0.1 Monitoring cliff erosion in the Chaleur Bay, Quebec, from Terrestrial Laser Scanning data.

0.2 Abstract

~~Th~~is study focuses on the monitoring of cliff erosion in the Chaleur Bay in Quebec. We process and analyse Terrestrial Laser Scanner (TLS) data ~~in order~~ to analyse the retreat rate of coastal cliffs in the region. Our study suggests that erosion occurs along vertical layers on the cliff, that fractures explain the differential erosional regimes better than rock type, and that rockfalls tend to propagate to their neirest neighbour.

0.3 Keywords

Erosion, Chaleur Bay, Terrestrial Laser Scanner (TLS), CloudCompare, Layered erosion.

0.4 Introduction

Erosion in the Chaleur Bay, in the Gulf of the Saint Lawrence River, has been generating interest for a few decades (Fraser et al., 2012). There, although erosion rates are usually slow, certain events can occur where very large amounts of rock will suddenly fall (Fraser et al., 2012). This study fits into the framework of the longterm monitoring of cliff erosion through Lidar imaging by the University of Quebec in Rimouski's (UQAR) laboratory for the dynamics and integrated management of coastal risks (DGIZC).

The study site is Caplan River, a coastal area in the Chaleur Bay region of Quebec. Data describing the cliff face at Caplan River were collected yearly on site, from 2014 to 2018, using a Terrestrial Laser Scanner (TLS, or Lidar). The goal of this study was to develop a methodology to process the data obtained at Caplan River in order to monitor erosional rates and dynamics at the site. The study also includes the first tentative analysis of the data processed.

The area is characterised by cliffs of the Carboniferous Bonaventure Formation, a type of rock made of sandstone and red conglomerate (Gosselin, 1988). At Rivière Caplan, the cliffs are dominated by sandstone, which is more readily eroded than conglomerate (Daigneault, 2001). The layers can be more or less fractured, and the more fractures the more vulnerable to erosion the rock is (Daigneault, 2001). In addition to the intrisic fragility of a rock with such structural properties, the harsh winters, storms and winds create a further stress on these cliffs (Xhardé, 2007).

The Chaleur Bay coastal cliffs are subject to a number of erosional stresses. First, the cliffs suffer from weathering due to the presence of ice and salt into fractures in the rock, the chemical reactions of water with minerals in the rocks, and the biological interactions between small organisms and algae and the rock (Daigneault, 2001, p.29). Second, mechanical processes alter the cliff through the action of waves, strong winds and storms hitting the rock. In fall and spring, when the ice-foot is not yet consolidated at the bottom of the cliff, these mechanical agents can break the sea-ice and throw ice pieces towards the cliff, which contributes to cliff erosion (Daigneault, 2001; Xhardé, 2007). Lastly, the cliff is also subject to the action of gravity on blocks, which can cause different sorts of rockfall : fall of an overhanging boulder, rockslide on an inclined layer, rock or debris fall, etc (Daigneault, 2001).

0.5 Method

0.5.1 Data collection

Once a year since 2014, our team has been collecting data at Caplan River. Fixed stations were placed on the foreshore and their coordinates were recorded. The data were collected by placing a Terrestrial Laser Scanner (TLS) on each station one by one, and scanning the portion of the cliff in front of that station. Each station would scan its corresponding portion of the cliff and have areas in common with the stations before and after it. This is so that every part of the cliff is scanned at least twice with a different angle, thus ensuring all parts of the cliffs are being scanned so that this leaves no "dead zones" empty of data points (Buckley et al., 2008; Jaud, 2011; Letortu et al., 2019).

0.5.2 Data processing

For this study, we processed the point clouds from the 2014, 2016, and 2018 trips using the free-access CloudCompare software. We started with one point cloud per station. On CloudCompare, we aligned the point clouds together and cleaned them of unnecessary data points representing vegetation or foreshore. We then merged the point clouds for each station together to obtain a single point cloud representing the whole cliff for a given year. We ended up with 3 clouds, one for 2014, one for 2016, and one for 2018.

