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GEOMORPHOLOGY AND SLOPE INSTABILITY FEATURES IN THE OUTARDES DELTA AREA, QUEBEC, CANADA

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ABSTRACT

The Outardes Bay Delta constitutes one of the best sites to study the formation of failure deposits in a modern lowstand system tract environment. These deposits are located in a pseudo-shelf-edge position along the northern part of the Laurentian Channel in the Saint Lawrence Estuary. The site of study has been investigated over the past 20 years with a Raytheon RTT1000 boomer (3.5 kHz, 400 J) and a Simrad Em1000 multibeam sonar (95 kHz). Those tools have permitted to obtain high-resolution seismic and bathymetric data. This paper mainly reports the interpretation of data sets collected by Long (1981) and onboard of the CSS F.G. Creed during the September 2000 cruise. These data have revealed many slope instability features like wavy, chaotic and contorted reflectors, compression bulges field, channel incisions, debris flow draping, and rotational slide scars. Those geomorphological and geophysical signatures are expressing past and actual sedimentological processes.

RÉSUMÉ

Le delta de la rivière Outardes constitut un des meilleurs sites pour l'étude de la formation de dépôts glissés au sein d'un cortège sédimentaire de bas niveau marin. Ces dépôts sont localisés dans une position de pseudo-bordure de la plate-forme continentale le long de la portion nord du chenal Laurentien dans l'estuaire du Saint-Laurent. Ce site a été investigué au cours des 20 dernières années à l'aide, entre autre, d'un boomer Raytheon RTTT1000 (3,5 kHz, 400 J) et d'un sonar multi-faisceaux Em 1000 (95 kHz). Ces outils ont permis d'obtenir des données séismiques et bathymétriques de haute-résolution. Cet article concerne principalement l'interprétation des données receuillies par Long (1981) et abord du NGCC F.G. Creed lors d'une mission en septembre 2000. Ces données ont révélé la présence de nombreuses évidences d'instabilité comme des réflecteurs ondulants, chaotiques et plissés, un champ de bourrelets de compression, des chenaux incisifs, des coulées de débris et des cicatrices de glissements rotationnels. Ces signatures géomorphologiques et géophysiques témoignent de processus sédimentologiques passés et actuels.

1. INTRODUCTION

Some Canadian Holocene deltas have been formed after a relative-sea-level falls of 100 m and, thus are good examples of modern lowstand deltas. Many of those have been studied intensively over the past decade; i.e. the Rupert Bay, Fraser, Natashquan, Moisie and Outardes deltas. Those modern system tract environments are showing geomorphologic evidences of slope instability, such as canyon erosion, compression bulges, shallow rotational slides, turbidites, collapse depressions, bottom water scarp systems, apron, fans, submarine channel systems, and distal debris flow deposits mainly caused by the progradation of those systems (Hart and Long, 1996; Hart et al., 1992). Sea-level fluctuations, sediment supply, basin morphology, and hydrodynamic parameters such as tides and currents (Sala and Long, 1989) control the progradation. Slope instability can generate important submarine landslides that are responsible of many damages cause to human infrastructures such as the rupture of submarine telecommunication cables and tsunamis (Hampton et al., 1996).

One of those deltas, the Outardes Bay delta, constitutes one of the best sites to study the formation and 3D internal structure of failure deposits in a modern lowstand system tract environment. This system is also representing a good analogy for continental margin settings. The Outardes Bay delta is located on the North Shore of the St Lawrence River, Quebec, Canada, at approximately 20 km west of Baie Comeau. The Outardes river drains an area of 18 780 km^2 and is bordered on both sides by two large rivers being the Betsiamites and the Manicouagan rivers (Hart, 1987). Those three rivers have been dammed for hydroelectric purposes. The average discharge of the Outardes river is 555 m^3s^{-1} and the tidal range is 2 to 3 m (Hart and Long, 1996). The Outardes Delta has formed after an abrupt drop of the relative-sea-level of approximately 140 m since the last glaciation (Wisconsinian). A paleo-shelf break has been erected 12 km north of the actual river mouth during an highstand on Precambrian bedrock. The Outardes Bay delta has been investigated in the past with high-resolution geophysical tools like a single channel Raytheon RTT1000 (3.5 kHz, 400 J), a Mesotec sidescan sonar, and an Em-1000 multibeam sonar (Hart and Long, 1996; Urgeles et al., 2001a). The different data sets have shown that this delta was a forced regression delta lying in a pseudo-shelf-edge position along the northern part of the Laurentian Channel in the St Lawrence Estuary. Major storm or earthquake events may have generated submarine landslides, canyon incision,

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density currents, and deep fan of 50 m thick in water depth of 300 m. The present study is mainly based on data collected by Long (1981), published by Hart and Long (1996), and by Urgeles et al. (2001a).

