Landslides: Stratigraphic Control and Trigger Mechanisms, Cannes de Roches Formation, Gaspe Peninsula, Quebec, Canada.

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Introduction

Enormous seacliffs line the southern coast of the Baie de Malbaie near Coin du Banc. This bay is located along the eastern edge of the Gaspe Peninsula, Quebec, Canada. The high seacliffs coupled with numerous, localized mass movements in the area pose an ominous presence. Landslides have scoured large gaps into the cliffs, which dip towards the bay at an angle of sixty degrees. The steep dip of the beds suggests that they are simply sliding along the bedding planes under the forces of gravity. While natural gravitational attraction may be one cause, the landslides can be attributed to several other factors (Varnes, 1978).

The folded beds of the Upper Mississippian Cannes de Roches Formation comprise the seacliffs, which dip at a 60 degree angle towards the bay. The Cannes de Roches Formation is subdivided into three lithologically distinct members. Closest to the bay, the Upper Member is a conglomerate with sandstone interbeds. The Upper Member serves as a protective retainer for the formation's successive members. The Middle Member, a bright red mudstone with calcareous hardpans, rests immediately inland. The Lower Member is a thick breccia.

Due to intense landsliding action, each member has been unevenly exposed along the southern coast of the Baie de Malbaie. A series of landslides has transported portions of each member of the Cannes de Roches Formation from their shoreline cliff exposures into the bay. The landslide debris is subsequently transported by longshore currents and redeposited on le Cordon littoral de Malbaie, a sand spit that was studied by Gary Creaser-Keck 1990.