We then proceeded to compare the point clouds two-by-two. We wanted to see how much of the cliff had been lost between 2014 and 2016, between 2016 and 2018, and over the whole period between 2014 and 2018. We meshed the oldest clouds and used the cloud-to-mesh distance tool on CloudCompare to find out how far the more recent cloud had receeded behind the older (reference) one. After computing the cloud-to-mesh distance, CloudCompare generates a new scalar field for the more recent cloud, which indicates how far each point in this cloud is from the reference mesh. The results of this cloud-to-mesh computation are presented and analysed in the rest of this article (CloudCompare Version 2.6.1–user manual, n.d.; DGM et al., n.d.; Girardeau-Montaut, 2019).

0.6 Results

The point clouds resulting from the cloud-to-mesh computation are shown in Figure 0.1. Looking at the resulting clouds, we notice the lower half of the cliff to be homogeneously colored in yellow, which corresponds to a low rate of erosion. Conversely, we see some orange and red patches along the cliff, which indicate the location of larger rockfalls.

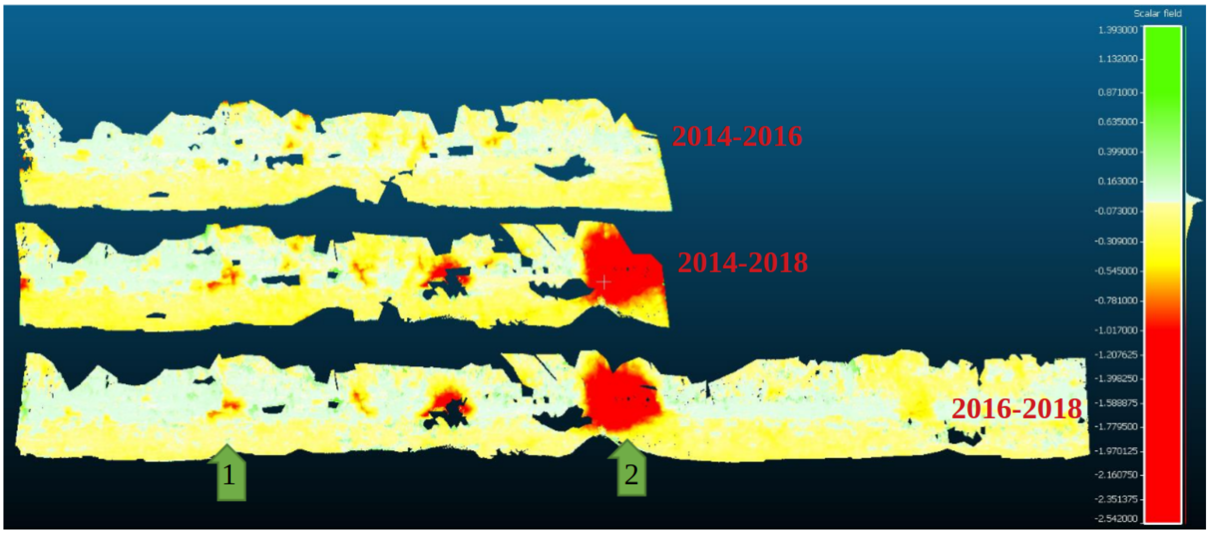

Figure 0.1 – Clouds with cloud-to-mesh distance as scalar field. The top cloud shows the erosion of the 2016 cloud compared to the 2014 mesh, the middle cloud is 2018 compared to the 2014 mesh, and the bottom one is 2018 compared to the 2016 mesh. The green arrows refer to the location of the two profiles presented in the upcoming analysis. The legend is in meters and shows accretion in green (corresponds to an unexpectedly large error, due for example to the removal of vegetation on the compared cloud but not on the reference one), fixed zones without erosion in white, including our error margin, and erosion in a gradient from yellow to red (from smaller to greater erosion).

0.7 Discussion

We generated a profile to visualise erosion from the side. Figure 0.2 is a profile of the cliff generated at the location of arrow 1 on Figure 0.1. This profile shows the different vertical layers of the cliff, which are subject to different types of erosion. In the rest of the analysis, we focus on each layer individually.