2. SEISMIC DATA

Previous seismic survey has been conducted in 1981 over an area covering 22 km long east of Betsiamites by 10 km long south of Ragueneau in 5 to 120 m water depth. The seismic data sets have shown over the study area, several slope failure features such as wavy, incoherent, truncated, incised and chaotic reflectors on subbottom profiles averaging 10 m below the sea floor (figure 1). The D-D' profile shows wavy, disturbed and, oblique reflectors. The wavy reflectors represent the draping of 12 m thick sediments over the bedrock. The strong oblique reflector that can be trace over 2500 m, has been interpreted as the prograding surface (10^{o} of incl.) of a new submarine lobe. The weaker oblique reflectors contain in the new submarine lobe correspond to the progradation fronts of the system and the disturbed reflector near the upslope break of the progradation surface represents slumped strata. The lobe is 7.5 m thick at is maximum thickness point. The C-C' section profile intersect the D-D' segment at D'. The C-C' section shows bedrock signature, undulated, chaotic, and steep oblique reflectors. The bedrock is 3 m deep near the C point and 7.5 m below the sea floor at the slope break. The same strong reflector previously identified on the D-D' line and interpreted as a progradation surface, can be followed on the C-C' profile. The weaker oblique reflectors are interpreted as truncated clinoforms. The chaotic reflectors at the base of the lobe slope are typical of failure deposits. The undulated seafloor on the top of those deposits has frequently been identified as compression dunes (Christian et al., 1997). The failure deposits are 4.5 m thick and are capped by 1.5 m of new submarine lobe sediments. Because of the steep slope gradient, the B-B' subbottom profile exhibit steep oblique reflectors. Wavy and contorted reflectors are also present in this segment. A reworking layer corresponding to the strong and discontinuous reflector, can be observed near the B point. Contorted reflectors show slumping activity on most of the slope. At the base of the slope, a series (appr. 3 m thick) of stratified strata slides can be suggested by the gently undulating reflectors. A 1 m thick seismic facies showing wavy reflectors, overlies the stratified strata slides deposits. The wavy reflectors may correspond to erosion features induced by bottom current circulation. The A-A' line contains seismic characters like oblique, discontinuous and incised reflectors. The oblique reflectors at the top of the sea floor slope indicate truncated clinoforms. The discontinuous strong reflectors may constitute in reworking layers. The undulated sea bottom slope reflector is interpreted as erosion signature and may be cause by seafloor currents. Finally, the small incisions at the top and the bottom of the strong discontinuous reflector can represent channel erosion. Thus, beside the incisions, the A-A' line reflectors express similar stratigraphic features as the B-B' line; i.e. eroded strata's, reworking layers, and truncated clinoforms.

From their seismic facies interpretation, Hart and Long (1996) have constructed the following paleogeographic reconstitution. During the last forced-regression, the main fluvial channel of the Outardes river eroded deltaic and prodeltaic sediments of the highstand system tract (HST) and FSST. During this period, the forced-regression delta plain has been incised. For this reason, the raised delta plain of the actual coastline is characterised by an incised Delta (adapted after Hart and Long, 1996).

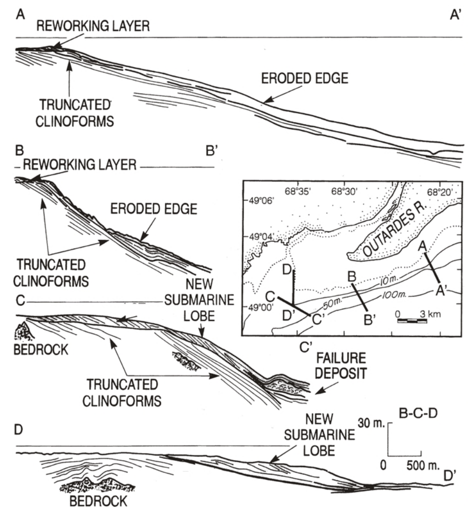

Figure 1. Line drawings of seismic profiles from Outardes

channel system and by numerous low terraces. The present active delta is feeding a submarine fan that is over 50 m thick in water deeper than 300 m.

