PRELIMINARY OVERVIEW OF THE MORPHOLOGY IN THE SAGUENAY FJORD WITH A PARTICULAR LOOK AT MASS MOVEMENTS

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ABSTRACT
In order to quantify the hazard associated with submarine mass movements, it is necessary to have a good understanding of the geomorphology in the area of interest. The Saguenay Fjord can be separated into three morphologically distinct regions, each with distinct morphological signatures, sediments and sedimentation rates. These factors control, to a large extent, the occurrence of submarine mass movements in a given area. A methodology for inventorying and evaluating the movements found in the fjord is described, and an example for slides at the confluence of the Bras Nord and Baie des Ha!Ha! is given.

RÉSUMÉ
Afin de quantifier l'aléa associé aux mouvement de masses sous-marins, il est nécessaire de connaître et de comprendre la géomorphologie qui se trouve dans la région d'intérêt. Le fjord du Saguenay peut être divisé en trois unités géomorphologique distinctes, toutes avec ses propres signatures morphologiques, sédiments et taux de sédimentation. Ces facteurs contrôlent dans une large mesure les mouvements qui peuvent se produire dans la région. Dans cet article, une méthodologie pour l'évaluation des mouvements de masses est décrite, et un exemple de l'utilisation de cette méthode est donné pour des glissements à la confluence du Bras Nord et de la Baie des Ha!Ha!.

1. INTRODUCTION

Fjords have been identified as environments prone to submarine mass wasting events (Hampton et al. 1996). A good example of this is the Saguenay Fjord, located approximately 200 km northeast of Quebec City (Figure 1), where evidence of many submarine mass movements exists. The Saguenay Fjord has a long history of natural disasters. Examples include the St-Jean-Vianney slides of 1663 and 1971 (Lasalle and Chagnon 1968, Tavenas et al. 1971), and the 1996 floods (Pelletier et al. 1999). It is also located in a seismically active zone, two significant magnitude earthquakes, magnitude 7 and 6.3, having occurred in the area in 1663 and 1988, respectively (Locat et al. 2003a).

Several authors have already identified and studied various submarine mass movements in the Saguenay Fjord region (Bergeron and Locat 1989, Pelletier and Locat 1993, Syvitski and Schafer 1996, Martin 2002, Urgeles et al. 2002, Locat et al. 2003b). Studies prior to 1994 relied on seismic reflection and sidescan sonar surveys to identify the submarine mass movements. In recent studies multibeam data, collected from various cruises aboard the RV Frederick G. Creed, was used to identify mass movements. It was demonstrated that most of the mass movements were located in the upper portion of the Saguenay Fjord. It is believed that the trigger for all of these submarine mass movements is the 1663 earthquake which shook the Charlevoix region.

One of the goals of the COSTA-Canada project is to develop a general approach to determine the hazard associated with submarine mass movements. The Saguenay Fjord affords an incomparable opportunity to study and understand submarine mass movements, and the hazards associated with these because it has been the centre of many studies over the years. Many geotechnical and geomorphologic data collected are available and housed at the Department of Geology and Geological Engineering in Laval University in Quebec.

In order to achieve the goal highlighted above, the following approach is proposed. The first step is to complete an analysis of the overall geomorphology and

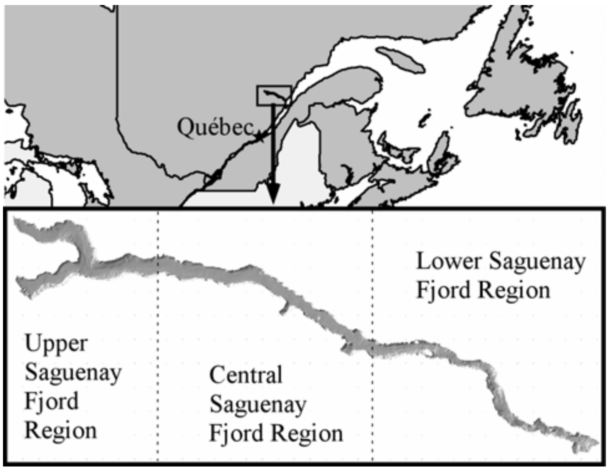

Figure 1. Localisation of the Saguenay Fjord, Quebec, Canada. Also shown are the tentative morphologic region boundaries.

general stratigraphy of the Saguenay Fjord region using multibeam surveys, seismic profiles and cores collected in the Saguenay Fjord. The next step is to do an inventory of the submarine mass movements in the Saguenay Fjord and do a detailed analysis in order to confirm the hypothesis that all of these were triggered by 1663 earthquake. Finally, the probability of new failures will be determined.

The following paper includes a preliminary review of the general morphology of the Saguenay Fjord and an example of the methodology used to inventory the submarine mass movements found within the fjord itself.

2. BACKGROUND AND METHODOLOGY

The advent of multibeam technologies make it possible to use images produced from multibeam bathymetric data in much the same way as aerial photographs making it easier to identify submarine mass movements and determine their morphometric parameters (Locat and Sanfaçon 2000). The EM1000, used in the Saguenay Fjord, is able to resolve changes in depth with a precision of 0.25% of the water depth, however due to the beam width it can only positively resolve features that have horizontal dimensions that measure at least 10% of the water depth (Kammerer et al. 1998). By combining geomorphological and geotechnical information it becomes possible to determine the hazard and ultimately the probability that more submarine mass movements will occur within the Saguenay Fjord.