0.7.1 Abrasion layer

This layer is up to 4m high. It is homogeneously eroded from west to east along the cliff, at a measured mean rate of about 25cm between 2014 and 2018, corresponding to around 6cm of erosion per year. We suppose that this layer is eroded through the recurrent brushing of the cliff by tidal and storm waves.

We notice that the lower half of this layer erodes at a greater rate than the upper half, which could mean that the upper half of the layer is too high to be reached as regularly by the waves, thus only gets abrased during stong storms associated to high tides. We also suppose that this upper half is more likely to be eroded during fall and spring, when the icefoot is not yet consolidated and waves carry bits of ice susceptible to reach and erode the cliff at these heights. We might be able to determine whether this erosion is caused by ice by analysing the 2015 data, since two trips were made that year. Since most storms occur in the fall (Fraser et al., 2012), this data can show whether the cliff keeps eroding in seasons other than fall, in the absence of storms.

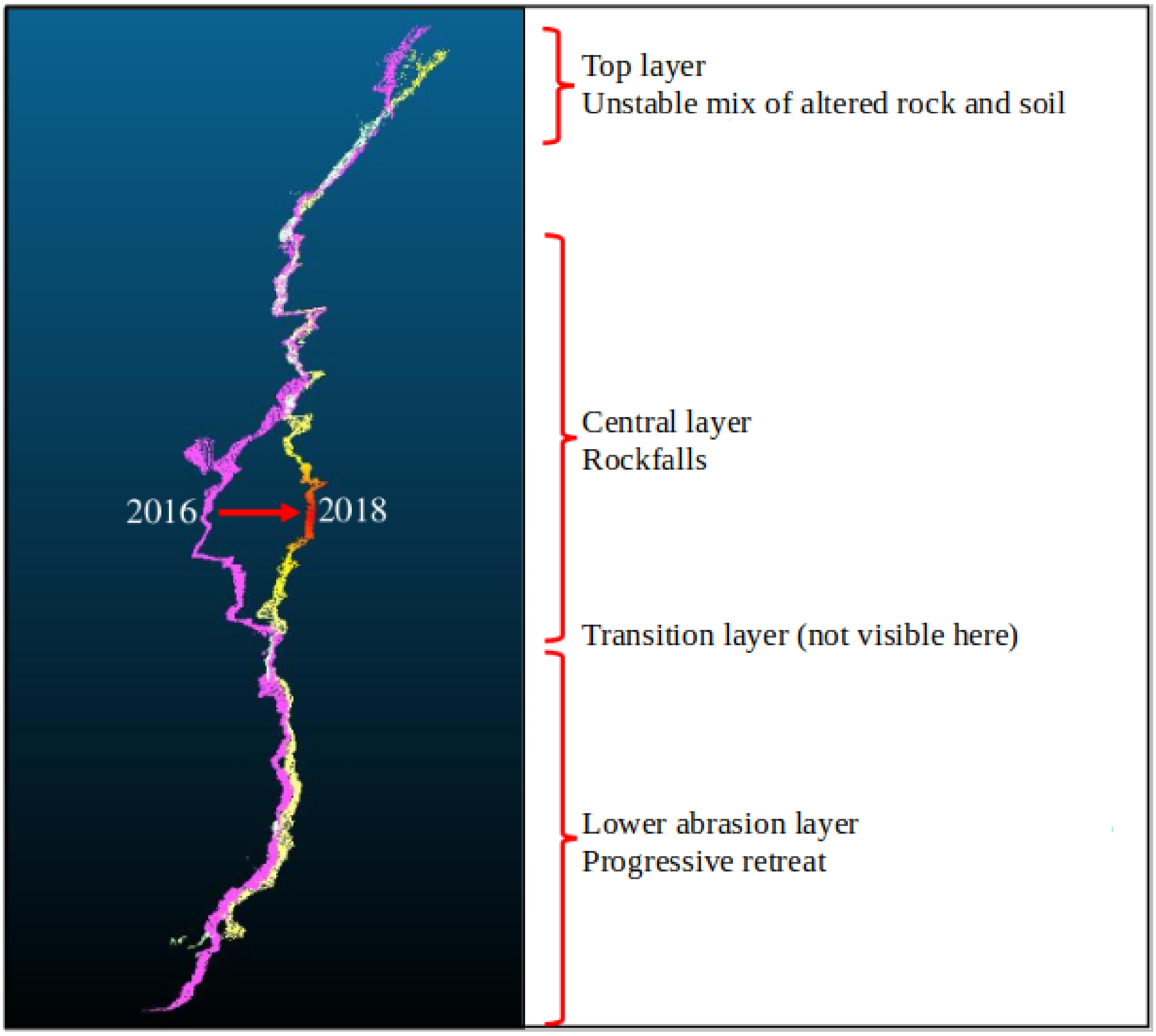

Figure 0.2 – Profile showing the vertical layering of cliff face dynamics (forms and processes). This profile was taken at location 1 (indicated with a green arrow in Figure 0.1). The pink cloud is the 2016 profile and the yellow and redish cloud the 2018 profile. Note that a red zone corresponds to greater erosion than a yellow one.

Rock lithology also plays a role in the cliff's erosion regime. The abrasion zone is made up of highly fractured sandstone. Water penetrates more easily into fractures in the rock. This causes enhanced erosion through the mechanical action of waves throwing water into the cracks, as well as the chemical weathering of water reacting with minerals in the rock.

0.7.2 Transition layer

Between the lower abrasion and the central layers, we distinguish a transition zone where abrasion seems to continue to occur but becomes heterogeneous along the cliff. We find our first boulders at this height, around which the sandstone continues to be abrased. The difference could be that these boulders are massive (i.e. not fractured) which makes them harder to erode.

0.7.3 Central layer