3. BATHYMETRIC DATA

High-resolution bathymetric mapping of the Outardes delta seabed has been carried out by using an EM 1000 echosounder installed on board the CSS F.G. Creed, a Canadian Hydrographic Survey vessel. The CSS F.G. Creed vessel is a catamaran designed to reduce wave motion on the ship and resistance on the ship's forward motion through the water that makes it a very stable platform for high survey speeds (Urgeles et al., 2001a). The stability of the platform is even enhanced with a computer-controlled system. The stabiliser system controls the pitch and roll of the vessel and allows adjustment of the heel and trim of the catamaran in real time during the navigation course. During the cruise, the positioning system used was a DGPS. The multibeam echosounder has permitted to determine the geomorphology of the seafloor and the sedimentary transport axis. The surface geology of the seabed has been deduced by using the backscatter intensity values of the multibeam data. Casts have been done to record the sound velocity profile of the water column in the area covered by the survey. Sound velocity was calibrated with a series of water casts. The EM 1000 operates at 95 kHz frequency with 60 beams spaced by 2.5^{o} for a total coverage of 150^{o} or 7.5. times the water depth (Hughes-Clarke et al., 1996).

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The data were collected during the September 3 to 5 2000 cruise. The data sets were processed onboard by using UNB's Ocean Mapping Group (OMG) softwares to correct artifacts and errors introduced during the data collection. During post processing, tidal correction were merged into the survey data files (Urgeles et al., 2001a). The resolution of the maps 20 m.

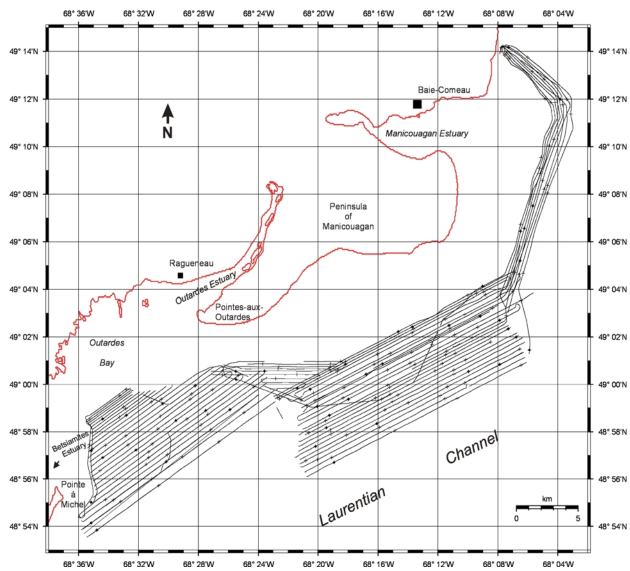

Figure 2. Localisation of the study area and localisation of the different multibeam lines realised during the September 3 to 5 cruise.

The study area is part of the lower forced-regression/lowstand deltaic complex connecting shallower to deeper marine settings (figure 2). The deltaic prism contains the Betsiamites and Outardes river deltas. In this sector, principal geomorphologic structures are compression "dunes", submarine landslide scars, and debris flows. The pseudo-shelf regroups anthropomorphic channels and sinuous to meandering « natural » channels. The anthropomorphic channels consist in two straight cavities formed by electrical cables installed in the mid-50's to experiment a potential electrical transport route to deserve south shore population of the St Lawrence river (Long, pers. comm., 2001). The two trenches incising the seabed have been caused when the cables were pulled back at the end of the '50's. The slope sector reveals several fresh submarine landslide scars related to the steep slope gradient.

Five zones (boxes 1 to 5) have been more specifically analysed because of the high concentration of significant failure and sedimentation signatures (figures 3 and 4). The first box presents a 3D projection of submarine landslide features approximately 3.6 km N.-E. of the Betsiamites Estuary (figure 5). This box is located in 20 to 120 m water depths and reveals geomorphologic evidence of compression bulges, alimentation braided channels, and sinuous channel. The compression bulges field can be observed on a surface of nearly 2 by 1 km in the N.-E. direction. The bulges wavelength (λ) is 90 m. The bulges field is lying on a 1.5^{o} slope. The braided channel incisions extend on 3.3 km in a north-eastern direction. The main channel is 90 m wide. The most distal part of the channel from the Betsiamites Estuary is fill with sediments. The sinuous channel is 300 m wide in is maxima and corresponds to a relict channel that can be followed on

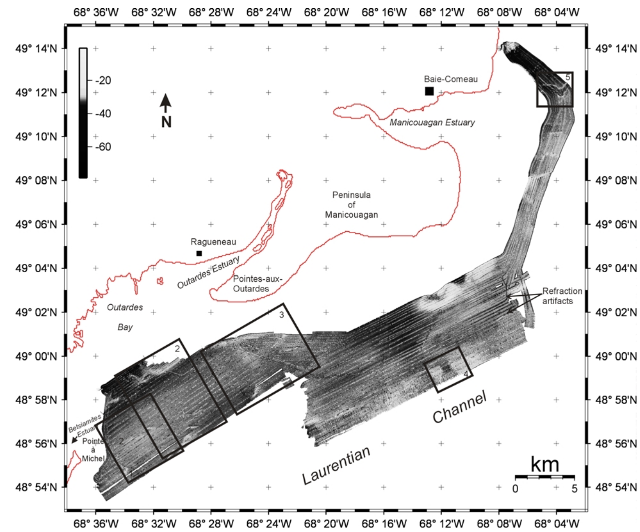

Figure 3. Em1000 sidescan imagery showing backscatter strength values of the multibeam surveyed area. Vertical scale is in dB. The boxes are locating the 5 different zones of detailed analysis