2.1 Geological Setting And Quaternary History

The Saguenay Fjord is approximately 90km long, and is rectilinear in shape. The depth within the fjord increases steadily from the Bras Nord to 270 m in the central sedimentation basin before decreasing again just east of Anse-St-Jean. Two smaller basins exist between Anse-St-Jean and Tadoussac. The depth in these basins varies between 60 m and 180 m in the basin nearest Anse-St-Jean, and between 60 m and 240 m in the basin closest to the entrance of the Saguenay Fjord. The majority of the freshwater input to the Saguenay Fjord comes from the Saguenay River which drains an area approximately 78 000 km^2 in size (Smith and Walton 1980) and enters the Saguenay Fjord at St. Fulgence.

The orientation of the Saguenay Fjord is controlled by the Saguenay Graben in which it flows (Rondot 1979). The NW orientation of the Saguenay Fjord also made it the preferred glaciation path during the last glaciation period in the region (Prest 1970, Lasalle and Tremblay 1978). For the most part the bedrock consists of metamorphosed Precambrian rocks. Glacial erosion gave the Saguenay Fjord its typical U-shape with cliff walls reaching as much as 400 m in height (Rondot 1979). The high lands are for the most part covered by till whilst the lower lands, through which the Saguenay River flows before entering the Saguenay Fjord, are covered by glacial marine sediments from the Laflamme Sea (Lasalle and Tremblay 1978). The isostatic rebound of the Saguenay region varied between 120 m on the south side of the Saguenay Graben and 140 m on the north side of the Saguenay Graben (Bouchard et al. 1983).

2.2 Tools And Methods Used In Geomorphological Analysis

The Saguenay Fjord has been the focus of many different studies. In the course of these various studies, several multibeam survey campaigns, seismic surveys and sampling campaigns were carried out within the fjord. As previously mentioned, many of these data can be found in the Saguenay Fjord database which is housed at the Department of Geology and Geological Engineering in Laval University in Quebec.

Most recently, two cruises were conducted in the Saguenay Fjord as part of the COSTA-Canada project, the first cruise taking place in October 2002 and the second in July 2003. During these two cruises aboard the RV Coriolis II many of the mass movement features found in the Saguenay were surveyed using a hull-mounted Edgetech chirp sub-bottom profiler. Piston and box core samples were also collected in order to date the submarine mass movements and where possible, confirm the depth of the failure surface. All of the cores were passed through a CAT-Scan making it possible to identify sedimentary structures of interest and confirm the depth to structures found in seismic profiles. Also, many of the cores were logged using a multi-sensor core logger, in order to measure the density and magnetic susceptibility of sediments in the cores.

The following methodology is being used to inventory the submarine mass movements in the Saguenay Fjord. First a digital terrain model (DTM) was constructed using bathymetric data from several multibeam survey campaigns. Submarine mass movements are then identified and coded using an alphanumeric code. The first part of the code consists of a letter which gives an indication of the sector where the mass movement is located. The second part is a number, even numbers are given to mass movements on the southern Saguenay Fjord slope, and odd numbers are given to mass movements found on the northern Saguenay Fjord slope.

Once the movements are identified, it is possible to use the DTM to determine various morphometric parameters shown in Figure 2. These include, the main scarp slope angle (α) and height (H), side scarp slope angles and heights (δ_1, δ_2, h_1, and h_2), sliding plane slope angle (β), width of scar (W_r), length of the scar (l), and run-out length (L) where possible. The approximate area and volume of the zone of depletion are then calculated. Where a debris field is identified, the approximate area and volume of the zone of accumulation are also calculated.

Seismic profiles are used in order to identify the failure surface, the depth and slope of the failure surface. When possible, the seismic profiles are also used to determine the direction and location of the debris field, in order to obtain the run-out length of the submarine mass movement. This information is then used to get a more

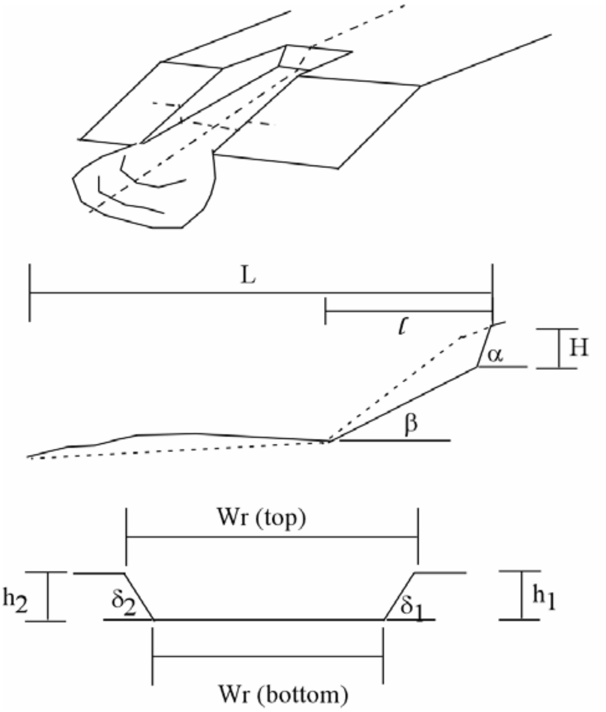

Figure 2. Schematic of a slide. Morphometric parameters are also shown.

accurate measure of the volume involved in the mass movement.

