquely cross small, filled slope channels.

The seismic profile that runs obliquely up the lower slope southwest from the "Gabriel high" (332/0300-0700 in Fig. 2) shows that the high is located at the downslope end of a channel system with steep walls, which was recognised on earlier Huntec and SeaMARC lines (Pereira et al, 1985). It is difficult to correlate reflectors along much of this seismic profile because of rapid thinning upslope and lateral changes in reflector character, and seismic penetration is generally limited to 15 msecs.

The seismic profile that runs parallel to the lower slope south of 47 10'N (322/1100-1700 in Fig. 2) in water depths of 850 to 1050 m shows a series of slope gullies with a 4 km spacing and typical depths of 30 m. Rare lenses transparent unit A are seen. A gully-cutting event or series of events is seen at about the same stratigraphic level as transparent unit B, which in this area, is thin and shows indistinct discontinuous reflectors.

Core control

Two cores were collected in the study area on Cruise 85-044 (Fig. 2). Preliminary interpretation of these cores provides some ground truth for the high-resolution seismic reflection profiles.

At core site 3 (Fig. 9), only the stratified facies is present. The alpha reflector occurs at about 7.5 msec (5.5 m) subbottom. There is also a slightly more transparent layer at the surface about 1.5 msec thick. The piston core is 7.88 m long; its top can be correlated with the 147 cm-long trigger weight core. It contains a varied sequence of muds and sandy muds; the alpha reflector may correlate with the top of a thick, uniform grey mud.

At core site 4 (Fig. 10), the Huntec DTS profile shows that the upper 5 msecs of sediment is of the stratified facies, overlying transparent unit B. The horizon equivalent to the lenticular developments of transparent unit A lies about 2 msecs below the surface. The top 15 cm of the piston core consists of a very mobile fine sand that was completely disturbed during core recovery. Below this is 3.2 m of soft grey mud that appears almost structureless, and rests on a slightly sandier grey mud with faint but distinct stratification. The soft grey mud may represent remobilised material from transparent unit A. Further penetration of the core was stopped by a diorite pebble lodged in the core catcher.

Interpretation of High-resolution Seismic Profiles

The acoustically stratified sediments seen in Huntec DTS profiles correlate with a variety of gravelly muds and sandy muds in cores, and appear to represent "normal" sedimentation in the area. The age of the stratigraphic section is uncertain because of the lack of detailed biostratigraphic work. The airgun data discussed below suggest that an average sedimentation rate on the floor of the Pass might be 0.25 m per thousand years. Interglacial sedimentation rates were probably substantially lower: Alam's (1979) data for core 3-1 suggests 0.1 to 0.2 m per thousand years. Thus the section penetrated by the Huntec DTS profiler probably corresponds to the Wisconsinan glacial section, and a thin overlying veneer of Holocene sediment. The interglacial sediments are hemipelagic (including an ice rafted component) which are modified by bottom current transport and deposition. The upslope increase in thickness suggests that much of the sediment supply during glacial periods was derived from ice sheets crossing the Grand Banks, or fluvioglacial sediment transported across the Grand Banks at times of glacially-lowered sea level (Fader and Miller, 1986). The thinning to the south may be the result of greater sediment supply in the central part of Flemish Pass, but the present data is insufficient to evaluate this hypothesis.

The distribution of the transparent facies suggests that it may have more than one origin. The abrupt lateral transitions from continuous coherent reflections to transparent facies on relatively low slopes may have resulted from in situ sediment failure, probably, seismically-triggered, since the facies is developed over a wide area at the same stratigraphic horizon, yet the sediments are discontinuous. The thick tongue-like bodies of the transparent acoustic facies at the "Gabriel high" appear to be debris flows that have flowed down a large slope gully. The transparent facies may have a similar origin in some other places. The transparent acoustic facies has not been sampled so that its geotechnical characteristics remain uncertain. Diapiric features rooted in transparent facies B extend to the seafloor.

Interpretation of Airgun Profiles

Seismostratigraphy

Between 500 and 1000 msec of penetration was obtained with the airgun seismic reflection system. Three key reflectors can be correlated throughout the study area and separate acoustic sequences of different characteristics.

The shallowest key reflector, termed "red", occurs at a depth of 100 msec on the western slope of the Pass and about 300 msecs subbottom on the floor of the Pass (Fig. 11). On the western slope it is overlain by a sequence of high amplitude irregular reflectors that appear to be cut by numerous channels (Fig. 12). At about the 550 m bathymetric contour, these grade upslope into a zone of incoherent high amplitude reflections.

A reflector termed "purple" occurs 200 to 250 msecs below the red reflector. The intervening sediment sequence maintains a fairly constant thickness, but thins slightly towards shallower water on the western slope of the Pass (Figs. 11 and 12). Reflectors within this sequence are quite continuous, but pinch and swell to give an overall irregular acoustic architecture (Figs. 12 and 13). This irregularity probably reflects shallow channelling on the western slope of the Pass. In water depths less than 600 m on the werstern slope of the Pass, this interval shows continuous reflections in contrast to the incoherent reflections of the sequence above the "red" horizon.

A reflector termed "brown" occurs about 350 msecs below "purple "reflector (Fig. 14). It corresponds to the Pliocene - Miocene boundary (apparent unconformity) intersected in the Gabriel C-60 well (Fig. 2). The sequence between the "brown" and "purple" horizons consists of continuous, coherent, parallel reflections.

Interpretation

The Late Cenozoic sedimentary sequence in the Flemish Pass area is similar in seismic character to that on the upper Scotian Slope (Fig. 1) in the vicinity of the Acadia K-62 well (Piper et al., 1986). Acoustic correlation with this area provides a basis for dating the Late Cenozoic sequence above the level of the first samples in the Gabriel C-60 well. On the Scotian Slope, the occurrence of parallel reflections characterises the Early Pliocene sequence, whereas the Late Pliocene and Early Pleistocene is characterised by increasingly deep channel cutting, in response to fluvial erosion on the shelf and headward erosion of submarine canyons. The Mid and Late Pleistocene is marked by another change in style of sedimentation, with the deposition of till on the upper slope and rapid supply of glacial sediments to deep water. We tentatively correlate these three phases of sedimentation seen on the Scotian Slope with the three seismic sequences recognised above the Miocene in this study of Flemish Pass. In this interpretation, the "purple" reflector would mark a horizon near the base of the Late Pliocene, and the "red" reflector a horizon near the base of the Middle Pleistocene. The zone of incoherent reflections above the "red" reflector in water depths of less than 550 m is interpreted as consisting of till and coarse ice margin sediments, by analogy with features seen on the upper Scotian and Labrador slopes.

Conclusions

1. The late Neogene - Quaternary acoustic stratigraphy of the western area of Flemish Pass is similar to that seen on the Scotian Slope. This suggests a similar sedimentation history, with fluvial sediment supply and slope valley incision in the Late Pliocene and Early Pleistocene and glacial sediment supply from the Grand Banks of Newfoundland in the mid and Late Pleistocene.
2. In the Wisconsinan section, there are three distinct horizons of sediment failure and debris flow represented by acoustically transparent sediment. Some of the failure may have been seismically triggered. The debris flows were probably probably transported down slope gullies or valleys and spread out on the floor of the Pass. Diapir-like structures rise to the seabed from these acoustically transparent horizons.

Acknowledgments

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FIGURE CAPTIONS

Fig. 1. General map of the southeast Canadian continental margin showing location of Flemish Pass survey area (black box), and of deep-water wells.

Fig. 2. Map of Flemish Pass survey area, showing location of Huntec DTS seismic profiles with hourly time marks (Julian Days 319, 321, 322), SeaMARC track shown as irregular continuous line in northern part of study area (see Pereira et al., 1985, for details). Core site 3-1 from Alam (1979); 85-044-3 and -4 are from this study. Location of Figures 3-14 shown in appropriate positions along tracklines.