This layer is made of massive boulders. It contains simultaneously the greater amount of fixed zones - zones that have not eroded throughout the entire study period -, and the greater amounds of rock losses locally. These large rockfalls are visible in red-orange on Figure 0.1. We observed that it was usually overhanging boulders that would tend to fall. On average, the falls correspond to a retreat of about 1m over an area of about $2m^2$.

We choose to focus on a notable erosion event which occured during our study period and which we call "the big fall". Between 2016 and 2018, an extraordinarily large rockfall occured which caused a retreat of up to 2.5m over an area of about $73m^2$. The boulder that fell was a massive piece of sandstone that had been overhanging above the abrasion layer (see the area's profile on Figure 0.3). Massive boulders are harder to erode since there are no cracks for the water to penetrate and erode progressively, which means that it is possible to obtain massive blocks that do not get eroded for a long time and remain overhanging. However, photos taken on the site allow us to spot a single crack to the right side of "the big fall", and the profiles show us that the fall occured exactly along that fracture (Figure 0.3).

Conglomerate is supposedly harder to erode than sandstone. Our study area is largely dominated by sandstone, but where we do find conglomerate, it does not seem to protrude. We are led to believe that, rather than the type of rock, it is amount of fractures that determines the erosional rate of the cliff.

We also find that a rockfall has a tendency to propagate to its nearest neighbour. This means that once a block has fallen in one location, the neighbouring block becomes the overhanging one since it is not supported by its neighbour anymore (which has now fallen). Once the initial block fallen, gravity's pull on the remaining overhanging rock tends to make it fall as well. This is illustrated in Figure 0.4 for our study site.

0.7.4 Top layer

This layer is characterized by a mix of soil and altered rock. Indeed, since there is soil and vegetation on top of the cliff, this layer is the location where the cliff ends and the soil begins. This layer has a slow erosion rate, characterized by the fall of small rocks. Although this area of the cliff is also very steep, we found no corellation between the steepness of the cliff

