Final Report

Brilliant Marine Research Idea 2019

1. General information

Title of the idea	Fjord sedimentary signature of an advancing glacier
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2. Brilliant Marine Research Idea – Report about the activities

Abstract

Proglacial sediments hold accurate, continuous, and high-resolution records of past glacier dynamics. In this study, we examine the sediments of Eyre Fjord (Fig. 1; 49°S), which is fed by the only glacier that is currently advancing in Chilean Patagonia (Pio XI), to gain a better understanding of how the advance of a surging glacier is recorded in marine sediments. An existing bathymetric map demonstrates that the fjord reaches depths between 400 and 600 m below sea level (*1*). Pio XI Glacier has experienced a net advance of >10 km since 1945 and its unique behaviour has been studied extensively by glaciologists (e.g., *2, 3*). It has had several surging phases that last 2-3 years and occur every ~14 years.

To achieve our goal, CTD casts were acquired along a 50-km long proximal-to-distal longitudinal transect and along three transverse transects in order to better understand the sediment pathways. Nine sediment cores were collected along a longitudinal transect from the glacier's front outwards (Fig. 1). The sediment cores were X-ray CT scanned, scanned on a Geotek Multi Sensor Core Logger (MSCL) for sediment physical properties and analyzed with an Itrax XRF core scanner to obtain downcore elemental profiles. Gamma spectrometric analysis was used to assess the sedimentation rates in the fjord.

From the CTD profiles we conclude that the main form of sediment transfer through the fjord during summer is by means of turbidity currents that form subaqueous, 20–100 m thick, sediment plumes. The sedimentation rates in the fjord exceed 2.5 cm/a. All the sediment cores consist mainly of fine glacial mud, sometimes intercalated with cm-scale thick sandy layers. Distally (>35 km away from the glacial front), the sediments are moderately bioturbated by bristle worms and XRF data (Br counts, ratio of incoherent-to-coherent X-ray scattering) indicates the highest level of marine organic matter in the fjord. The sediment cores in the proximal part (<35 km away from the glacier front) are well laminated. The XRF, CT and MSCL data all indicate the presence of sandy layers in the upper part of the sediment records. These show that the glacier has experienced enhanced hydrological activity, which could be linked to a new surging phase of the glacier.

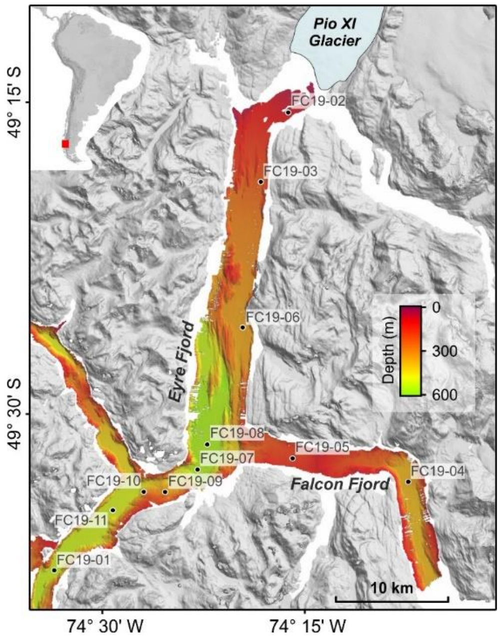

Figure 1: Bathymetric map of Eyre and Falcon Fjord (1). The sediment core locations together with the core labels are indicated.

Intro

Glaciers respond rapidly to changes in atmospheric temperature, warm sea water intrusions and winter precipitation, and therefore constitute one of the best indicators of variations in the climate system. Reconstructing glacier dynamics in the past can therefore provide precious information regarding variations in climate. In addition, understanding how glaciers respond to changes in climate on timescales that extend beyond instrumental records is increasingly important to better predict the future evolution of glaciers in our rapidly changing world.

Reconstructing past glacier dynamics is traditionally done using geomorphic evidence and exposure dating. Although this approach has resulted in an accurate knowledge of past glacier advances, geomorphic archives are notoriously discontinuous (e.g., moraines only represent maximum glacier extent) and they do not allow reconstructing past glacier dynamics at high temporal resolution. Proglacial sediment records are therefore increasingly used since they can hold accurate, continuous, and high-resolution records of past glacier dynamics (*4, 5*).