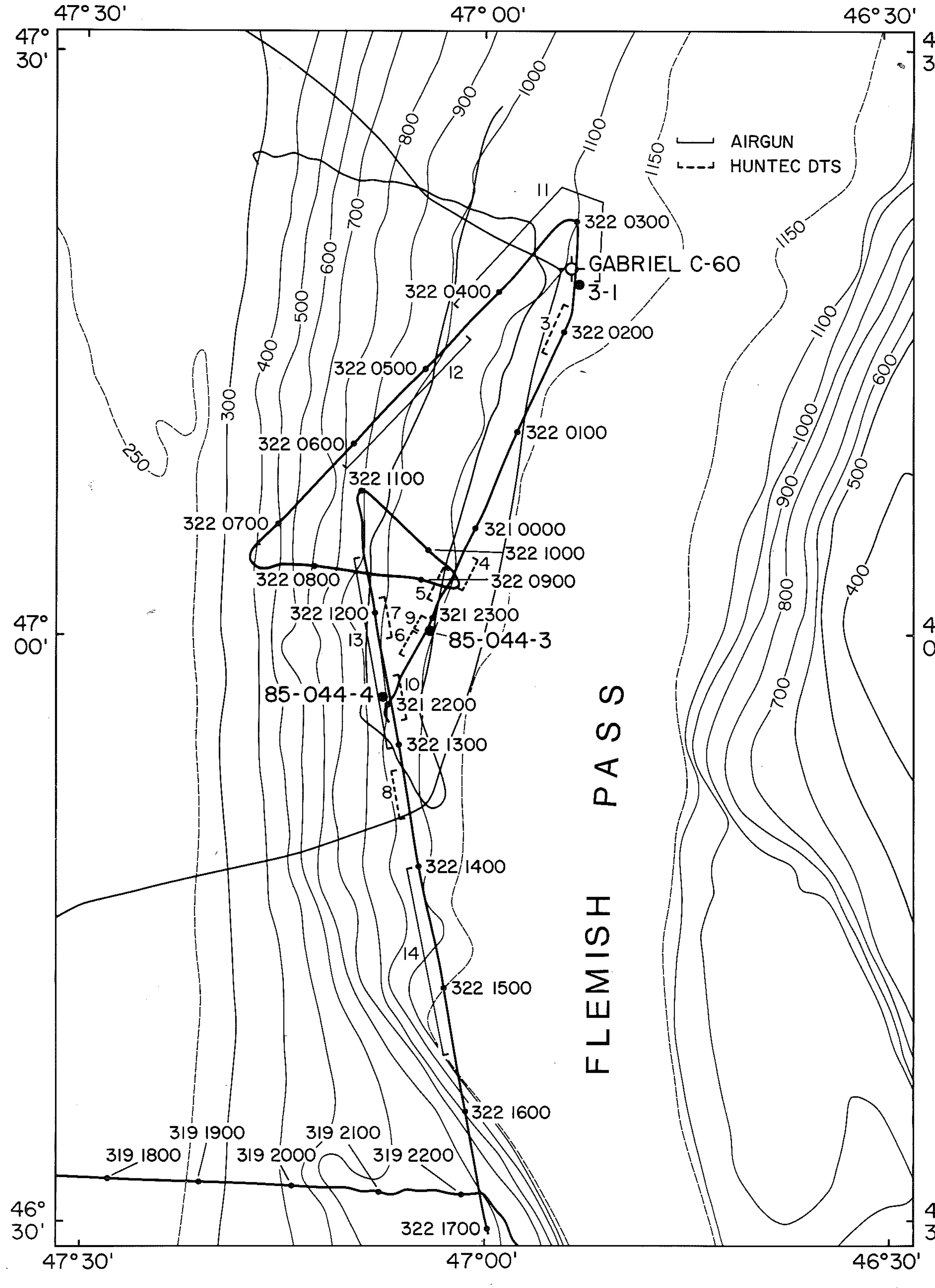
Fig. 3. Type section of high-resolution acoustic stratigraphy in the Flemish Pass study area, just south of the "Gabriel high" (see Fig. 2 for location). Huntec DTS profile 0140-0210/322. s = stratified facies, t = transparent facies. Three units of the transparent facies are identified, shown as A, B and C. α is a widespread reflector within the stratfied facies. Transparent unit A forms a tongue-like body at the edge of a thick development of transparent facies beneath the "Gabriel high". Diapir-like features (indicated by arrows) cut the surface stratified unit on the "Gabriel high".

Fig. 4. Huntec DTS profile (2325-2345/321) showing irregular development of transparent acoustic unit B. Arrows mark abrupt terminations of stratified sediment, passing laterally into unit B. y indicates irregularities in the stratified sequence inherited from deeper in the section.

Fig. 5. Huntec DTS profile 2310-2330/321 showing transparent units A and B and diapir-like feature rooted in unit B that extends to the seabed. Northern end of this profile is continuous with Figure 4, and shows abrupt termination of stratified sediment (marked by arrow).

Fig. 6.	Huntec DTS profile (2230-2245/321) showing, lenticular developments of the transparent unit A. Underlying transparent unit B shows abrupt contact with stratified sediment (marked by arrow).
Fig. 7.	Huntec DTS profile (1150-1215/322) showing lenticular development of transparent unit A and gulley cutting (g) at about the time of transparent unit B.
Fig. 8.	Huntec DTS profile (1310-1325/322) showing stratified sediments at 46° 52' N alpha reflector is at a shallow depth below the surface. There is a gulley cutting event (g) below the horizon equivalent to the transparent unit B. 1310-1325/322.
Fig. 9.	Huntec DTS profile at closest approach to core site 3 at 2253/321.
Fig. 10.	Huntec DTS profile at closest approach to core site 4 at 1240/322.
Fig. 11.	Air gun seismic reflector profile (0230-0430/322) showing seismic sequence on the floor of Flemish Pass near the Gabriel C-60 well site, and the location of the red and purple reflectors. Note thick sequence of near-surface acoustically unstratified sediments (d) interpreted as debris flow or turbidite sand deposits.
Fig. 12.	Air gun seismic reflection profile (0430-0600/322) of the western slope of Flemish Pass, west of the Gabriel C-60 well site, showing the key red and purple reflectors. Above the red horizon, reflections are high amplitude, in discontinuous packages suggesting cut and fill sequences. Between the red and purple horizons, reflections are more continuous, but reflection packages gently pinch and swell. Below the purple horizon, reflections are continuous and parallel.
Fig. 13.	Air gun seismic reflection profile (130-1300/322) on western slope of Flemish Pass showing acoustic character of units above the red, between the pruple and red, and below the purple reflectors. For detailed description, see Figure 12)

Fig. 14.	Air gun seismic reflection profile (1400-1540/322) of the western slope and floor of southwest Flemish Pass showing distribution of the purple and brown key reflectors.
Fig. 15.	Isopach map of transparent unit B, showing thick development of transparent facies at the "Gabriel high" and gradual thinning to the south. Contours in msec two way travel time.