Relationships between various parameters can then be determined and evaluated in order to identify any local conditions which lead to slope instabilities.

3. GENERAL MORPHOLOGY OF THE SAGUENAY FJORD

Submarine mass movements are controlled by a combination of the local morphology, geotechnical properties of the materials and trigger mechanisms. It is important to carry out a geomorphological analysis of the Saguenay Fjord in order to see any potential link between mass movement types and frequency. In this study a sun-illuminated image of the bottom of the Saguenay Fjord is used to divide the fjord into three morphologically distinct regions. These are the Upper Saguenay Fjord region, the Central Saguenay Fjord region, and the Lower Saguenay Fjord region.

3.1 Morphology in the Upper Saguenay Fjord

The Upper Saguenay Fjord region is shown in Figure 3. This region includes the Bras Nord, the Baie des Ha!Ha!, as well as a portion of the Saguenay Fjord past the confluence. The tentative eastern limit of the Upper Saguenay Fjord region is found near Sainte-Rose-du-Nord. This geomorphology in portion of the Saguenay Fjord has been extensively studied and is reported in Urgeles et al. 2002, and Locat et al. 2003a.

In the Bras Nord the Saguenay Fjord starts at St. Fulgence, where the Saguenay River forms a large river delta (Syvitski and Schafer 1996). The surface sediments in the Bras Nord vary from sandy silts in the delta region to silty clays at the confluence (Perret et al. 1995, Urgeles et al. 2002). The rate of sediment accumulation decreases from ~7 cm/yr near the delta to ~0.3 cm/yr at the confluence. (Smith and Walton, 1980).

As can be seen in Figure 3 several slide scars are found along the sidewalls of the Bras Nord. Two common types of mass movements are found in the Bras Nord, slumps and spreads (Urgeles et al. 2002; Locat et al. 2003b). In addition to these slide scars various channels can be seen in the Bras Nord, including a central channel which was most likely formed by strong bottom currents.

The most dominant feature found in the Upper Saguenay Fjord is the escarpment in the Baie des Ha!Ha! (Hampton et al. 1996, Syvitski and Schaeffer, 1996, Locat et al. 2000, and Locat and Lee 2002). This scarp is believed to be associated with a possible fault (Locat and Lee, 2002), and seems to be the scar from a major liquefaction event which has been attributed to the 1663 earthquake that took place in the region. (Syvitski and Schaeffer, 1996, Locat et al., 2000, Urgeles et al. 2002). Another significant flow in the Baie des Ha!Ha! is the Pointe-du-Fort flowslide which has been characterised by Locat et al. 2003b. Slide debris is also found at the foot of the side slopes along both sides of the Baie des Ha!Ha!. As can be seen in Figure 3, this debris is only found below the escarpment.

In addition to the mass movements found in the Baie des Ha!Ha!, two small deltas can also be found near La Baie. These are located at the mouths of the Ha!Ha! and Mars rivers. Associated with the 1996 flood which affected the Saguenay region, the combined volumes of these deltas is approximately 2 million m^3. The usual sediment load from these inputs is much smaller than that from the Saguenay river and the overall sedimentation rate in the Baie des Ha!Ha! varies between 0.1 cm/yr near the deltas to 0.15 cm/yr near the confluence of the Baie des Ha!Ha! and the Bras Nord (Barbeau et al., 1981).

As has been discussed by Locat et al. (2000), there is a significant difference between the north and south slopes in the Baie des Ha!Ha!. The slope angle on the northern slope of the Baie des Ha!Ha! is quite steep with slope angles exceeding 40º (Locat et al. 2000). As can be seen in the satellite image in Figure 3, the shoreline on this side of the Baie des Ha!Ha! is lined by steep rock walls. On the other side of the Baie des Ha!Ha!, there is a zone of postglacial marine deposits along the shore of the Baie des Ha!Ha! (Lasalle and Tremblay 1978). The erodability of these materials causes the southern slope to be much gentler than the northern bedrock controlled slope (Locat et al. 2000). Another feature in the southern slope is the series of gullies which occur near the mouth of the Ha!Ha! River, as previously mentioned by Locat et al. 2003a and Urgeles et al. 2002 (Figure 3).