1.8 km in an E.-S.-E./W.-N.-W. axe on a 1^{o} slope. These two precedent features suggest that the sedimentary discharge of this river play a significant role in the formation of the slope. In addition, we cannot put aside the impact of the Outardes river sedimentary discharge on the geomorphologic signature of this sector. Partial lateral filling processes of the braided channel incision probably result from minor submarine slides induced by the high sedimentation rate of the Outardes Estuary. The apparently constant vertical filling of the entire sinuous channel suggests that this channel is a relict. The two different channel-incision patterns may represent the alimentation of the large seafloor mass wasting attributes. The compression "dunes" field has been generated by slumping activity or creeping induced by high sedimentation rates.

The second sector is influenced by both the Betsiamites (S.-W. of box 2) and the Outardes (N.-E.-E. of box 2) estuaries (figure 6). This box contains two perpendicular slopes; one dipping in the N.-E. (1^{o}) direction and the other dipping in the S. (1^{o}) direction. On the northern part of this box several failure scars can be seen. Those scars are in average between 150 to 250 m wide and are sparse in a relatively shallow position in water deep of 20 to 80 m.

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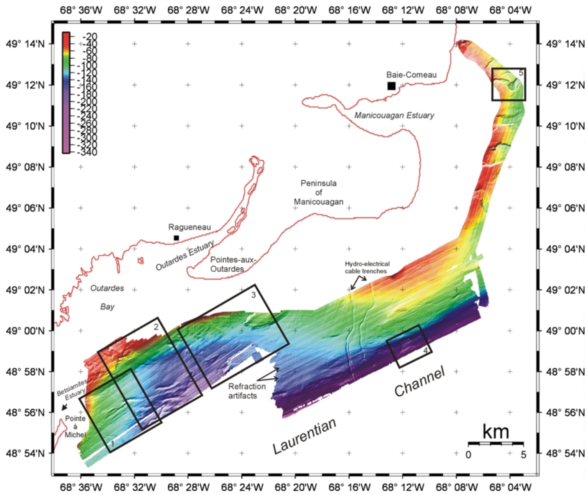

Figure 4. Swath bathymetry of the surveyed area with shaded relief of the surveyed area. Vertical scale is in m. The boxes are locating the 5 different zones of detailed analysis.

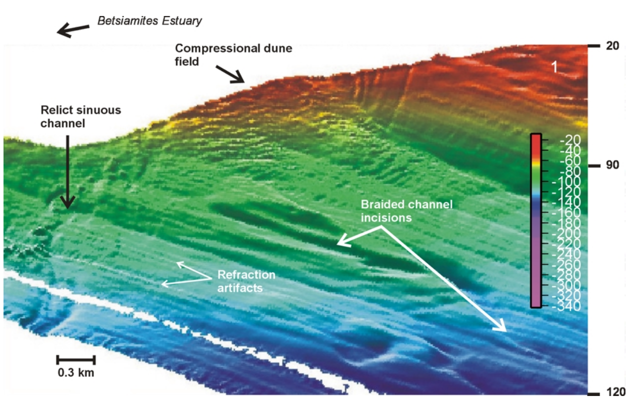

Figure 5. Zoom and 3D projection of box 1 showing detailed Description of the Betsiamites River estuary sector. Vertical scale is in m.

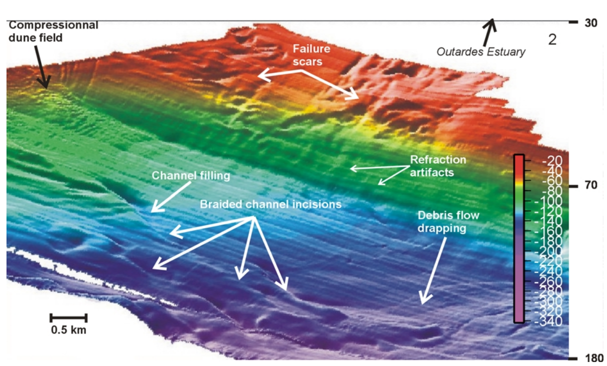

Figure 6. Zoom and 3D projection of different submarine landslide features. Vertical scale is in m.