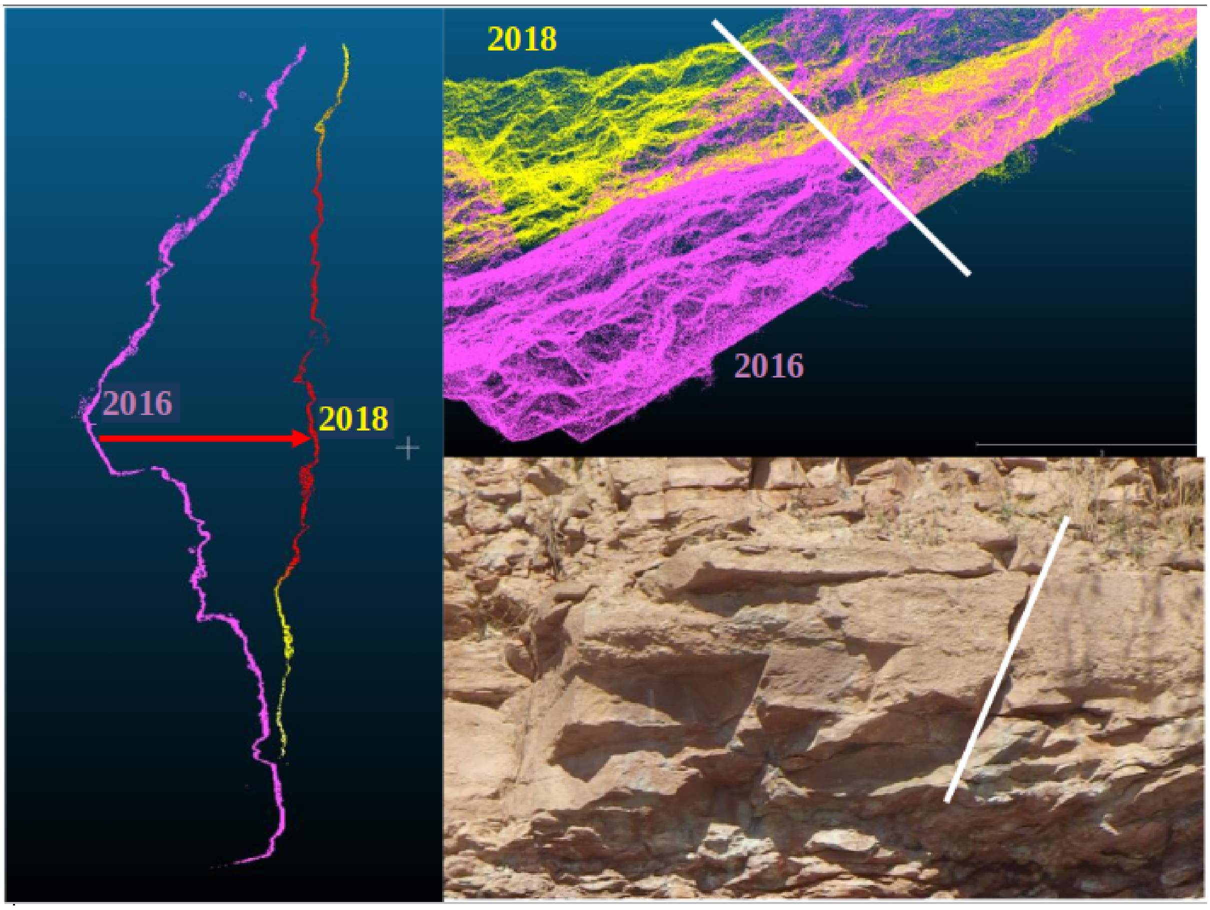

Figure 0.3 – Left: profile of the big fall, in pink the 2016 cloud, in yellow and red the 2018 cloud. The profile was taken at the location of green arrow 2 on Figure 0.1. Right : the white line shows the fracture zone, and to the left of the line is the overhanging boulder that had fallen in 2018. This is shown on the clouds seen from above (top) and on a frontal photo of the boulder before it fell (bottom).