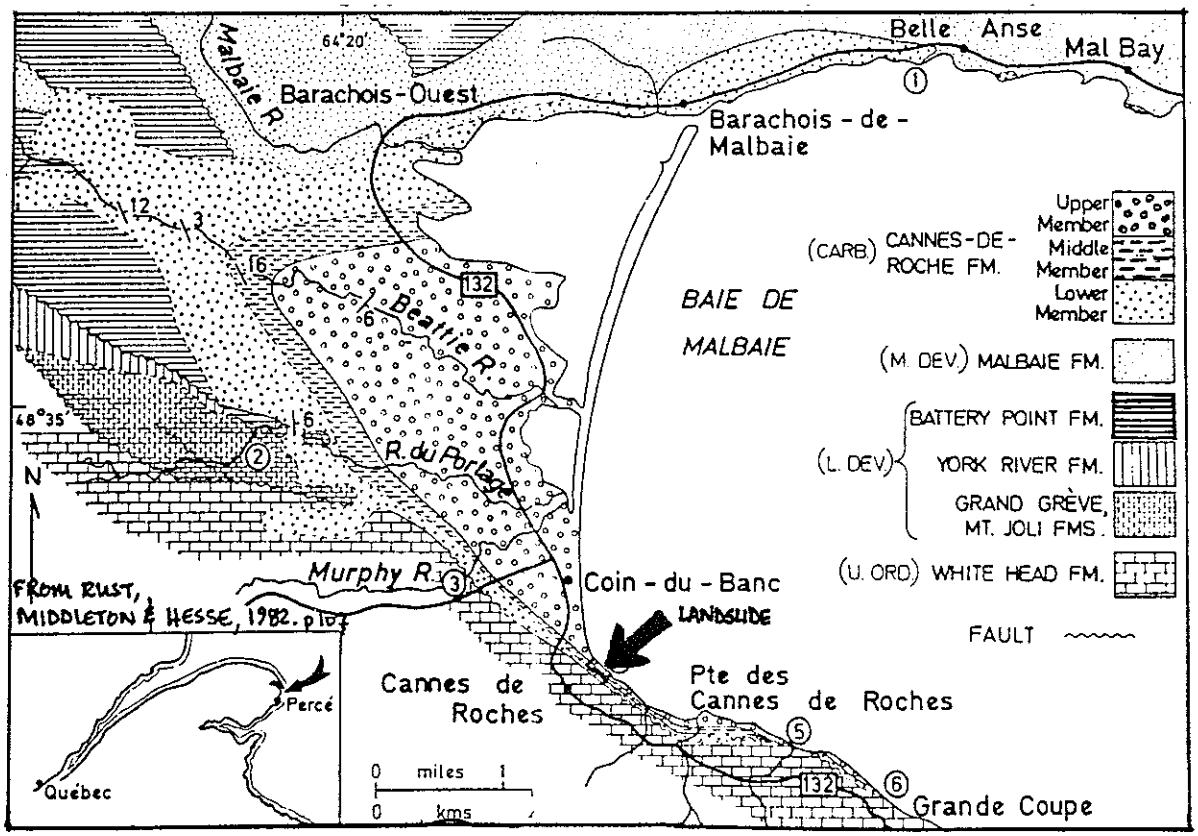

Figure 1: Geologic map of the field study area. Landslide is marked, and the Cannes de Roches Formational Members are clearly delineated. The spit where the sediment is being transported to is directly north along the coast. (Taken from Rust, Middleton and Hesse, 1982)

The purpose of this study was to determine the origin of the landslides, based especially on the analysis of a single landslide deposit located along the beach approximately 500 meters east of the town of Coin du Banc. Attempting to explain the landsliding action, field analysis focused upon the Upper Member's stratigraphy because of its importance as a protective retainer. The stratigraphic analysis determined the lithological, structural and stratigraphic properties of the Cannes de Roches Formation, especially its Upper Member, and their relationship to the landslide action.

Field Methods

The beach along the southern coast of the Baie de Malbaie was measured and divided into 100 meter segments from a creek near the town of Coin du Banc to a fisherman's cove 1600 meters away. The beach's subdivision provided reference points, facilitating the preliminary study of the Cannes de Roches Formation's three members. At different segments along the beach, the outcrops of each member were studied where best exposed. After a preliminary study, a landslide was selected from among many similar mass movements in the area. The slide was selected because of its proximity to the base camp, and because the dimensions of the landslide's sharp incision into the formational members are clearly observeable. The landslide has very well-defined, linear boundaries.

After the preliminary study, the field work focused on three different tasks: surveying and mapping the landslide, determining the topographic profiles of the submerged area in front of the slide, and examining the local Upper and Middle Member's stratigraphy. The survey recorded 80 points within and around the landslide that were used to complete a topographic map of the landslide (see Figure 2).

The beach profiling determined the bathmetry of the submerged area adjacent to the landslide. Seven profile lines were measured from a previously marked baseline. A bathymetric map was constructed using this data. An irregular contour pattern reveals the obvious seaward extentsion of the landslide. The final and principal field task was a stratigraphic analysis of the formation's Upper and Middle Members. The excellent exposure of the Middle Member within the landslide facilitated its analysis. A thorough investigation of the Upper Member's stratigraphy ensued. Four ten-meter sections of the Upper Member were measured along the beach, east of the landslide. The four sections were representative portions of the entire Upper Member. Each section was studied for lithological, structural or stratigraphic parameters which could combine to weaken the Upper Member, and subsequently the entire formation.

Results and Discussion

The landslide under study classifies as a compound landslide because it exhibits rotational and translational characteristics. The step-like appearance that has formed within the body of the landslide attests to the slide's rotational character. The translational aspect is defined by the obvious movement that has occurred along the steep, well-defined bedding planes. Varying shear strengths of different beds in contact with each other facilitate movement. This is especially applicable along the contacts between the mudstones and hardpans of the Middle and Lower Members.

The originally horizontal members of the Cannes de Roches Formation dip towards the bay at angles of 60 to 65 degrees, creating steep seacliffs. The Upper Member rests on the shoreline, with the Middle and Lower Members following in succession immediately inland. The Middle Member is a soft, bright red mudstone that becomes highly plastic when wet. The high plasticity increases the possibility of slippage, which is multiplied by the gravitational forces along steeply dipping bedding planes. The Upper Member, a petromictic conglomerate, has a greater resistance to erosion than the members which rest behind it; therefore, it naturally serves as a protective retainer of the mudstone.