In the second box, the braided channel incision system presented (figure 6), covers the deepest part in a S.-W./N.-E. trend. Like the proximal part of this system to the Betsiamites Estuary (box 1), the channel are partially filled in their long axes. A debris flow, also present in this study area, draps a 0.8 km wide sector and seems to bypass and to fill the distal part of the braided channel system. The multibeam imagery (figure 6) reveals the effect of the two slopes on the sedimentation and the geomorphologic record of this box. This sector indicates that the sedimentation processes induced by Betsiamites Estuary are no longer dominant in this area and that the sedimentologic conditions are now dominantly influenced by the Outardes Estuary system. This assumption is corroborate by the partial channels filling triggered by the S. dipping slope. The large dimension of the braided channel system clearly indicates that this system as once been drained, at least one, mass wasting event. The failure scars suggest that several minor submarine landslides took place on that slope. Those submarine landslides may have been caused by the instability generated by the conjonction of the steepness of the slope, hydrodynamic conditions, and high sedimentation rates.

The third box located 4.8 km south of the present Outardes Estuary by 80 to 160 m water depths (figure 7), covers an area of approximately 20 km^2 and presents different slope instability features: a rotational slide, a channel incision, and a debris slide. The rotational slide is the predominant feature of this sector and can be followed on almost 3 km long by 0.7 km wide. The scar left by the slide at the crown is evaluated to be 15 m high. The volume of material displaced by the event may represent a few million of m^3. The channel incision is sinuous and lays on the steeper part of the slope (9^o). This « V » shape geomorphologic element is 1.2 km long and 0.2 km wide. The channel ends on a thick ridge at is most southward point. The maximum length of the debris lobe slide is restricted to a distance of 320 m. The debris slide exhibits a main scarp of 760 m long by 40 m high. The volume of that slide is estimated to a million of m^3. Two transverse ridges can also be observed on Figure 7.

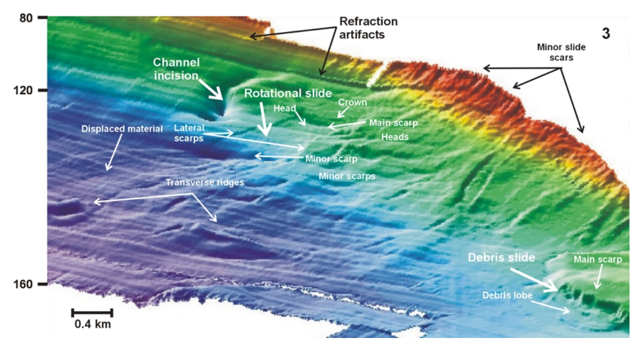

Figure 7. Zoom and 3D projection of box 3 showing 3 types of slope instability features (bigger characters). Vertical scale is in m.

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The left ridge can only be seen in part. The right one is ≈ 1.5 km long and 0.24 km wide. The two ridges are located at the base of the slope (170 m of water depths). On the top right of this box, numerous minor slide scars cannibalises the upper and steeper part of the slope. The rotational slide and the debris slide present fresh scars and no evidence of sediment draping. The restrain height of the main and lateral scarps clearly indicates that this mass wasting event is related to a surficial displacement. The instability factors responsible of this slide may have been controlled by the Outardes Estuary discharge, by the upslope erosion, and by the angle of the slope. The short runoff distance of the debris slide lobe and the sea floor physiography of the debris slide sector indicate that the gravity parameter was not the main cause of this slide. Earthquakes must be considered as main triggering mechanism for this debris slide. The predominant « V » shape of the channel incision support the theory of an erosion canyon induced by the wasting of displaced material coming from the upper part of the slope. The thick ridge located at southward point of the channel may represent the deposition zone of the canyon-drained material. The fact that this canyon like feature did not showed fresh scars when the data were collected, reveals that the channel had not been active since a while at this moment. Two hypotheses can be raised to explain the presence of the transverse ridges. The two ridges can be linked to the braided channels system presented in boxes 1 and 2 and may represent the distal part of the Betsiamites Estuary system. The two ridges may correspond to compression “mega-bulges” system formed at the front of displaced material fans constructed by recent Outardes Estuary system triggered events. Therefore, the overview of the study area (figure 4) seems to support the first hypothesis but the lack of multibeam imagery data in this portion of the study area does not permit the establishment of a clear conclusion. The minor upper slope slide scars show active processes occurring on this sector. The important scar number and their small sizes may contribute to relate those geomorphologic signatures to high frequency processes. The steep slope of this area prevents the accumulation of important sediment volumes. The Outardes Estuary must play a significant role on the sedimentary evolution of this sector.