Interpreting sediment records in terms of glacier variability is however not as straightforward as it may seem, which has led to conflicting interpretations in the recent scientific literature. For example, increased clastic sedimentation has been interpreted to indicate both glacial advance and recession (*6*). Likewise, decreasing sediment grain-size has been interpreted as representing increasing distance to the ice front (*7, 8*) or decreasing meltwater discharge (*9, 10*). Therefore, the main goal of my PhD thesis is to accurately determine how glacier variability is recorded in sediments. Specifically, I am studying sediment records from Patagonian fjords and lakes with well documented glacier retreat histories (*11-13*) which will be used to calibrate the high-resolution sediment records. Ultimately, our results will allow for more accurate centennial to millennial glacier evolution reconstructions, which is urgently needed to better predict the evolution of glacierized regions in a rapidly changing climate.

In this study, which is partially funded by the VLIZ BMRI grant, we examine the sediments deposited in Eyre Fjord (49°S), which is fed by the only glacier that is currently advancing in Chilean Patagonia (Pio XI). Indeed, Pio XI has experienced a net advance of >10 km since 1945 and its unique behavior has been studied extensively by glaciologists (e.g., *2, 3, 14*), providing the ideal conditions to understand how a glacier advance is reflected in marine sediment proxies.

Material & Methods

1. Sediment Coring

Nine sediment cores were collected in Eyre Fjord during a cruise on board R/V Sur Austral in February 2019. The sediment cores were taken along a ~50 km long proximal-to-distal transect from Pio XI Glacier's front through Eyre Fjord and Icy Canal. Coring locations were based on an existing multibeam bathymetric map (*1*). The sediment cores were collected with a gravity corer and 1.5 m long transparent liners. Weights of 5–20 kg were added to ensure a vertical fall and to enhance penetration. A core catcher was also installed at the bottom of the liners to prevent the sediment from sliding out upon retrieval. The cores were then shipped from Coyhaique (Chile) to Ghent University (Belgium) with Blue Express and Elemar shipping companies. Shipping of the sediment cores was funded by the VLIZ BMRI grant.

2. CTD casts

One longitudinal transect from Pio XI Glacier trough Eyre Fjord and Canal Icy was selected, together with three transverse transects to assess the subaqueous sediment pathways. Thirty CTD casts were taken with a RBR Maestro, which is equipped with conductivity, temperature, pressure, turbidity, dissolved oxygen and chlorophyll sensors. It was operated at a vertical speed of 0.69 m/s with an acquisition rate of 6 Hz, and a maximum depth of 600 m. In order to calibrate the turbidity data from Nephelometric Turbidity Unit (NTU) to suspended sediment concentration (SSC), four water samples were taken with a Niskin bottle and filtered through 47 mm GF/F filters to collect suspended sediment.

1. CT scanning

The full cores were subjected to X-ray computed tomography scanning to visualize the internal structures. Scanning happened at the Ghent University Hospital on a Siemens SOMATOM Definition Flash, with a voltage of 120 kV and a rotation time of 1 s. A resolution of 0.13 mm was achieved in the x and y directions and 0.3 mm in the z direction (downcore). The reconstructed CT volumes were visualized and analyzed in VGStudio 2.0 software.

2. MSCL scanning

The sediment cores were split lengthwise with a UWITEC core splitter and described, focusing on variations in lithology, colour, and possible sedimentary structures. The archive half of each core was imaged at a resolution of 200 pixels cm^{-1} with a Geoscan IV Linescan imaging system. The GEOTEK Multi Sensor Core Logger (MSCL) was used to log physical sediment properties at a resolution of 2 mm. The MSCL is equipped with a Cs source and detector to measure gramma ray attenuation density, a Bartington MS2E surface sensor to measure magnetic susceptibility and a Konica Minolta CM-2600d spectrophotometer to analyse colour spectra.

3. XRF core scanning

Downcore elemental profiles were obtained with an ITRAX X-ray fluorescence (XRF) core scanner at the SLAM lab of the department of Geological Sciences, Stockholm University. All cores but one were scanned at 2 mm resolution with an exposure time of 25 s using a molybdenum (Mo) tube that was set at 30 kV and 50 mA. The sediment core that seems to hold the longest sediment record (FC19-07) was scanned at 1 mm resolution with the same exposure time and x-ray tube settings. The XRF analysis was funded by the VLIZ BMRI grant.