Karl Terzaghi determined that external and internal causes trigger landslides (Hansen 1984). The applicable external causes which apply to the study landslide include undercutting, erosion and rainfall, while freeze-thaw, cohesion reduction and solutional erosion are observable internal causes (Hansen 1984). While Terzaghi's causes act upon the Cannes de Roches Formation, they combine with the lithological, structural and stratigraphic parameters of the Upper Member to undermine the entire formation. The stratigraphic analysis of the four ten-meter sections provided many trigger mechanisms.

The Upper Member is a poorly indurated and poorly sorted conglomerate with sub-rounded clasts of limestone, quartzite, and chert. The clasts range from 0.5 to 10 centimeters and float in a coarse, sandy matrix of 0 to 5 percent. The member strikes N57W and dips 64NE. Calcite veins dissect the conglomerate. The depositional environment was a trunk river system (Rust, Middleton and Hesse, 1982), evidenced by the numerous channels which follow the general strike of the member. With an inclined bedding plane, gravitational forces induce slippage along the channels' contacts with the surrounding member. The contacts are zones of movement also because differing lithologies do not bond well.

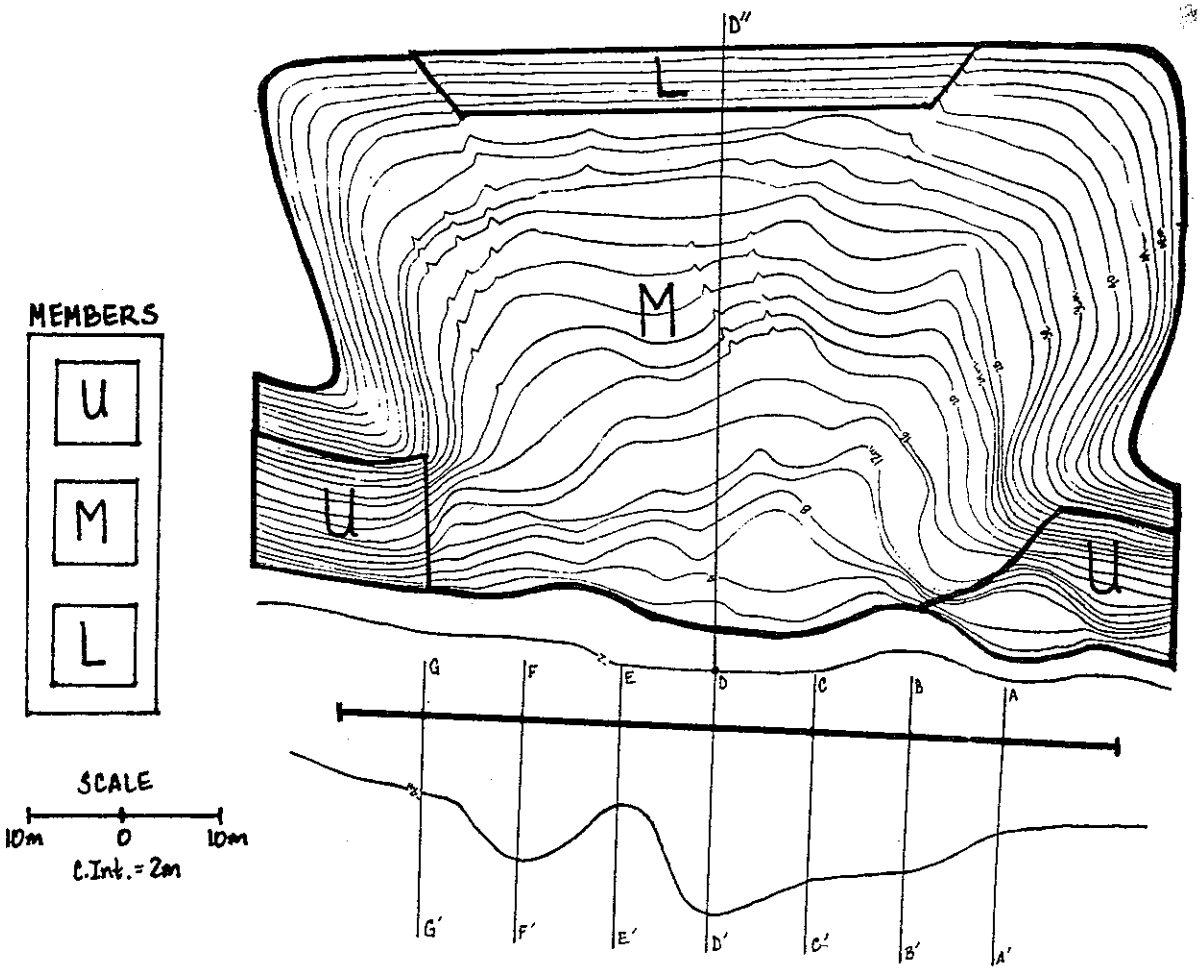

Figure 2: Topographic map of the landslide with the boundaries of each member outlined. At one time the Upper Member extended across the front of the slide, but it has since collapsed leading to the mass movement. D-D" represents a profile line used of the cross-sectional diagram in Figure 3. A-A' through G-G' are the seven beach profile lines measured from a baseline.

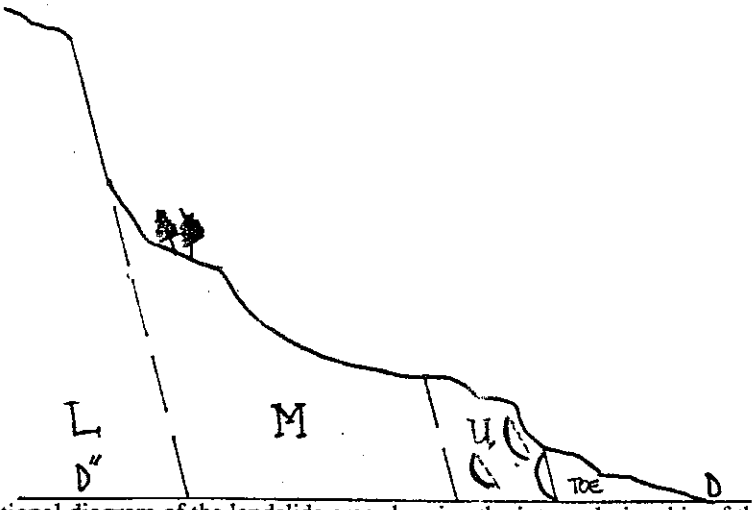

Figure 3: A cross-sectional diagram of the landslide area showing the inter-relationship of the three members and the steep bedding planes. The channels in the Upper Member are included.