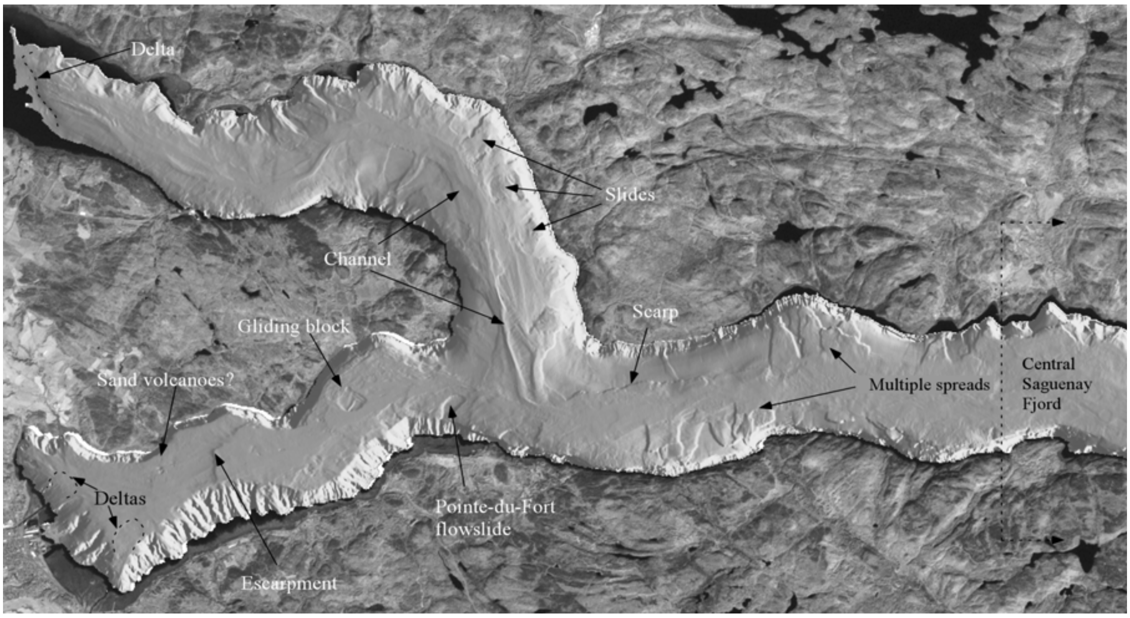

Figure 3. Sun illuminated DTM of the Upper Saguenay Fjord. Illumination direction is 270º.

Several other mass movement features are also found at the confluence of the Bras Nord and the Baie des Ha!Ha!. These mass movements occur in the talus material that has accumulated at the bottom of the sidewalls. In most of these cases only the scarps are left, indicating that these were rapid mass movements. There is also a small scarp that extends along the talus. This scarp is part of a basin collapse which occurred in 1663 (Syvitski and Schafer 1996).

3.2 Morphology in the Central Saguenay Fjord Region

This section of the Saguenay Fjord, which extends between Sainte-Rose-du-Nord and Anse-St-Jean has very little local sediment input, other than a few lateral inputs at Baie Éternité and Anse-St-Jean. The sediment accumulation rates reported by Barbeau et al. (1981) and Smith and Walton (1980) range between 0.1 cm/yr and 0.4 cm/yr. The surface deposits in this portion of the fjord tend to be bioturbated silty clays. The depth in this region of the Saguenay Fjord varies between 250 and 270 m, and the width varies between 1.5 and 3 km.

One feature which occurs in this portion of the Saguenay Fjord is the collapsed zone shown in Figure 4a. This zone of subsidence occurs at a depth of 270m, near the transition from the Upper Saguenay Fjord region to the Central Saguenay Fjord region, and is most likely linked to the 1663 earthquake.

The transition from the steep side slope to the gentle floor slope is much more rapid than in the Upper Saguenay Fjord region and less talus material is collected at the foot of the sidewalls. For this reason, fewer surficial submarine mass movements are identified in this region of the Saguenay Fjord. Instead a few deep seated debris fields can be seen. As shown in Figure 4b, the surface expression for these debris fields resembles compression waves. When the sub-bottom profile is examined (Figure 4c), it is obvious that the debris are deep, and that whilst they are covered by a draping turbidite unit, this latter unit does not succeed in masking the debris.

3.3 Morphology in the Lower Saguenay Fjord

The transition from the central basin to the lower fjord occurs below Anse-St-Jean. As shown in Figure 5, this transition is marked by a change in both the general morphology of the bottom, and the materials which can be found at the surface.

Where the bottom of the fjord in the Upper and Central Saguenay Fjord regions was quite regular, in the Lower Saguenay Fjord, it is quite irregular. Even within the two smaller basins there are significant changes in the depth, as shown in Figure 5a.

Added to this difference is the change in the sub-bottom profiles. At the transition between the Central and Lower Saguenay Fjord, the top reflector begins to mask the lower reflectors. By the time the first basin in the Lower Saguenay Fjord is reached, the top reflector completely obscures any lower reflectors (Figure 5c). Samples collected near these seismic lines also show the change in material. Near the transition zone, a piston core (COR0210-62) measuring approximately 4.9 m was collected. The material consisted of stiff grey silty clay with sand. The cores collected at COR0210-64 and COR0210-65 were only 35 – 40 cm in length and contained sands, gravels, and clays, suggesting that the material is possibly a till material which was deposited during the last glaciation period.

The area also presents different morphological signatures than those found in the Upper and Central Saguenay Fjord regions. As shown in Figure 5, no slide scars are found in the area. However, several other distinct landforms are found in this region of the Saguenay Fjord.