4. Core Chronology

The most promising sediment core (FC19-07) was selected to develop a core chronology. Seven samples with wet weights between 24 and 40 g were freeze dried and used for high resolution gamma spectrometric analysis at GAU-Radioanalytical Laboratories, Southampton, UK. The activity of all gamma emitters was determined on HPGe detectors for approximately 24 h. To establish a core chronology, the activities of ^{137}Cs and ^{210}Pb and ^{234}Th were investigated in details. The resulting spectra were analysed with Fitzpeaks spectral deconvolution software (JF Computing Services). The gamma spectrometric analysis was funded by the VLIZ BMRI grant.

Results/Conclusions

The CTD profiles show that the highest turbidity values occur at the bottom of the fjord, which indicates that sediment transfer through the fjord in summer primarily happens as turbidity currents. The thickness of this sediment plume at the seafloor varies between 20 to 100 m.

The activities of ^{210}Pb and ^{234}Th are too low to construct a reliable core chronology. The ^{137}Cs peak, representing the year 1964 CE, is absent from the longest sediment record, which implies that it contains less than 55 years of mud and suggests that fjord sedimentation rates exceed 2.5 cm/a. This is similar to fjord sedimentation rates of other calving glaciers in Patagonia (*15*).

The sediment cores consist mainly of fine glacial mud, sometimes intercalated with cm-scale thick sandy layers. Based on their position along the fjord (Fig. 1) and on the CT scans, the sediment cores were divided in two groups: the 'proximal group' (<35 km away from the glacier front; 5 cores) and the 'distal group' (>35 km away from the glacier front; 4 cores). The distal sediment cores are characterized by prominent bioturbations, likely created by bristle worms (Polychaeta) (*16*). The proximal sediment cores are well laminated. Bromine counts and the ratio of incoherent-to-coherent X-ray scattering, which are proxies for marine organic matter content (*17*), show the highest values in the distal cores, especially in the low density mud. The downcore profiles of the inorganic elements (Fe, Ti, K, Mn, Zr, Zn, Rb, Sr) are highly correlated with density and magnetic susceptibility profiles. Downcore variations in the concentration of these elements are therefore likely driven by grain-size variations and can be used as high-resolution proxy records of the fjord hydrodynamic conditions. The upper part of the proximal sediment records (above approx. 60 cm) contain sandy layers that are absent from the lower part of the records. These sandy layers are indicative of high energetic conditions and could represent floods. The increase in flood-related sediments through time suggests that the glacier has experienced enhanced hydrological activity in recent times. This could be explained by the onset of a new surging phase of the glacier, i.e. the glacier moves at velocities that are an order of magnitude larger than its mass balance flow velocity.

Future analyses on the sediment cores include high resolution grain-size measurements and quantitative Ice Rafted Debris (IRD) analysis based on the CT data of the most proximal sediment core (the only sediment core holding IRDs). We will furthermore perform a detailed study on the evolution of the glacier front and moraine formation between 1982 and 2019 based on Landsat and Sentinel imagery, which will later be compared to the sediment records.

Reference list: *https://users.ugent.be/~lpiret/RefListVLIZBMRI.htm*

3. Overview of the expenditures

Describe in detail how the requested fund was spent within the implementation period (1 March 2019 and 28 February 2020). Be as specific as possible.

The VLIZ BMRI funds were used to ship the cores back to UGent, for XRF core scanning and to perform high resolution gamma spectrometric analysis in order to establish a core chronology. All the analyses were performed within the implementation period (March 2019 – February 2020).

1. **Sediment core shipping**
   Nine sediment cores were shipped from Coyhaique (Chile) to Ghent University on 7 March 2019.
   Cost € 1069.62

2. **XRF core scanning**
   ITRAX XRF core scanning was performed on nine sediment cores in the period of 21-25 October 2019.
   Cost Five days of instrument time: € 1154.87
   Transport and accommodation: € 1150.46
   Total: € 2305.33

3. **Gamma spectrometric analysis**
   Seven sediment samples from sediment core FC19-07 were shipped to GAU-Radioanalytical Laboratories (Southampton, UK) on 21 November 2019.
   Cost Shipping cost: € 8.37
   Analysis cost: € 946.30
   Total: € 954.67

4. **UGent overheads**
   UGent overhead charge of 17 %.
   Cost € 726

   Grant total: € 5055.62

In total € 5000 was received from VLIZ and € 5055.62 was spent. The remaining costs (€ 55.62), and those of the coring cruise and internal analyses, were funded by FWO research grant 1512318N "GLADYS" to Sebastien Bertrand.

4. Pictures

A set of five pictures (low resolution in this document). The five High Resolution pictures should be delivered to VLIZ by email to karen.rappe@vliz.be.