Movement also occurs along minor fault planes. Slickensides mark areas where movement has occurred. Wave-cut gaps line the base of the member where it meets the rocky beach. Waves pound the formation's base, crushing the poorly indurated conglomerate and undermining the formation's foundation. Other weaknesses with the Upper Member include horizontal (0 dip) cracks which run for 10's of meters and dissect the conglomerate.

Conclusion

According to Varnes (1978) and Terzaghi (Hansen 1984), a variety of factors generate landslides. The landslides within the Cannes de Roches Formation are the result of many factors combined: external, internal, lithological, structural and stratigraphic. The Upper Member is weakened by the physical parameters within its stratigraphy. It has a varied lithology which causes a very poor induration. The weakly indurated conglomerate crumbles under the slightest pressure. These factors lead to the conglomerate's disintegration. The conglomerate has numerous cracks, joints, faults, channels and wave-cut gaps which exemplify its fragility. The Upper Member also has many zones of movement which are structural weaknesses. Movement along fault planes weakens the conglomerate. The stratigraphy of the Upper Member contains many channels. The channels break away from the Upper Member by slipping under the forces of gravity. These physical characteristics of lithology, structure and stratigraphy combine with Terzaghi's external and internal causes of landslides. The steep dip of the wave-cut conglomerate succumbs to the force of gravity leading to its collapse. With the breakdown of the Upper Member, the succeeding members also collapse, leaving enormous gaps in the seacliffs which line the southern coast of the Baie de Malbaie.

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