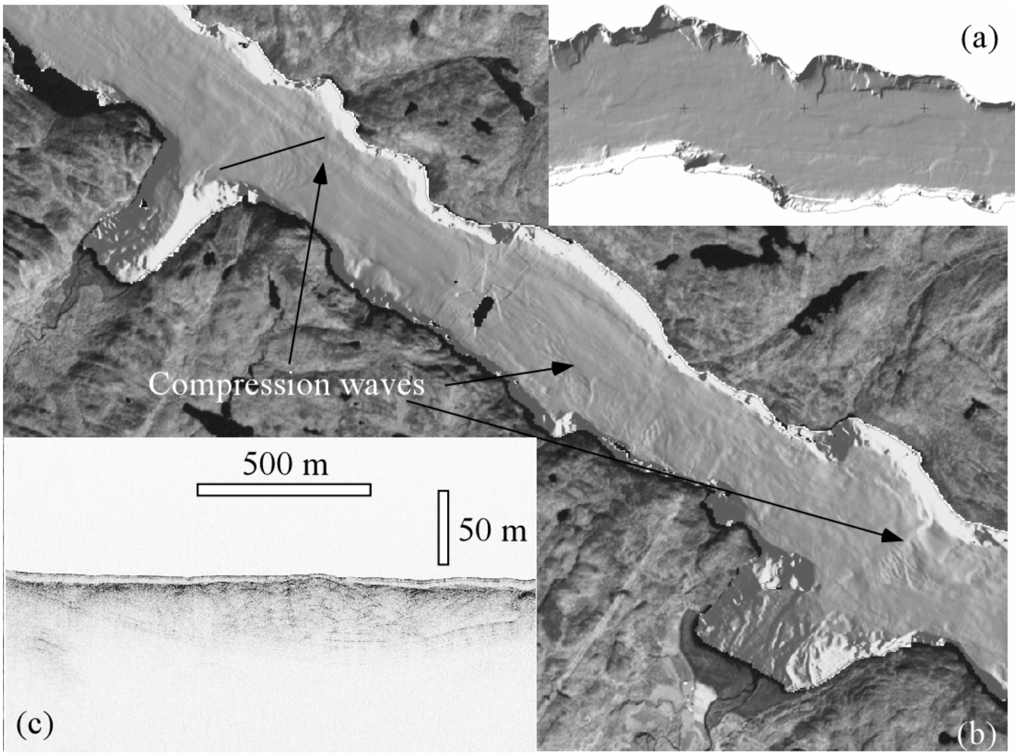

Figure 4. Sun illuminated DTM of the Central Saguenay Fjord. Illumination direction is 270º. (a) Subsidence zone near the boundary between the Upper Saguenay Fjord and the Central Saguenay Fjord regions. (b) Close-up on the sector between Baie Éternité and Anse-St-Jean. (c) Sub-bottom profile across compression waves near Baie Éternité.

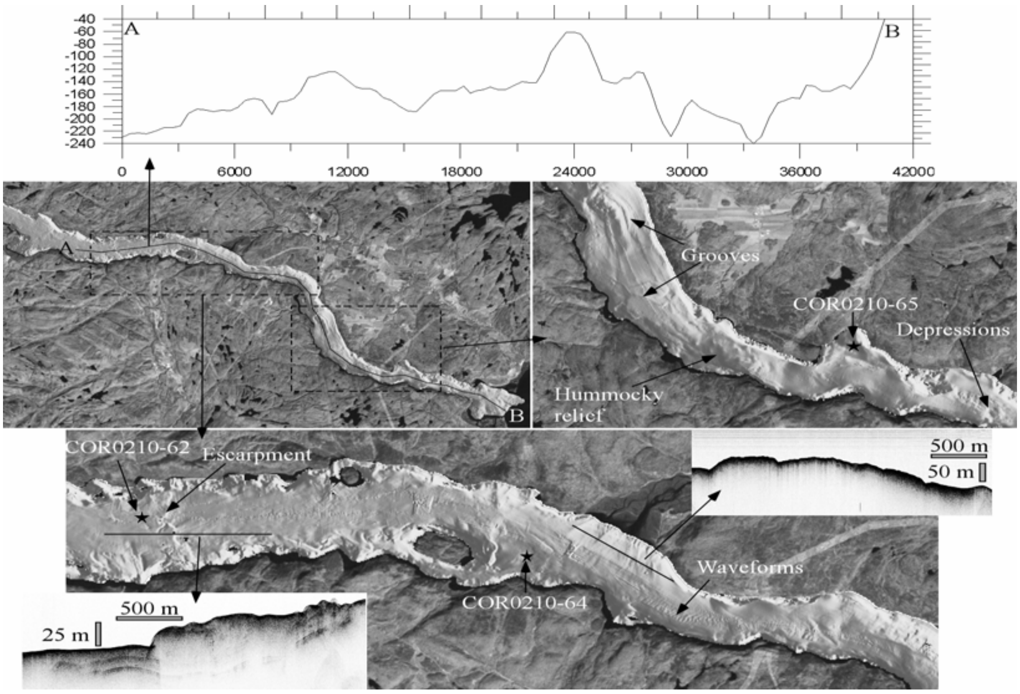

Figure 5. Sun illuminated DTM of the Lower Saguenay Fjord. Illumination direction is 270º. (a) Depth along the centreline of the fjord. (b) Close-up on the downstream portion of the Lower Saguenay Fjord. (c) Close-up of the upstream portion of the Lower Saguenay Fjord.