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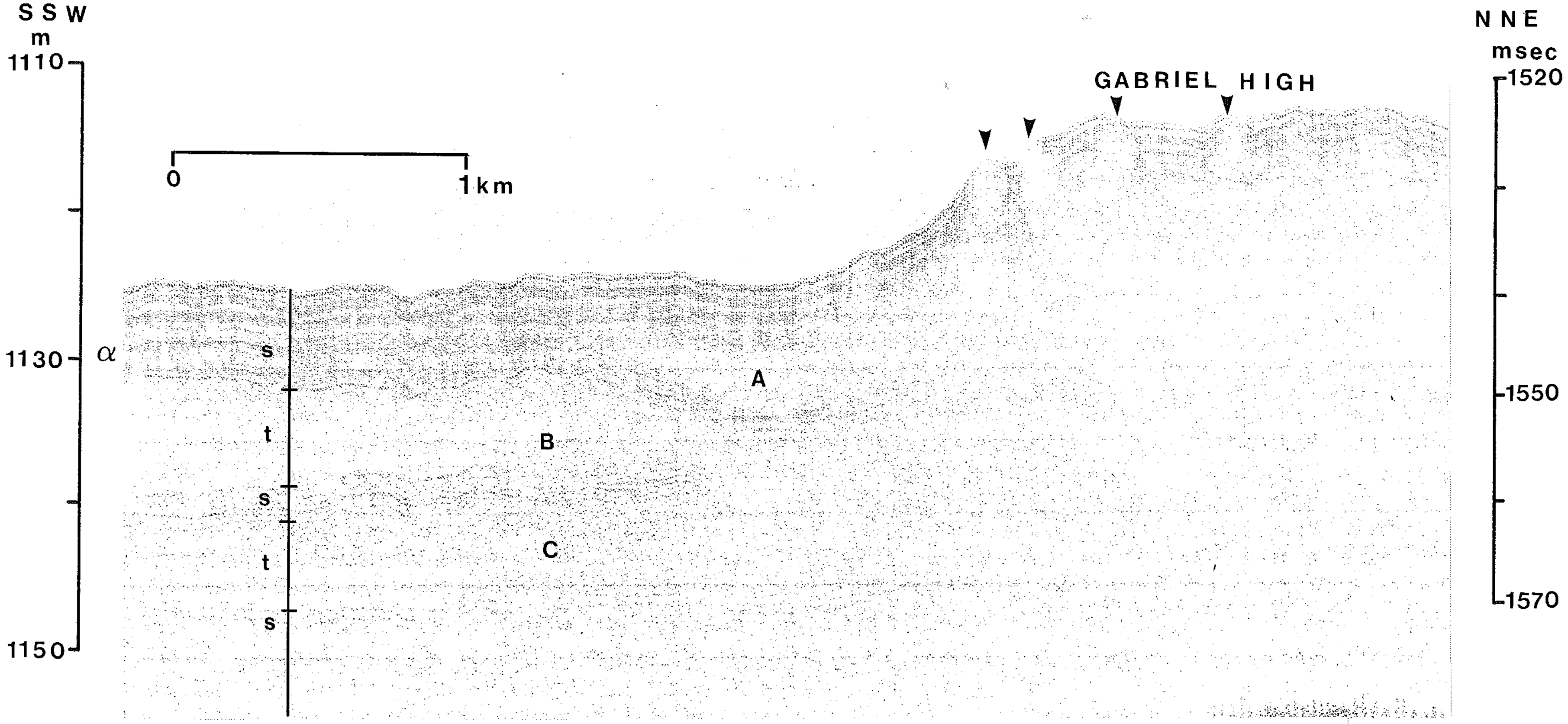

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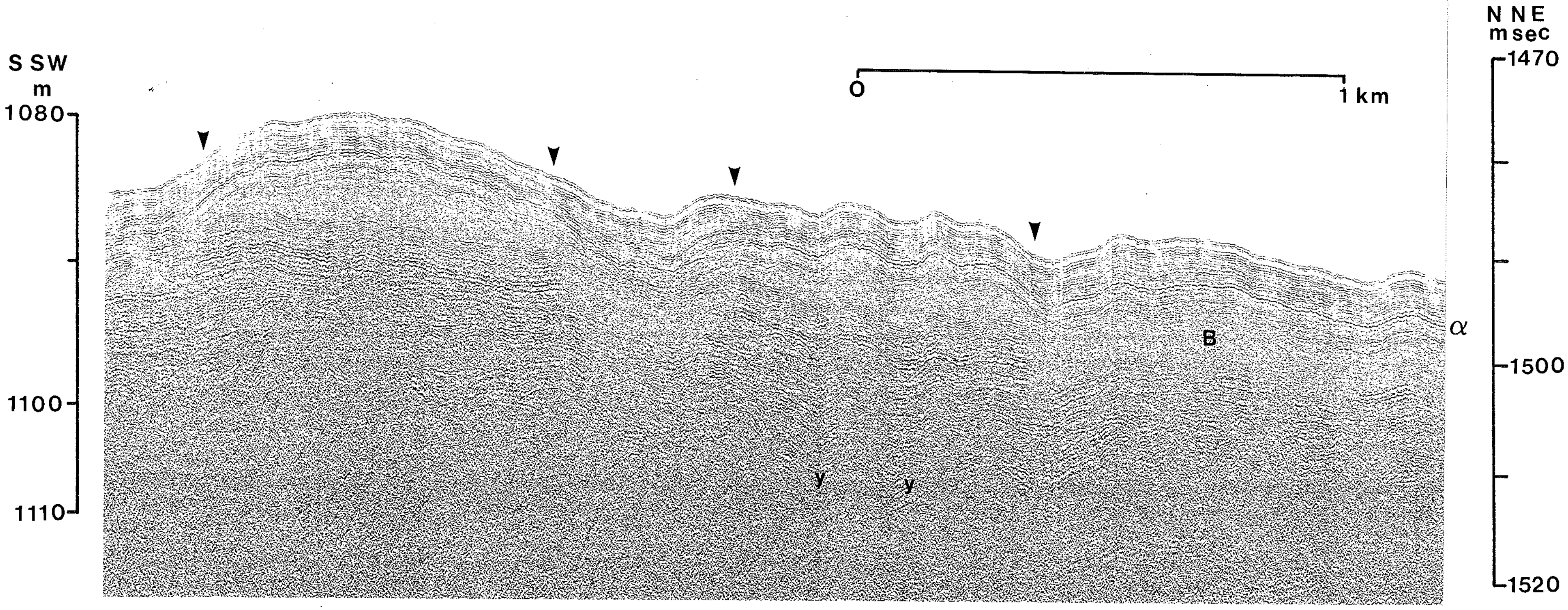

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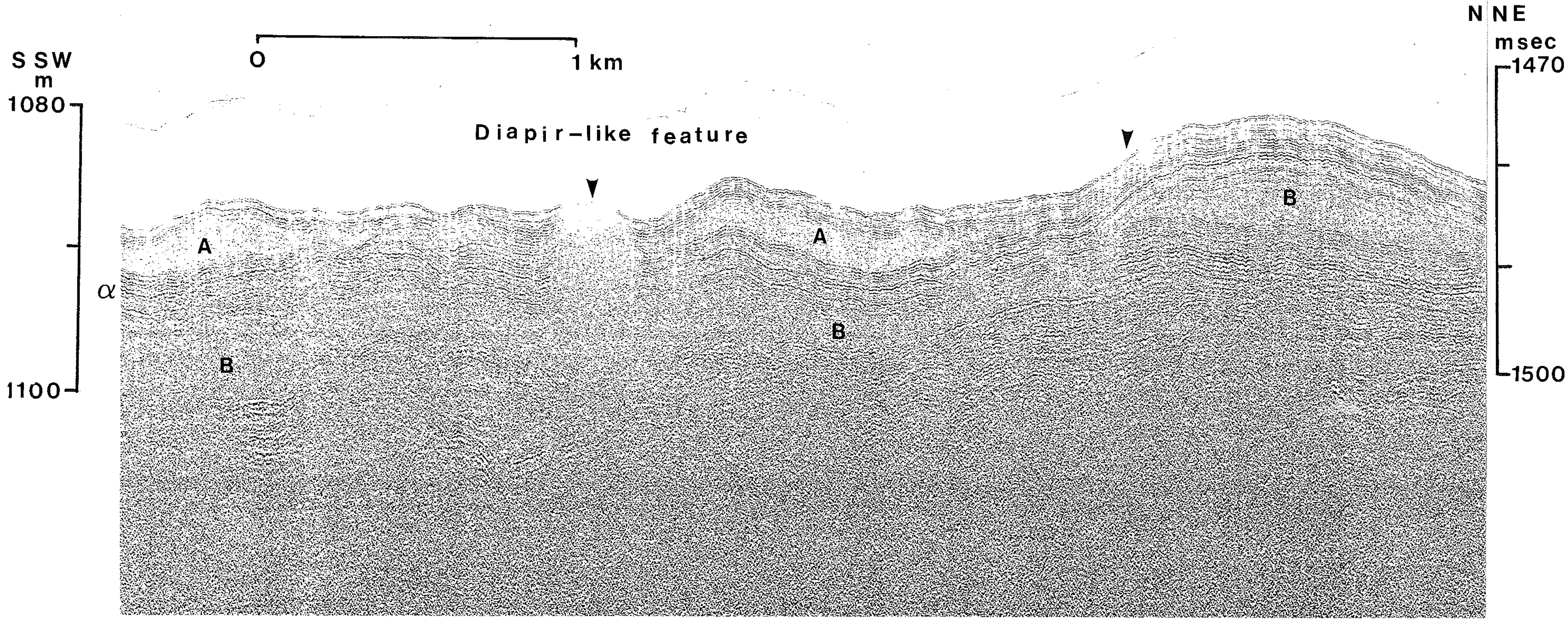


Fig. 5. Huntec DTS profile 2310-2330/321 showing transparent units A and B and diapir-likefeature rooted in unit B that extends to the seabed. Northern end of this profile is continuous with Figure 4, and shows abrupt termination of stratified sediment (marked by arrow).