The fourth box located along the Laurentian channel on the deepest part of the surveyed area (figure 8), presents a major rotational slide on a 5° slope. The slide is 3 km long and 2 km wide at is toe. The main scarp is 80 m high. The volume of the slide contains many millions of m^3. This major slide is characterised on both sides by the presence of minor lateral slides. Minor slides are also present on the right side of the slope. Other major slide geomorphologic evidence can be seen on the left side of the described rotational slide. The pseudo-shelf edge is thought to induce frequent submarine landslide because of 1) the fresh character of the slide scars and 2) the number and the dimensions of those scars. Three mechanisms can be proposed to explain the presence of instability elements in this box : 1) the steep slope gradient 2) the gas expansion and 3) earthquakes but in function of future studies in this area , more triggering mechanisms can be found.

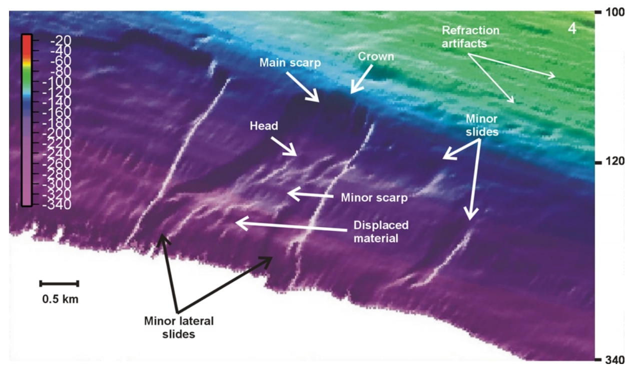

Figure 8. Zoom and 3D projection of box 4showing a detailed description of a rotational slide. Vertical scale is m.

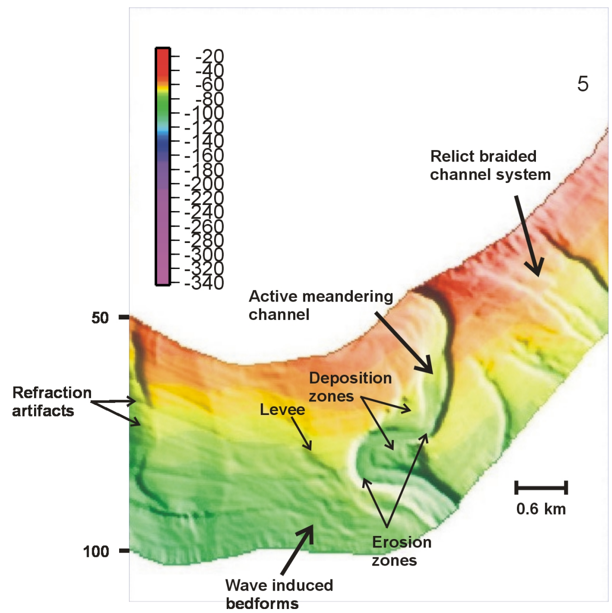

Figure 9. Zoom and 2D projection of box 5 showing a detailed description of an active meandering channel. Vertical scale is m.

The fifth box corresponds to the shallower part of the study area (figure 9). The figure 8 is in 2D and shows an active meandering channel of ≈ 3 km long by 0.6 km wide in the W./E. axe. The deposition zones are respectively covering (from the top to the bottom of the box) 180 000 and 144 000 m^2. An other deposition zone, external to the main channel and interpreted as levee deposits, represents a surface of ≈ 200 000 m^2. A relict braided channel system can also be observed in box 5 and is partly filled by sediments and is showing a S.-W./N.-E. trend. Some wave-induced bedforms can be seen on an area of 2.2 km^2. The bedforms are oriented in the N.-W. direction and are 240 m in λ. The meandering channel and the Manicouagan Estuary have the same W./E. azimuth. Thus, this is the evidence that the active character of the meandering channel is closely linked to the Manicouagan Estuary dynamics. This channel drains sedimentary discharge generated by upper system submarine slope failures. When the channel cannot contain the volume of the flow, it overflows and forms levee deposits. The relict braided may therefore indicates the hydrodynamic evolution of this portion of the study area. The formation of the bedforms is related to actual bottom currents coming from the S.-E. direction (Cremer, 2001).