Beyond Anse-St-Jean the floor has a slightly irregular relief, and the water depth decreases from 220 m to 120 m at the crest of the first basin. The irregular relief in this region is visible due to the lack of infilling in this portion of the Saguenay Fjord. The surface materials are likely tills which are generally deposited under glaciers, meaning that the irregular relief was most likely caused by the movement of a glacier.

Near the opening of the Ste-Marguerite River there are some waveforms along the bottom of the fjord (Figure 5c). These occur near the south shore and just below where the river meets the fjord, at a depth of approximately 150 m. The waves decrease is size with distance from the Ste-Marguerite River, and disappear near the foot of the ridge separating the first basin from the second basin.

Grooves which tend to follow the axis of the fjord can be seen in Figure 5b. These grooves extend from the crest of between the first and second basins to the bottom of the second basin. The relief changes once more at the bottom of the second basin to become a hummocky relief. This hummocky relief becomes attenuated further down the Saguenay Fjord. One last feature of note is some depressions which occur near the entrance of the Saguenay Fjord. It is possible that these depressions are scour marks created by glacier movement.

4. EXAMPLE OF MORPHOMETRIC ANALYSIS OF MOVEMENTS IN THE UPPER FJORD

In order to clearly understand the conditions which will lead to failure in the Saguenay Fjord it is important to inventory and determine the morphometric parameters of submarine mass movements in the area. For the purposes of this article, the small zone shown in Figure 6 was isolated and the morphometric parameters were determined (Table 1). Sub-bottom profiles and CAT-Scan profiles of cores in the area show that the sediments in this portion of the fjord are a layered sediment system, with several strong reflectors. Failures occurred along distinct reflectors. An example of the chirp sub-bottom profile across one such movement is shown in Figure 6.

The values for the main scarp slope (α) have slightly asymmetrical distribution ranging from 9° through 33°, the mean being 19°. Most of the high α values are found in slides which originated high in the walls of the Saguenay Fjord, where the precision of the multibeam data is reduced due to the steepness of the wall. However three of the highest α measured occurred in relatively flat portions of the walls (C18, C20 and C22). In these cases the precision is within a fraction of a degree. There is a marked difference in the distribution of the side scarp slopes (δ). In this case there is a bi-modal distribution with peaks occurring at 5° and 11°. The δ values range between 1° and 18°, with an average value of 8.5°. The average intact slope angle in the area is approximately 5°.

There is a positive correlation between the scarp slope angle and the height of the scarp with which it was associated. For the main scarp, the coefficient of correlation between α and H is 0.60. In the case of the side scarps, the coefficient of correlation between δ_1 and h_1, and δ_2 and h_2, is equal to 0.79. Similar values were reported by McAdoo et al. (2000). There is a weak negative correlation between α and ℓ, the coefficient of correlation being -0.44. In McAdoo et al. (2000), a similar coefficient of correlation was found between run-out length and the main scarp slope angle. Unfortunately, in this case, it was not possible to determine the individual run-out lengths for the mass movements since the individual debris masses quickly merged into one large debris mass.

The areas and volumes shown in Table 1 only include the zone of depletion. The coefficients of correlation between the main scarp slope angle and the area or the volume are -0.05 and 0.02 respectively, indicating that there is no correlation between these parameters. McAdoo et al. (2000) reported higher coefficients of correlation than those found in this study but with values on the order of -0.2 to -0.3, it is clear that the relationship between these parameters is still weak.

As with other mass movements in the Saguenay Fjord, it is believed that these particular mass movements were caused by the 1663 earthquake which shook the area. The shaking most likely caused some of the coarser layers found in this portion of the fjord to liquefy, in turn causing lateral spreading in the soil above the liquefied layer. This alone was not enough to create the scars found in this portion of the fjord, since the material would not have moved very far unless it could be completely evacuated from the bottom of the slope. However, as proposed earlier by Syvitski and Schafer (1996), there was first a collapse of the material in the centre of the fjord. This created the small central scarp which is shown in Figure 6. This collapse further destabilized the slopes by undercutting the bottom of the slope. It then became possible for the material above the liquefied layer to be evacuated from the departure zones, creating the scars shown in Figure 6. This hypothesis is based on an analysis of the multibeam and seismic reflection data. Piston cores taken in this zone must still be extruded. The characterisation of the core samples will include a description of the types of materials found, the geotechnical properties of these materials, the age of the mass movements, and where possible confirm the depth of the failure surface.

The mass movements identified in Table 1 only make up a fraction of all the movements in the Saguenay Fjord. The remaining movements are also being inventoried in the same fashion. Once all the movement information is collected a complete statistical analysis of the slides in the Saguenay Fjord can be completed.