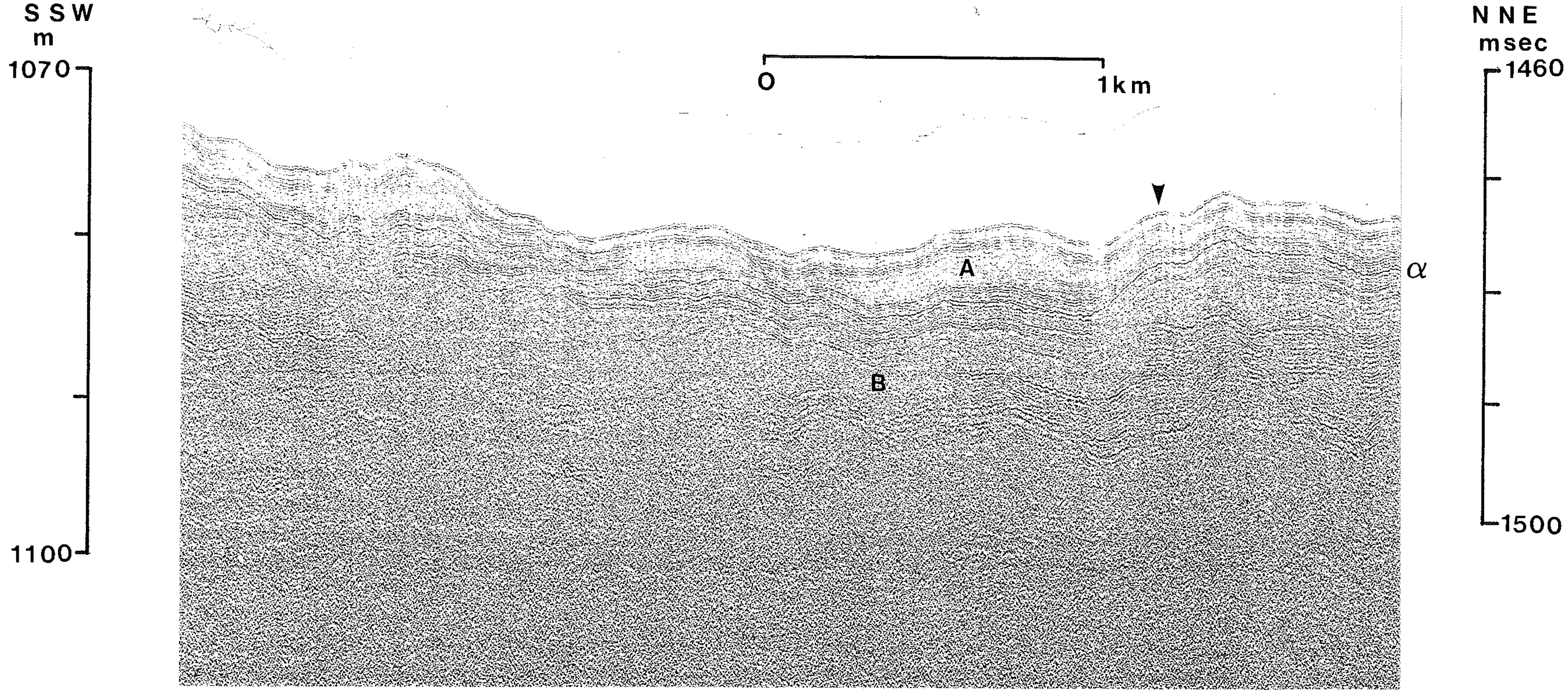


Fig. 6. Huntec DTS profile (2230-2245/321) showing, lenticular developments of the transparent unit A. Underlying transparent unit B shows abrupt contact with stratified sediment (marked by arrow).

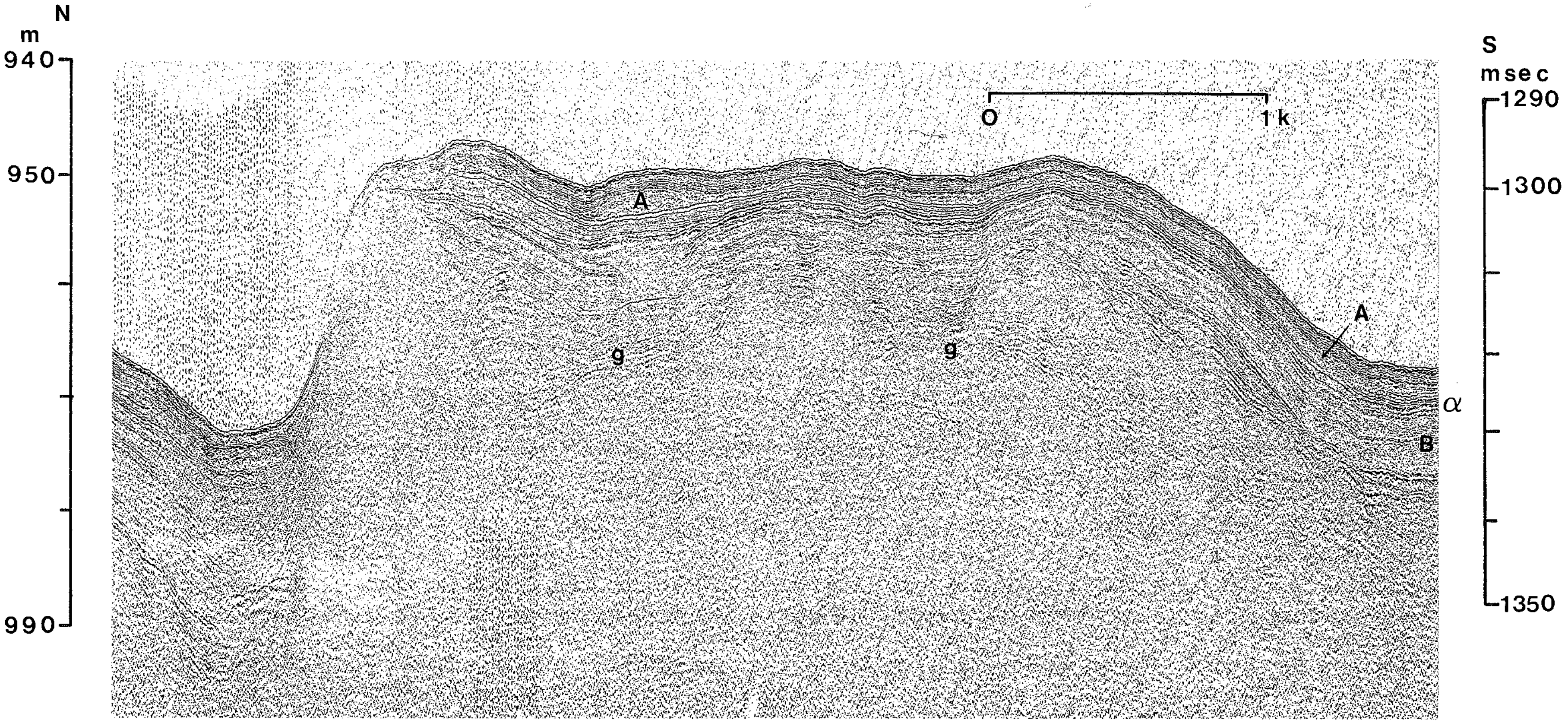


Fig. 7. Huntec DTS profile (1150-1215/322) showing lenticular development of transparent unit A and gulley cutting (g) at about the time of transparent unit B.