4. BACKSCATTER DATA

In general, the absorption of the backscatter signal in the sediments corresponds to the half of the wavelength (λ) for a vertical incidence beam; i.e. < 50 cm (Urick, 1975). Previous studies have demonstrated that, generally, backscatter strength increases with grain size (Hughes-Clarke et al., 1997). However, some studies have shown the opposite (Urgeles et al., 2001b; Borgeld et al., 1999). In fact, two cases, one in the Saguenay Fjord and the other on Eel shelf (California) have revealed an association between high backscatter values and finer materials. Because, the backscatter signal response is closely linked to the roughness of the seabed, one of the major concerns in the study of the backscatter is the determination of the factors that contribute to roughness generation. Two factors have been previously highlight by Urgeles et al. (2001b): 1) physical energy conditions acting on the seafloor and 2) bioturbation. In general, the backscatter mosaic mostly reflects low backscatter intensities of approximately –30 dB (figure 2). The higher backscatter zones are located on the proximal environments, near the Betsiamites and Outardes deltas and on the slope area. The most predominant backscatter features correspond to landslide located patches on the slope (Urgeles et al., 2001a). According to Urgeles et al. (2001a), the slope itself is mainly constituted by high backscatter areas excepted for the submarine landslide features that consist in lower backscatter strength values. Most of the submarine landslides are occurring on surficial geology composed of fine-grained materials (Hampton et al., 1996). The high correlation between submarine landslide features and fine grained deposits is due in most part to high water content and extremely underconsolidated character of those materials (Perret et al., 1995). Thus the geomorphologic signature of the submarine landslides is related to fine-grained deposits. The most predominent signal (-30 dB) on the backscatter mosaic (figure 2) might correspond to a mixed facies of sand and fine-grained sediments and represent reworked material. Past studies on the actual (Hart and Long, 1996) and the Quaternary (Hart and Long, 1990) Outardes delta have presented hydrodynamic conditions that can generate bottom roughness; i.e. storm action, tides and waves, bottom currents, and rivers discharge. Normally bioturbation is inversely related to the level of physical energy (McCall and Tevesz, 1982) but some studies (Cremer, 1996; Hart, 1987) have observed the presence of intense bioturbation in the surficial sediments on some parts of the actual Outardes delta sector. Urgeles et al. (2001b) have suggested that the high backscatter values of the finest sediments in the Saguenay Fjord are due to bioturbation induced roughness. The bioturbation can modify the surface roughness by changing the void ratio of the material. We believe that both, the physical energy conditions and the bioturbation, have played a significant role in the spatial variations of the backscatter values in the study area. Because of the lack of core data in this sector, we cannot argue that the higher backscatter values correspond to coarse grain materials

5. REFRACTION ARTIFACTS

The refraction artifacts (see figures 3 to 8) are present in most (if it is not all) of the multibeam processed data because of the sound speed variations in the water column (Hughes-Clarke, 2000a). The sound speed variations are due to water column structure changes that is a function of the local ocean physiography, in both space and time (Hughes-Clarke, 2000b). In this study, the sound velocity profile was measured every 4 minutes to calibrate the multibeam sonar data (Furlong, pers. comm., 2001). This may have caused bad estimation of the water column profile and then contribute to generate artifacts because of the delay between the sound speed acquisition and the application of the proper correction factor onboard. The difference in the water sound speed causes the distortion of the outer beam ray paths. The refraction artifacts can be observed as parallel tracks that look like small-scale ridges along the ship's track (figures 3 to 8). Two types of artifacts were encountered during the onland processing; i.e. 1) punctual bathymetric low features and 2) parallel small-scale ridges. The first one was easily remove with the SwatEd's « refraction editor ». We were unable to completely remove the second one because of its more subtle signal. Those artifacts are mostly related to the outer beam patterns. This problem was partly solved on land during post-acquisition processing by using the « SwathEd refraction editor » tool created by the OMG. The « refraction editor » allows to empirically estimate systematic biases due to imperfect measurement of the water column (as a function of time). In the present case, those artifacts features have not been considered as a problem for the geomorphologic interpretation of submarine landslide signature because of their small dimension and their constant presence.

6. DISCUSSION

6.1 System's evolution

Many truncated clinoforms show a basinward progradation of the system during the Holocene forced regression (Hart and Long, 1996). The steepness of the clinoforms reveals important fluvial sediments input. The Manicouagan Peninsula is interpreted as Holocene prodeltaic deposits generated in part by the Outardes system (Hart, 1987). The fluctuations of this system reveal processes wich have played a strong role in the evolution of the sedimentation Wave remobilised the sediment distribution around the Manicouagan Peninsula. Bedforms orientation are induced by the fetch (S.-E.) (figure 8). The important sea-level drop that has occurred during the past 10 kyr, has generated fluvial channel incisions in the deltaic and prodeltaic deposits and a direct alimentation of the slope. The different subsurface morphologies indicates that erosion mechanisms are still active on the Outardes delta. Those mechanisms are believed to be partly related to submarine landslides because of the observation of failure deposits seismic signature (figure 1 see B-B' profile). Other mechanisms can be mentioned for the sedimentation of reworking layers such as bottom currents, waves, tides and storms.