5. CONCLUSIONS

The Saguenay Fjord can be divided into three morphologically distinct regions. Each of these regions has a different number of submarine mass movement

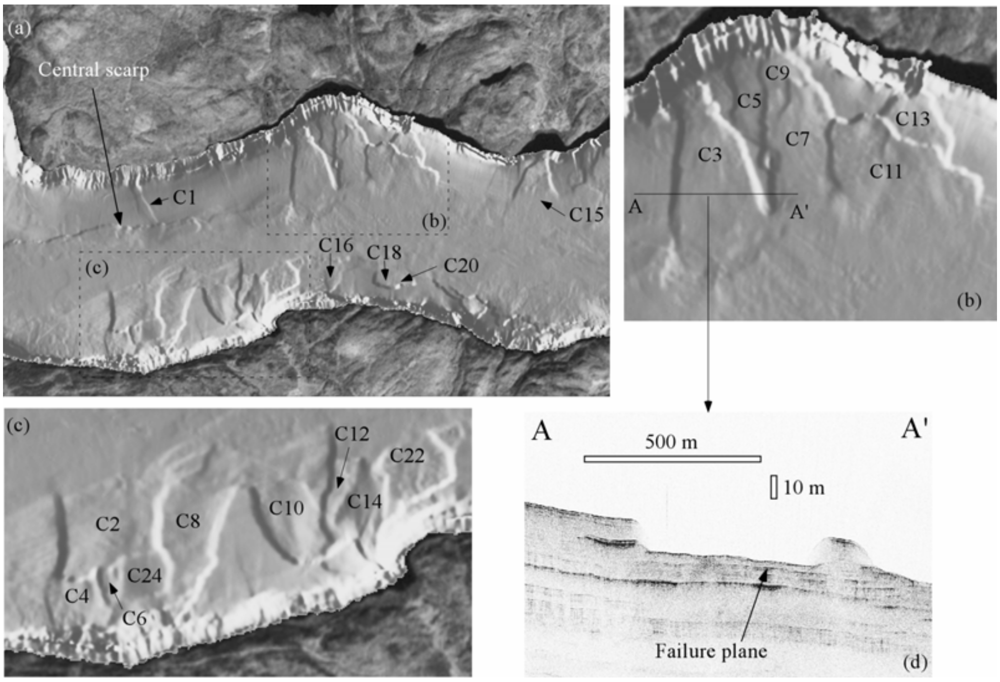

Figure 6. (a) Close-up of the region inventoried to date. Illumination direction is 270º. (b) Close-up on the mass movements found on the north shore of the Saguenay Fjord. (c) Close-up of the mass movement features found on the south shore of the Saguenay Fjord. (d) Sub-bottom profile across one of the features.

Table1. Morphometric parameters measured using DTMs and sub-bottom profiles.

ID	H m	$\mathcal{L}$ M	W_r (top) M	W_r (bottom) m	h_1 m	h_2 m	α °	β °	δ_1 °	δ_2 °	Slope of failure surface* °	Depth to failure surface* m	Area m^2	Volume X 10^3 m^3
C1	N.D.	660	150	80	4	4	19	5	5	6	5	2	99000	455
C2	13	670	790	635	11	13	15	3	10	10	3	7	529300	9070
C3	20	1150	510	415	13	15	13	3	18	15	3	7	586500	9042
C4	N.D.	430	405	330	3	4	14	1	4	5			174200	4316
C5	9	660	595	495	12	12	24	5	12	12			392700	4316
C6	6	440	160	10	4	4	9	4	5	4			70400	150
C7	9	910	115**	55**	4	5	9	3	9	10	4	7	381000	4382
C8	15	1360	460	350		12	16	2		6	3	7	625600	10465
C9	N.D.	430	325	150	5	6	24	5	8	3	4	5	139800	1072
C10	17	1050	385	260	12	7	18	4	13	5		1	404200	3556
C11	21	620	1165	1035	9	6	22	2	7	6	3	16	722300	16027
C12	27	770	215	170	11		9	4	16				165600	1630
C13	20	370	520	405	12	11	29	6	13	12		4	192400	2652
C14	24	830	210	105	8	7	19	5	6	8			174300	980
C15	N.D.	640	415	335	10	7	27	8	11	10	6	4	265600	3000
C16	11	520	330	160	3	4	16	7	4	2			171600	456
C18	30	260	505	365	10	2	33	1	15	1		4	131300	1583
C20	28	150	165	95		7	29	3		7		4	24800	214
C22	27	520	515	460		11	28	5		13		6	267800	4310
C24	9	360	355	125	8	9	11	4	3	11	5	2	127800	907
Central scarp	35						10							

Note: Slope angles are rounded to the nearest degree. Vertical distances are rounded to the nearest metre, and horizontal distances to the nearest 5 metres.
* Calculated based on the failure surface identified in sub-bottom profiles.
**W_r measured across the upper portion of the spread.

features, the Upper Saguenay Fjord region having the most evidence of submarine mass movements. A preliminary morphometric analysis has shown that there is a positive linear relationship between scarp height and scarp slope angle, similar findings were reported by McAdoo et al. (2000). There was a weak negative relationship between main scarp slope angle and scar length, and there are no correlations between the main scarp slope angle values and area or volume of the zone of depletion. Many more mass movements still need to be inventoried. Once these have been included it is possible that more relationships will be found.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Barbeau, C., Bougie. R., & Côté, J.-E. 1981. Variations spatiales et temporelles du césium-137 et du carbone dans des sédiments du fjord du Saguenay. Canadian Journal of Earth Sciences. 18: 1004-1011.