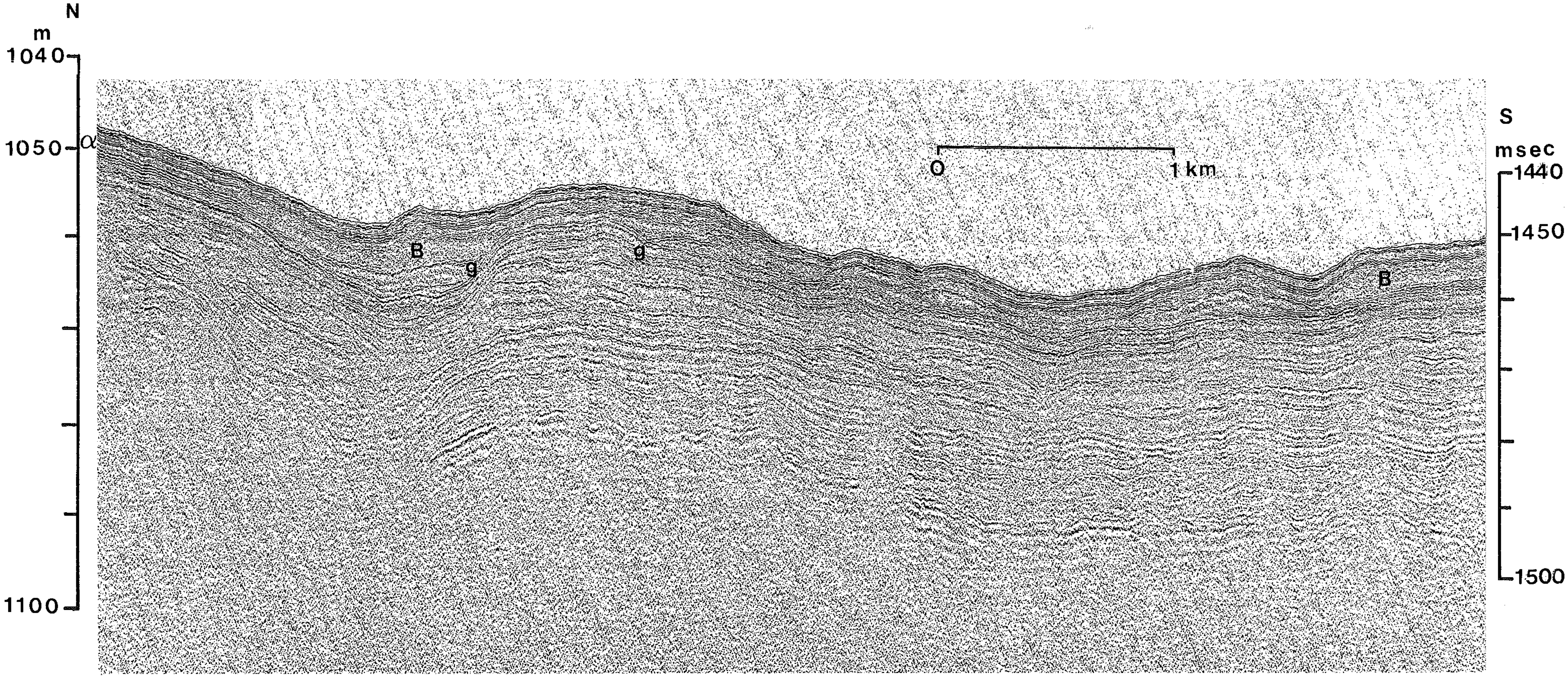


Fig. 8. Huntec DTS profile (1310-1325/322) showing stratified sediments at 46° 52' N alpha reflector is at a shallow depth below the surface. There is a gulley cutting event (g) below the horizon equivalent to the transparent unit B. 1310-1325/322.

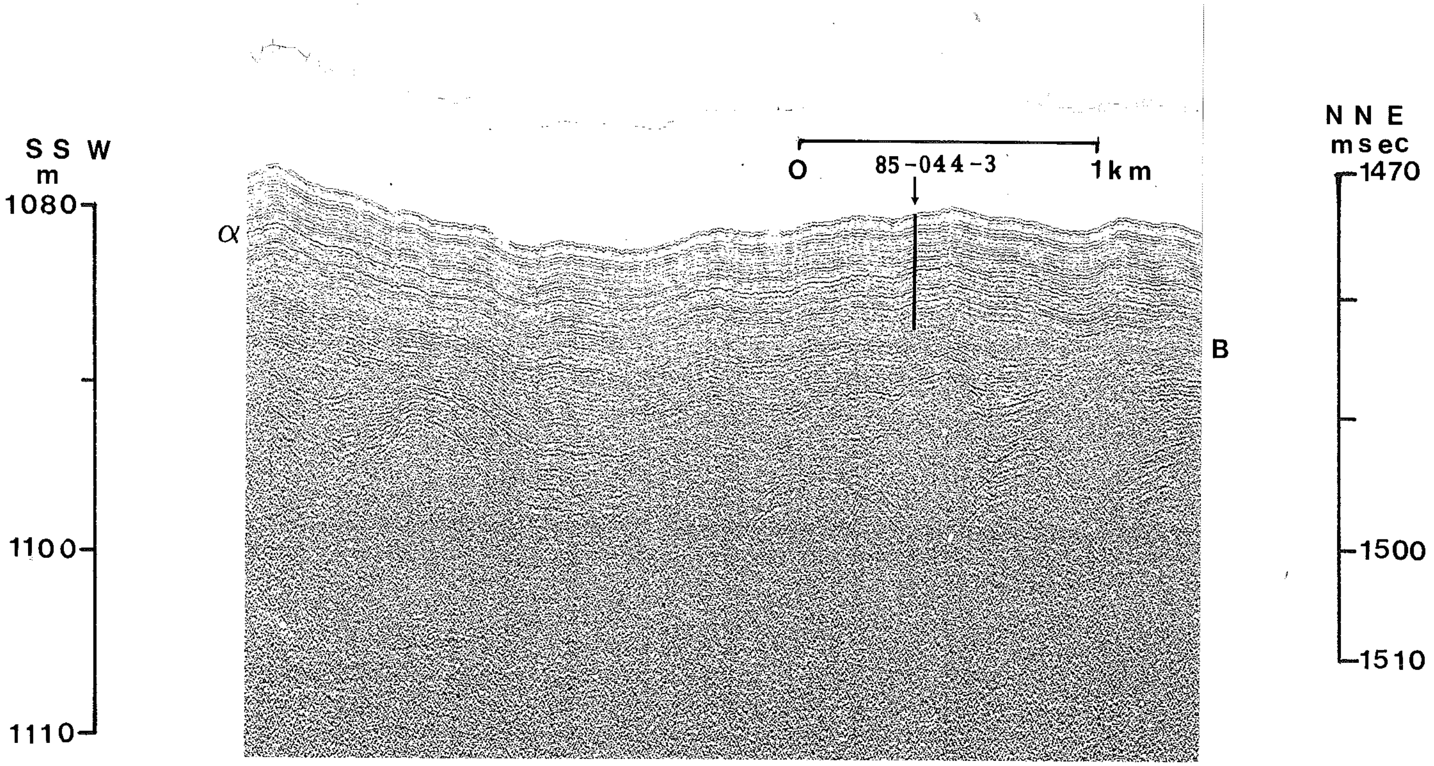


Fig. 9. Huntec DTS profile at closest approach to core site 3 at 2253/321.