6.2 Actual system's dynamics

The steepness and the high sedimentary discharge of the system have led to the generation of submarine landslide features in the shallower parts. The geomorphologic instability evidences in the deeper part of the system, specially along the pseudo-shelf-break, may have been caused by storm wave action and probably earthquakes if gas content is important. According to Hampton et al. (1996) and to the Geological Survey of Canada (GSC), it is unlikely that earthquakes could have triggered recent submarine landslide in this region. In fact, to induce submarine landslide $M \approx 6$ earthquakes are necessary. In the Lower St Lawrence/New Brunswick earthquake seismic zone, no event of $M<5.1$ have been recorded in the past century (GSC, 2001). Though, because of the high biotic content of the sediments (Cremer, 1996; Hart, 1987), the decay of this organic matter could have form expansive interstitial gas. The presence of gas has been associated in previous studies (Christian et al., 1997; Hampton et al., 1996) as a parameter that can predispose to instability. The gas is affecting static shear strength of the material and weakens this last one. Thus, the weaken deposit can move down on nearly flat surfaces driven by small gravitational forces produced, for example, by floods and high river sediment discharge (Hampton et al., 1996).

The multibeam imagery has also contribute to the observation of submarine channels that may have been used as pathways to drain mass wasting material down the slope system's. The main submarine channel features are located near the Pointe-à-Michel in the Bestiamites Estuary area. Those features may represent an ancient submarine braided channel system that has been alimented by slope failure material coming down from the paleo-Betsiamites Delta. The draping and the filling of these channels can contribute to prove that the Outardes Delta is now the dominating system in this sector. The Pointe-à-Michel orientation is, like the Manicouagan Peninsula, suggesting that the fetch was and is still a dominant factor in the context evolution. In the Manicouagan Estuary zone, parts of shallow meandering, sinuous, and straight channels can explain, in part, the dynamics of this portion. According to the sediment filling of those different channels, the distributary system seems to migrate northward. The active meandering drainage pattern suggests that the channel incision occurred on a gently dipping slope. The southward channel parts are exhibiting sediment filling and thus demonstrate that they were inactive when the data were collected. Therefore, the lack of data in this sector limits the interpretation of the dynamics processing that control the evolution of this part of the system. It can be hypothesised, that those channel may have fed (for the inactive ones) or are feeding (for the active one) fan(s) eastward in deep marine settings as it is the case for the Outardes system (Hart and Long, 1996). The quasi-absence of bedforms and the omni-presence of submarine landslide signatures in the study area clearly indicate that the driven sedimentation mechanisms are linked to mass wasting events.

The surficial geology of the study area can be a noticeable factor in the triggering of submarine landslide (Hampton et al., 1996). In the present paper, backscatter strength represented by the sidescan imagery (figure 3) is the main tool for the illustration of the seafloor geology. According to the backscatter strengths mapped in dB in figure 3, the surficial geology of the Outardes Delta sector is principally constituted of very fine sand, silt, clay, and reworked sediments. Sometimes, bioturbation induced bottom roughness can modified the seafloor echo and thus cause misinterpretation errors. In those cases, ground truth validation (i.e. with seabed samples) is necessary. In this study, the backscatter values cannot be used with full confidence for interpretation purposes because of the absence of seabed geology samples.

7. CONCLUSION

The present paper has highlighted past and actual sedimentation processes related to submarine landslides in the Outardes Delta sector. Seismic data have permitted to show, in part, the prograding evolution of the delta in the past 10 Kyr in relation to relative-sea-level fluctuations. Seismic lines have also contributed to underline the strong erosion activity imposed on the system. Bathymetric data have shown geomorphologic elements generated by operating hydrodynamic conditions in this area. Because of the steep regional slope those geomorphologic constituents are constantly susceptible of being reworked by mass wasting events. The 3D view has allowed us to have a better observation of the two different slope vectors effects over the field of study. Even more, this view has permitted to see the encroachment of the Outardes system over the Betsiamites system.

Different parameters can be cited as causes for the observed submarine landslide features : 1) high sedimentation rates, 2) high slope gradients, 3) gas, 4) earthquakes, and 5) storm events. Surficial geology of the sea floor and biogenic gas production may be also mentioned as eventual causes for the formation of submarine landslide evidences. The lack of ground truth validation concerning surficial geology and the presence of gas don't allow us to draw significant interpretations on those topics. The restricted volume of multibeam data is another concern in regard of the system's evolution. Indeed, the partial view of the system imposed by the restrained amount of data is the major limitation to fully understand the dynamics of this system. Fortunately, data acquisition time is planified in the study area during summer 2001 and 2002;

i.e. seismic and multibeam profiling as well as coring activity. Earthquakes are not believed to be a contributing factor for recent (i.e. during the past century) mass wasting generation in the field of study because of their insufficient magnitude to trigger landslides.

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