Bergeron, M. & Locat, J. 1989. Analyses géotechniques à rebours de glissements sous-marins, fjord du Saguenay, Québec. Rapport GGL-89-40. Département de géologie et de génie géologique. Université Laval. Québec, Canada.

Hampton, M.A., Lee, H.J., & Locat, J. 1996. Submarine landslides. Reviews of Geophysics. 34(1): 33-59.

Kammerer, E., Hughes Clarke, J.E., Locat, Doucet, N., and Godin, A., (1998). Monitoring temporal changes in seabed morphology and composition using multibeam sonars: a case study of the 1996 Saguenay River floods. Proceedings of the Canadian Hydrographic Conference 1998, Victoria, Canada, 450-461.

Lasalle, P. & Chagnon, J.-Y. 1968. An ancient landslide along the Saguenay River, Quebec. Canadian Journal of Earth Sciences. 18: 607-629.

Lasalle, P. & Tremblay, G. 1978. Dépôts meubles, Saguenay Lac Saint-Jean. Rapport géologique 191. Ministère des Richesses Naturelles du Québec. 61 p.

Locat, J. 2001. Instabilities along ocean margins: a geomorphological and geotechnical perspective. Marine and Petroleum Geology. 18(4): 503-512.

Locat J., & Lee H.J. 2002. Submarine landslides: advances and challenges. Canadian Geotechnical Journal. 39: 193-212.

Locat, J., & Sanfaçon, R. 2002. Multibeam surveys – a major tool for geosciences. Sea Technology. 43(6) : 39-47.

Locat, J., Urgeles, R., Schmitt, T., Houareau, L., Martin, F., Hill, P., Long, B., Simpkin, P., Kammerer, E., & Sanfaçon, R. 2000. The morphological signature of natural disasters in the upper Saguenay Fjord area, Québec, Canada. Proceedings of the 53rd Canadian Geotechnical Conference. Montreal. Canada. 109-116.

Locat, J., Martin, F., Levesque, C., Locat, P., Leroueil, S., Konrad, J.-M., Urgeles, R., Canals, M., & Duchesne, M.J. 2003a. Submarine mass movements in the upper Saguenay Fjord, (Québec, Canada), triggered by the 1663 earthquake. Proceedings of the 1st International Symposium on Submarine Mass Movements and Their Consequences. Nice, France. 509-519.

Locat P., Leroueil, S., Locat, J., & Duchesne M.J. 2003b. Characterisation of a submarine flow-slide at Pointe-du-Fort, Saguenay Fjord, Quebec, Canada. Proceedings of the 1st International Symposium on Submarine Mass Movements and Their Consequences. Nice, France. 521-529.

Martin, F. 2002. Caractérisation géotechnique et étude du comportement cyclique des sédiments marins de la Baie des Ha!Ha!, Fjord du Saguenay, Québec. Masters thesis. Université Laval. Québec, Canada.

McAdoo, B.G., Pratson, L.F., & Orange, D.L. 2000. Submarine landslide geomorphology, US continental slope. Marine Geology. 169: 103-136.

Pelletier M. & Locat J. 1993. Les glissements sous-marins du Bras Nord du fjord du Saguenay : aspects géomorphologiques et géotechniques. Rapport GREGI 93-21. Département de geologie et de génie géologique. Université Laval. Québec, Canada.

Pelletier, E, Mostajir, B. Roy, S., Gosselin, M., Gratton, Y., Chanut, J.-P., Belzile, c. Demers, S. & Thibault, D. 1999. Crue éclair de juillet 1996 dans la région du Saguenay (Québec). 1. Impacts sur la colonne d'eau de la baie des Ha!Ha! et du fjord du Saguenay. Canadian Journal Fisheries and Aquatic Sciences. 56: 2120-2135.

Perret, D., Locat, J. & Leroueil. S. 1995. Strength development with burial in fine-grained sediments from the Saguenay Fjord, Quebec. Canadian Geotechnical Journal. 32: 247-262.

Prest, V. K. 1970. Quaternary geology of Canada. Chapter 12 from Geology and economic minerals of Canada. Department of Energy, Mines and Resources. Ottawa, Canada. 676-758.

Rondot, J. 1979.Reconnaissances géologiques dans Charlevoix-Saguenay. Rapport géologique. 44 p. Ministère des Richesses Naturelles du Québec.

Smith, J.N. & Walton, A. 1980. Sediment accumulation rates and geochronologies measured in the Saguenay Fjord using the Pb-210 dating method. Geochimica et Cosmochimica Acta. 44: 225-240.

Syvitski, J.P.M., & Schafer, C.T. 1996. Evidence for an earthquake-triggered basin collapse in Saguenay Fjord, Canada. Sedimentary Geology. 104: 127-153.

Tavenas, F., Chagnon, J.-Y., & La Rochelle, P. 1971. The Saint-Jean-Vianney landslide: Observations and eyewitness accounts. Canadian Geotechnical Journal. 8: 463-478.

Urgeles, R., Locat, J., Lee, H.J., & Martin, F. 2002. The Saguenay Fjord, Canada: integrating marine geotechnical and geophysical data for spatial seismic slope stability and hazard assessment. Marine Geology. 185: 319-340.