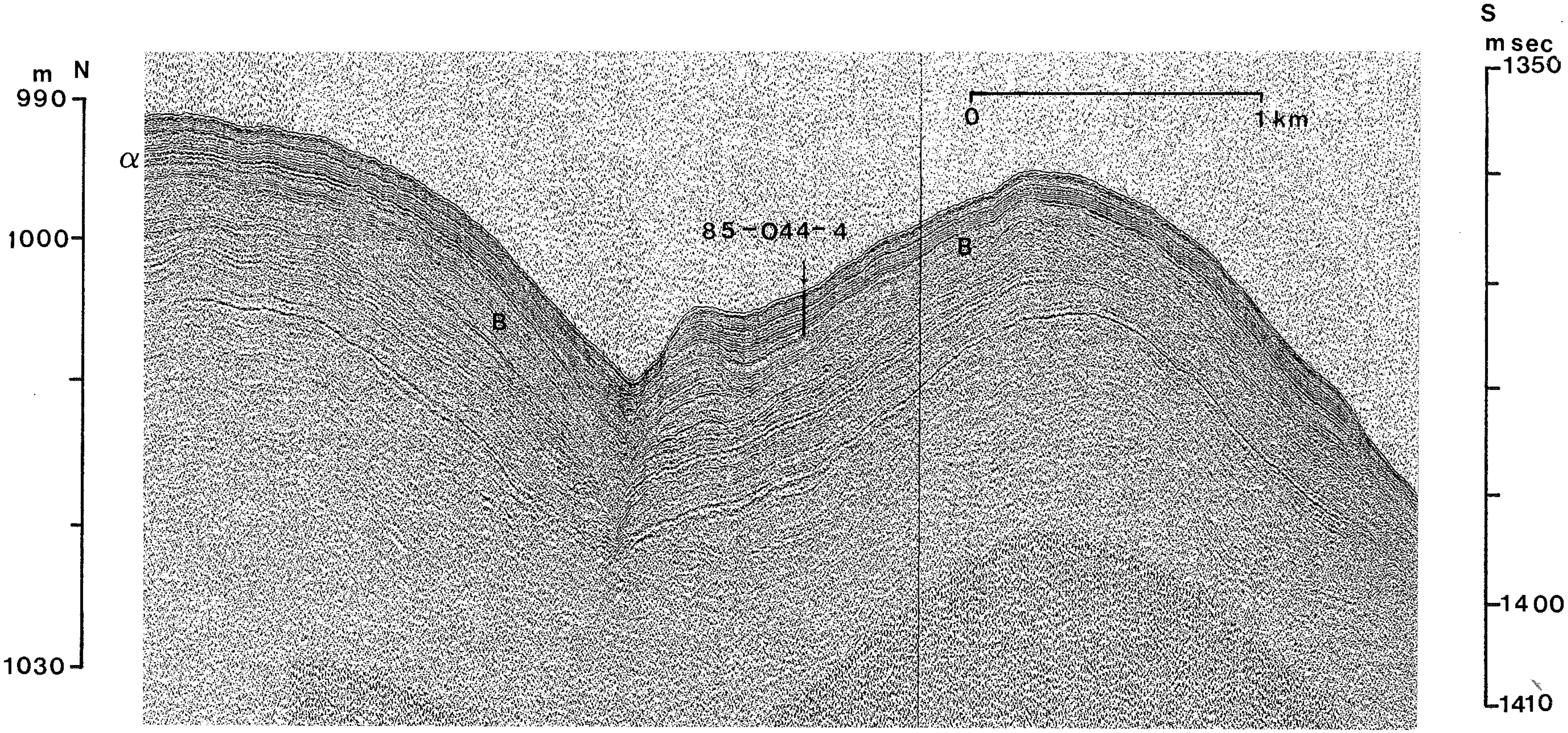


Fig. 10. Huntec DTS profile at closest approach to core site 4 at 1240/322.