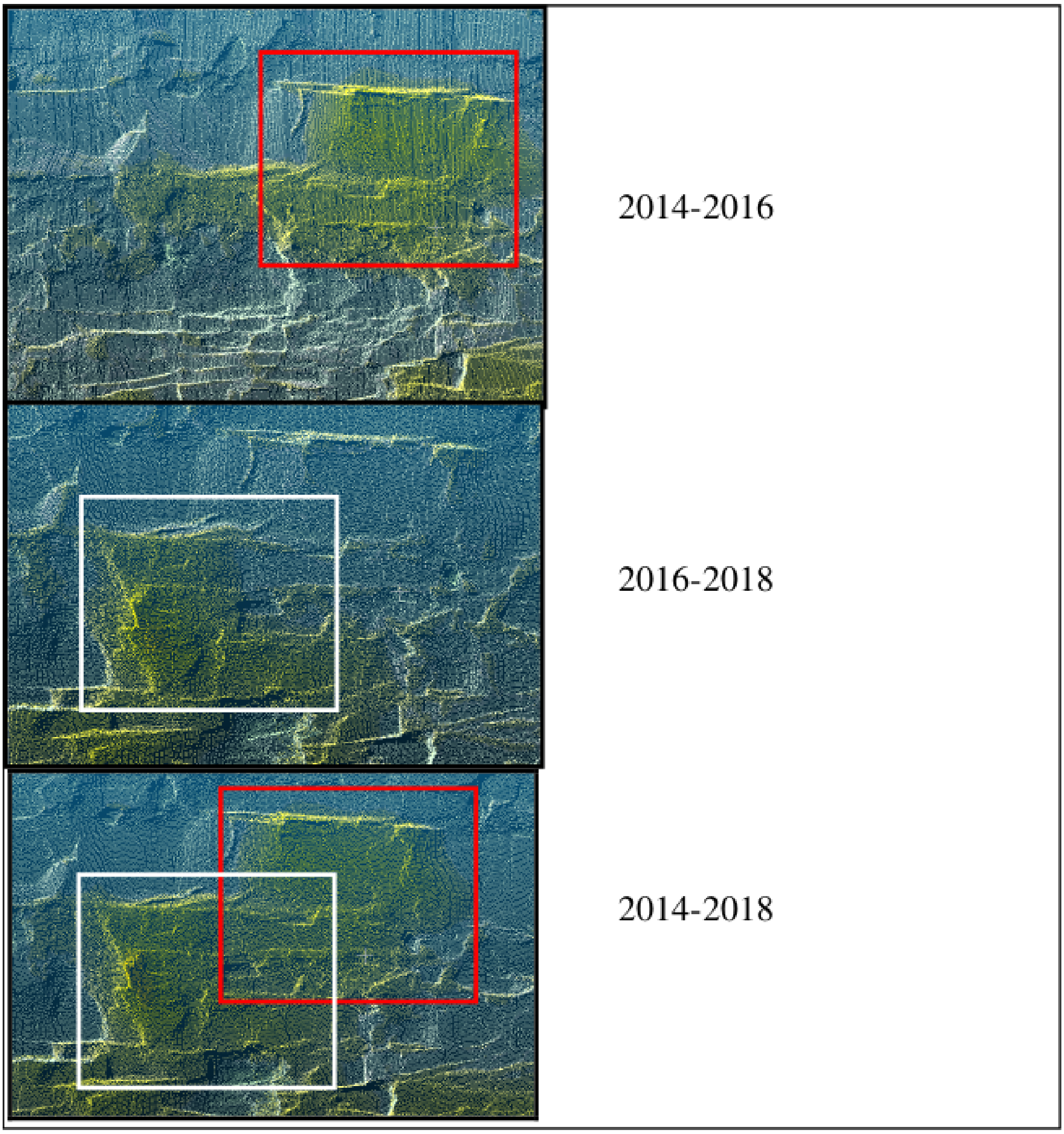

Figure 0.4 – Illustration of rockfall tendency to propagate to their nearest neighbour.The area in the red square fell between 2014 and 2016, and an area very close to it, in the white square, fell between 2016 and 2018.

face and rockfalls. Rather, it seems that it is the presence of soil that makes small rocks detach from the cliff as they mix with the soil. This makes these small rocks unstable and causes them to fall.

0.8 Conclusion

This study finds new results for the erosion of the Chaleur Bay of Quebec. We find that the erosion regime is largely organised in vertical layers that undergo differential erosion processes. We also find that the presence of fractures in the rock seems to dictate erosion rates and dynamics, and that rockfalls seem to propagate to their nearest neighbour. The rest of the data will need to be analyzed in order to better quantify yearly variations. In order to determine the role of different erosion agents, this work will need to be put in relation with other studies of the area, for example on the meteorological conditions of the site. This work allows for a better understanding of the erosional dynamics of this area of the Gulf of St Lawrence, which will also be useful to understand the dynamics at other sites of similar characteristics.

0.9 Bibliography

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