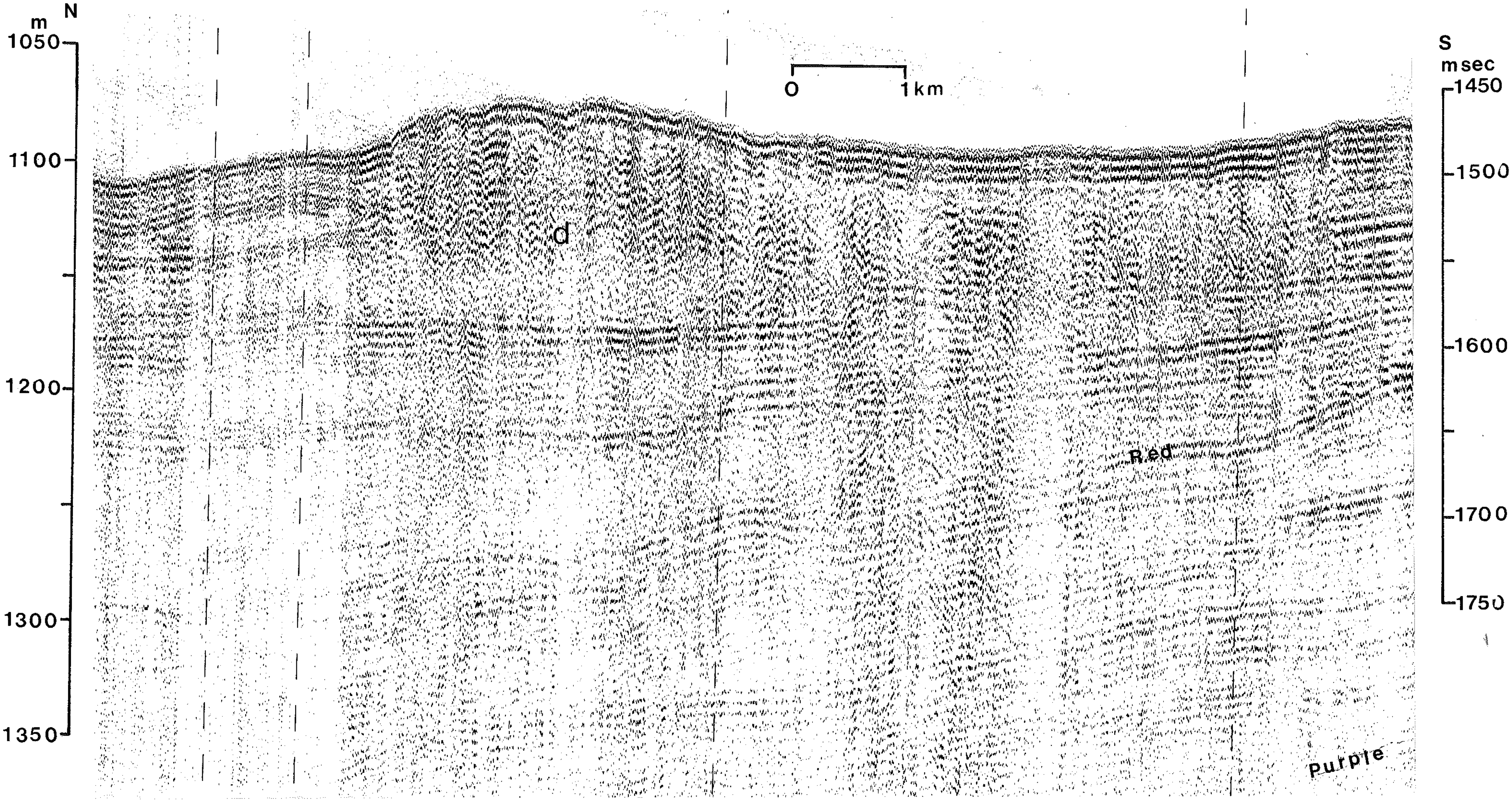
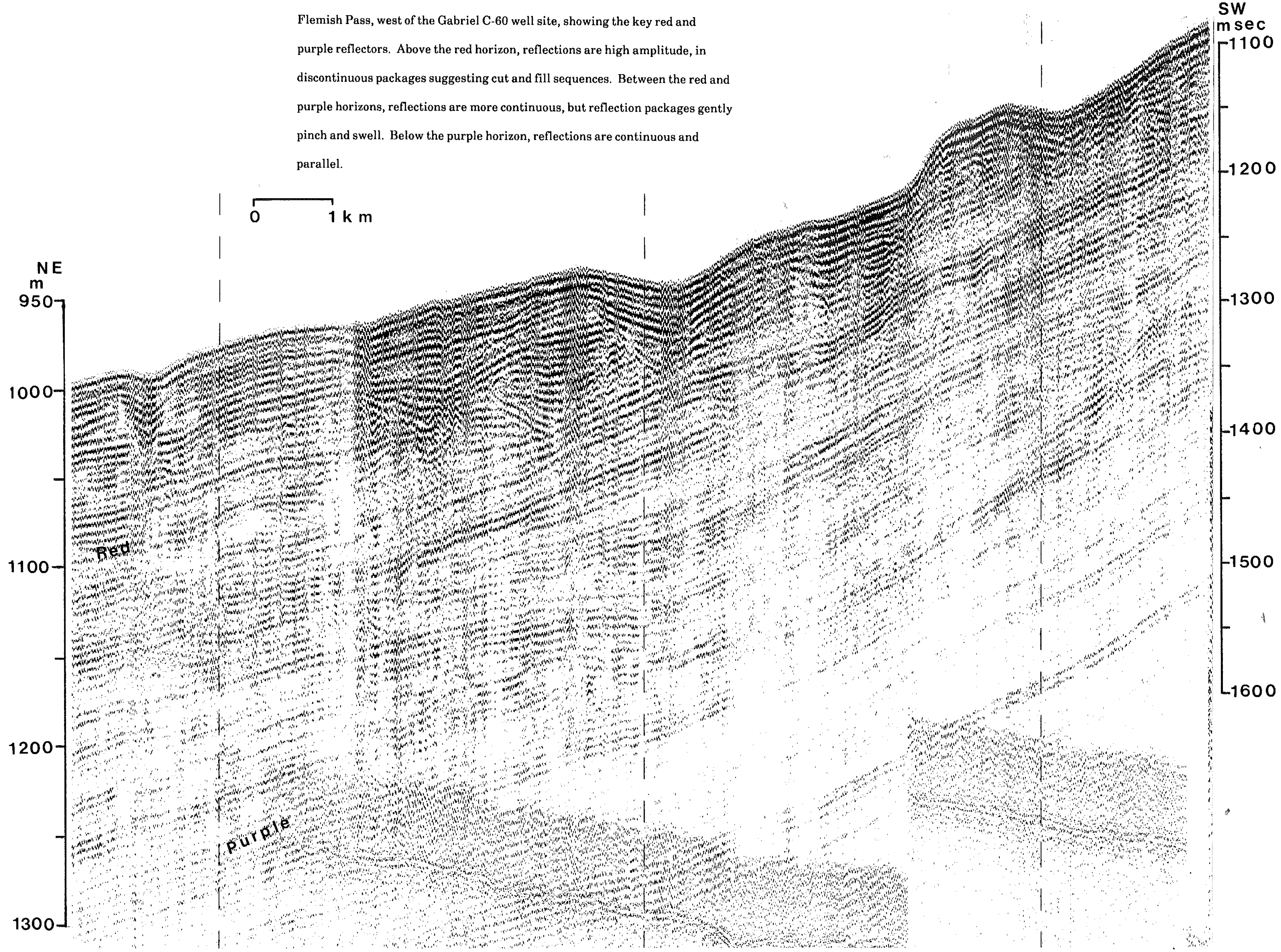
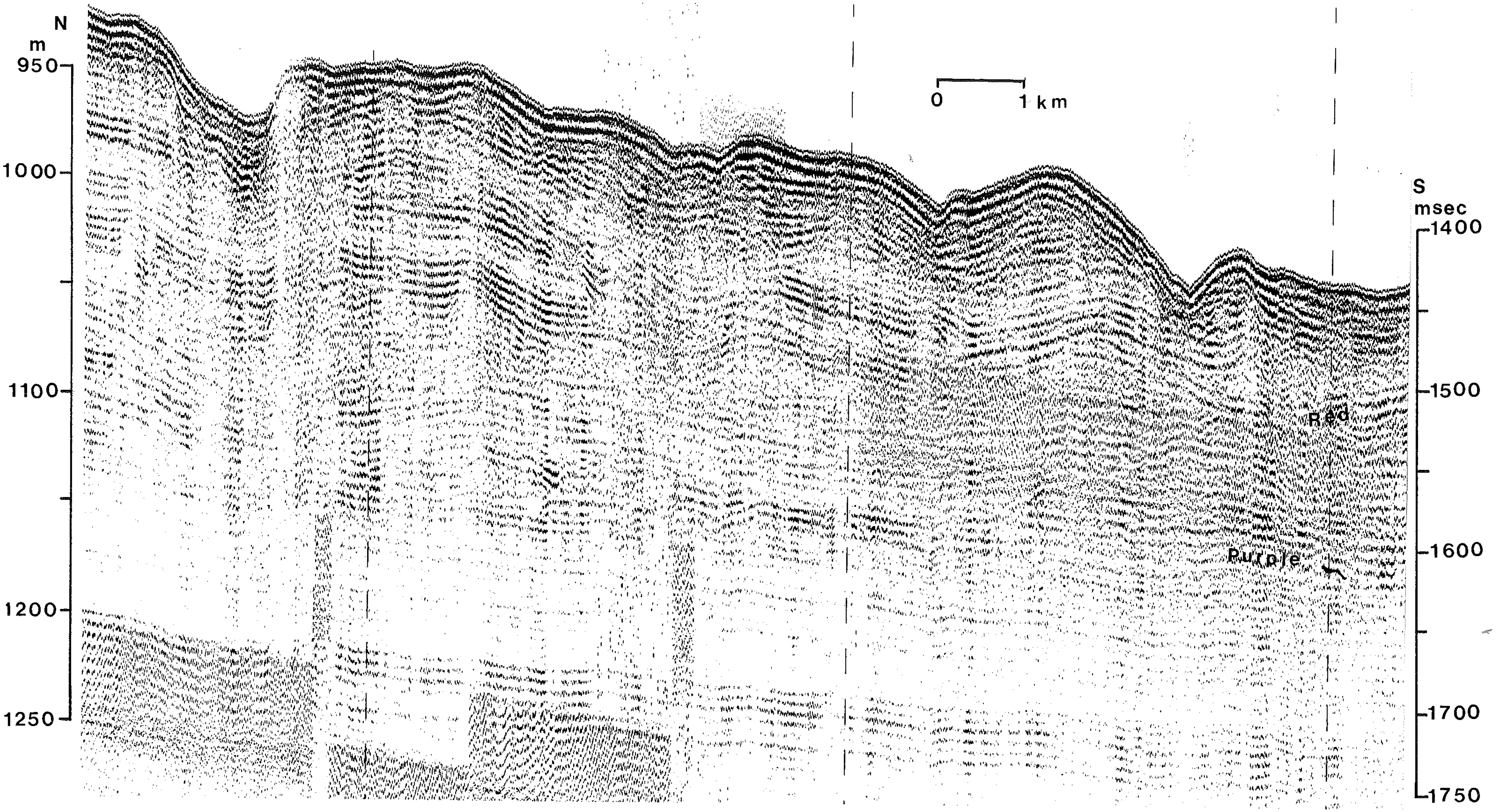


Fig. 11. Air gun seismic reflector profile (0230-0430/322) showing seismic sequence on the floor of Flemish Pass near the Gabriel C-60 well site, and the location of the red and purple reflectors. Note thick sequence of near-surface acoustically unstratified sediments (d) interpreted as debris flow or turbidite sand deposits.

Fig. 12. Air gun seismic reflection profile (0430-0600/322) of the western slope of Flemish Pass, west of the Gabriel C-60 well site, showing the key red and purple reflectors. Above the red horizon, reflections are high amplitude, in discontinuous packages suggesting cut and fill sequences. Between the red and purple horizons, reflections are more continuous, but reflection packages gently pinch and swell. Below the purple horizon, reflections are continuous and parallel.





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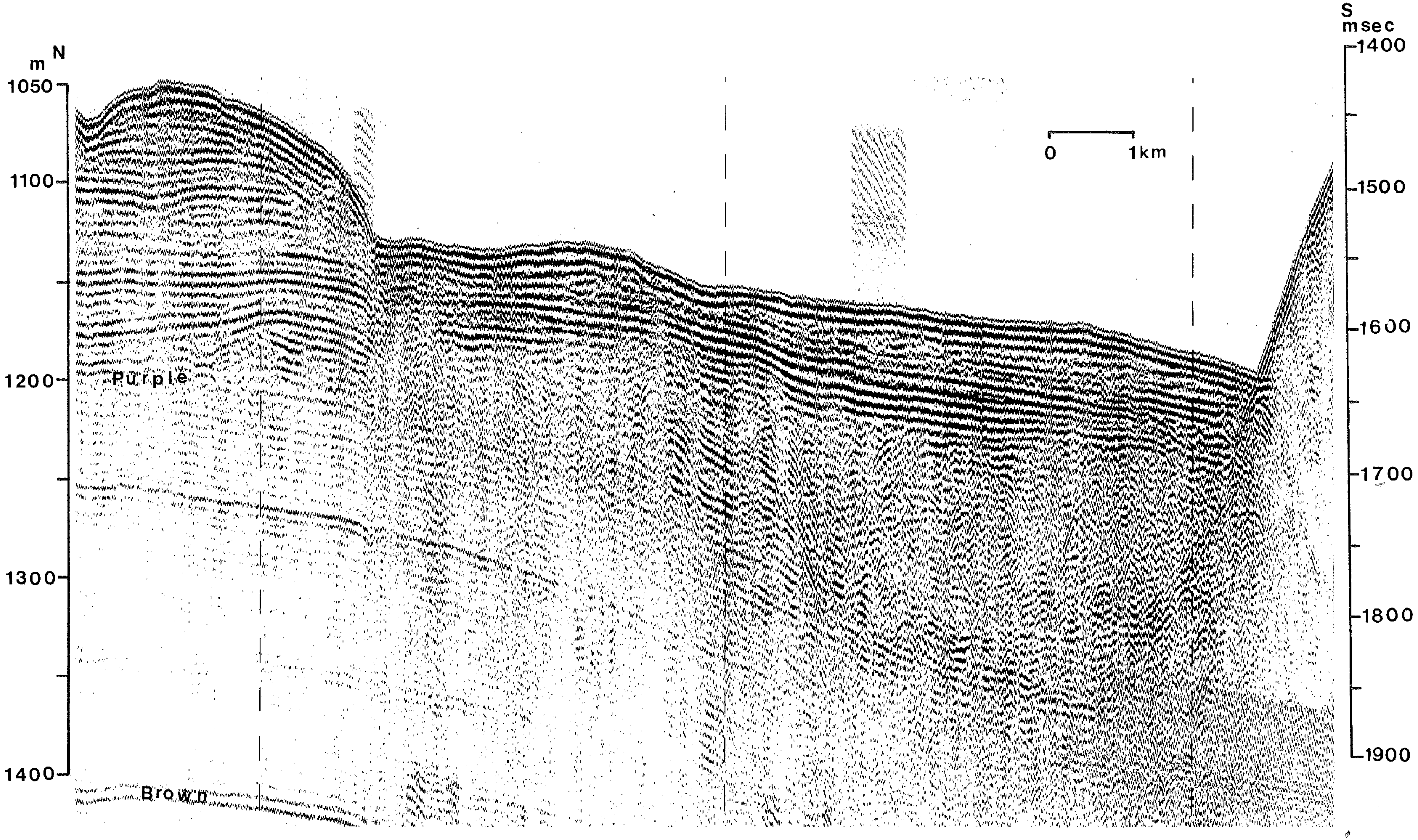

Fig. 14. Air gun seismic reflection profile (1400-1540/322) of the western slope and floor of southwest Flemish Pass showing distribution of the purple and brown key reflectors.

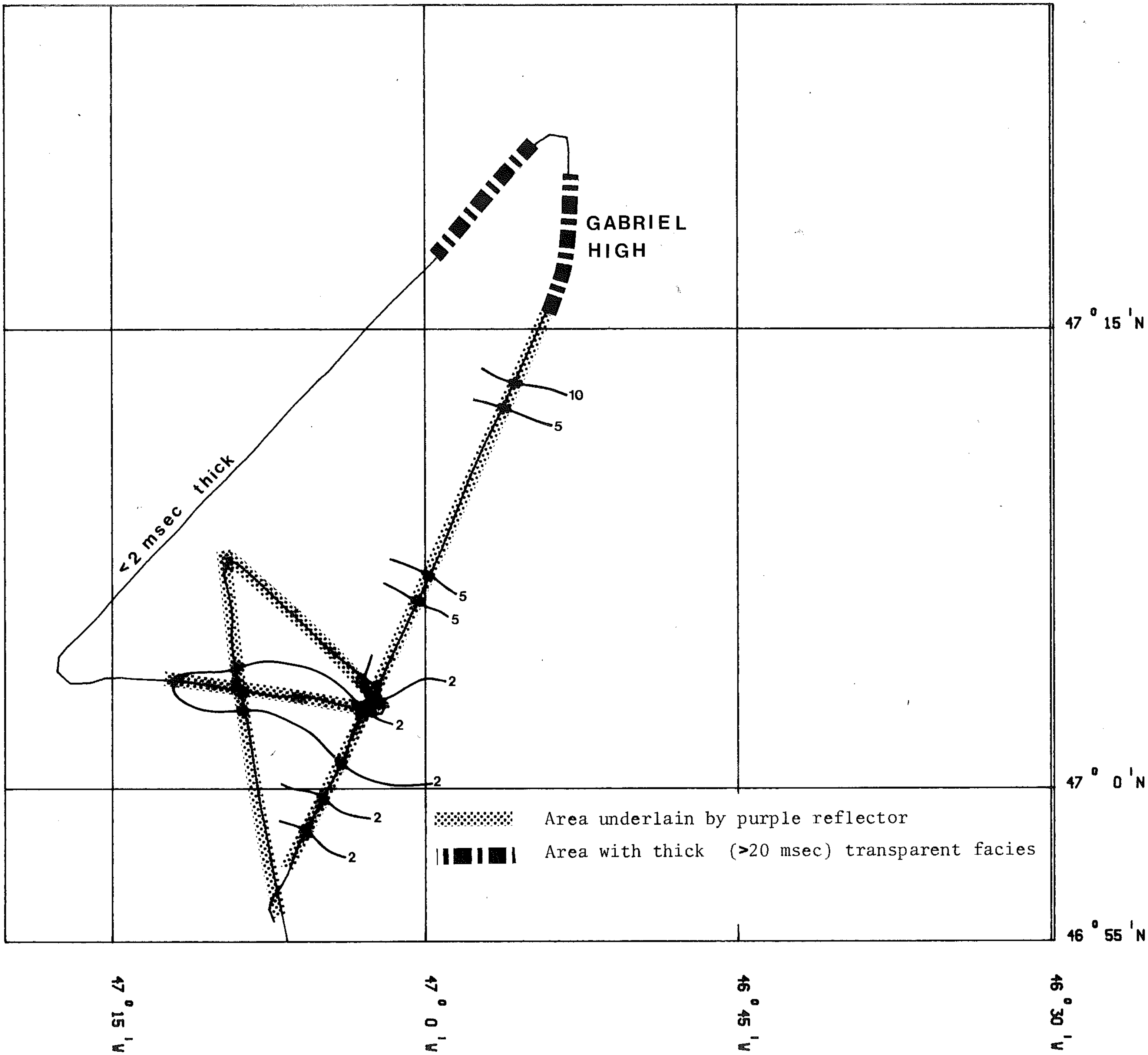

Fig. 15. Isopach map of transparent unit B, showing thick development of transparent facies at the "Gabriel high" and gradual thinning to the south. Contours in msec two way travel time.