Investigating the Impacts of Mining on Glacier Change in the Central Chilean Andes

Salto del Olivares, Chile
33°10'40.50"S, 70°07'22.50"W
Universidad Glacier, Chile
34°42'50.50"S, 70°20'56.75"W

Photo: Charlotte Curry flying Mavic-3E Drone in Salto del Olivares Basin, Chile, in April 2023

Expedition Leader/ Organiser: **Charlotte S. Curry**
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MEF Reference: **23-2**

Expedition Members
Charlotte S. Curry (12th April – 1st of May)
Christiaan R. Diemont (12th April – 1st of May)
Claudio A. Bravo (15th – 30th April)
Benjamin A. Robson (23rd – 30th April)

Project Context, Aims and Objectives

Geochronological studies in the Andes have suggested that glaciers were particularly sensitive to localised changes in temperature and precipitation during the Last Glacial Maximum (LGM) and Holocene, as glacial histories are not synchronous throughout the region. Crucially, there is no coherent overview of Andean glacier change, with sporadic and site-specific studies showcasing Quaternary glacial changes derived from geomorphological studies. In particular, large research gaps exist between 31°S and 40°S in the arid Chilean Andes. At shorter time-scales, mining for copper, gold and other metals at sites such as Andina and Los Bronces present additional complications for understanding glacier evolution. These mines generate large volumes of mineral dust that is deposited on glaciers in the Olivares basin. This affects glacier albedo and acts to accelerate melt and thus the demise of these glaciers, which can have a detrimental impact on the timing and volume of glacially derived water resources for highly populated neighbouring areas such as Santiago.

In light of this, we organised a field campaign with the aim of understanding both long-term and short-term glacier change in the Olivares Basin, Chile. We planned to address this through the following scientific objectives:

O1: Collect moraine boulder crest samples that are representative of glacier change since the Last Glacial Maximum and during the Holocene for cosmogenic nuclide exposure-age dating.
O2: Gather surface reflectance measurements across different surface types on Olivares Alfa Glacier to assess spatial variability in albedo.
O3: Collect sediment samples from the surface of Olivares Alfa Glacier for geochemical analysis to identify the contributions of dust from the Andina and Los Bronces mines, relative to mineral dust eroded from the surrounding landscape.
O4: Carry out a drone survey to classify the variation in albedo across the entire area of Olivares Alfa Glacier, and if possible, the other four Olivares Glaciers.

When we were in the field, the weather conditions meant that it was unsafe to travel to the upper Olivares Basin. Therefore, we could not work to address Objectives 2, 3 and 4 as originally planned. Instead, we travelled to an alternative glacier (Universidad Glacier) and applied the same methodological framework, where possible, to supplement scientific datasets that already exist. As a result, the revised themes of our fieldwork were:

O1: Collect moraine boulder crest samples that are representative of glacier change since the Last Glacial Maximum and during the Holocene for cosmogenic nuclide exposure-age dating at the Salto del Olivares.
R2: Gather surface reflectance measurements across different surface types on Universidad Glacier to assess spatial variability in albedo at a glacier site not affected by the supraglacial deposition of mining dust.
R4: Carry out a drone survey to classify the variation in albedo across Universidad glacier.

Given the site-specific nature of Objective 3, we were unable to revise it. Therefore, collecting sediment samples for XRD analysis was a made redundant.

Expedition Dates: 12th April to 1st May 2023

Phase 1: 17th April to the 22nd of April 2023
Phase 2: 25th April to the 27th of April 2023

Field Sites

The Olivares Basin, Chile (Figure 1)

Location type	Co-ordinates	Comments
Drop off for Salto del Olivares trail	33°24’13.86”S 70°08’02.50”W	Met arriero at this location. Need vehicle to access. Walk well signposted
Camp 1 – Vega Honda	33°15’46.75”S 70°08’17.19”W	Sheltered camp on the LHS of the Rio Olivares.
Camp 2 – Salto del Olivares	33°11’23.02”S 70°06’55.08”W	Sheltered camp between large boulder and glacier moraine.

Permits: To enter the Rio Olivares-Gran Salto area, you need individual access permits from El Ministerio de Bienes Nacionales. Due to the scientific nature of our project, we required our permit to be upgraded to allow for Actividades Especiales (Special Activities). The permit and documentation (including our passports) were checked in El Alfafal, on our way to our drop off location for Phase 1. The initial access permits were granted very quickly (almost immediately), and the Special Activities permit took around 8 weeks to be finalised. This involved writing a letter of application, following the guidance at https://www.rioolivares.cl. All permits are provided free of charge.

Logistics: Claudio Bravo was our logistics coordinator for Phase 1, as he organised the arriero and our transport to the start of the walk.
We had one arriero, one horse and two mules guide us along the Río Olivares, to the Salto del Olivares. This was vital as we would not have been able to carry all our equipment and food up the valley, especially with our additional boulder samples on the return journey. The arrieros of the Olivares do not have a webpage, however it is possible to coordinate with them via email. Our arriero was called Erwin Carrasco, and our email contact was Fernando Ortega (fernandoortega668@gmail.com). Erwin met us at the start of our hike (Figure 1) and walked ahead of us with his animals and our equipment/ bags.
To take us from Santiago to the start of the hiking trail, we arranged transport with Pablo Zenteno. It would also be possible to hire a car and drive to this location.
The hike up the valley was enjoyable. It could be done in one long day if necessary, however we walked up over the course of two half-days (~800 m elevation gain).
https://rutas.bienes.cl/ruta_patrimonial/andes-de-santiago/
The camping logistics were simple. We camped at Vega Honda when walking to/ from the Salto, and in a flat area between a glacier moraine and a large boulder when in the Salto del Olivares. At both camping locations it was obvious that other visitors had camped there before.

Universidad Glacier, Chile (Figure 2)

Location type	Co-ordinates	Comments
Parking in the Universidad Glacier foreground	34°43'24.15"S, 70°21'47.48"W	Steep drive to this part of the valley. Lots of loose material. 4x4 vehicle essential
Camp	34°43'23.40"S, 70°21'46.69"W	We camped beside where we parked our vehicle. Tourist camping pods closer to the glacier.

Permits: To access Universidad Glacier, permission was obtained from Glaciares de Colchagua (https://glaciaresdecolchagua.cl/) via Roberto Franck. This was provided free of charge.

Logistics: We did not require additional logistical support in this location.
We drove a 4x4 vehicle to our camp location, approximately 1.5 km from the present-day glacier terminus (Figure 2). This area hosts a hydroelectric power facility. The use of a 4x4 vehicle was crucial, as the access tracks we unpaved with loose sediment and were very steep (with switchbacks) towards the glacier foreground.
We accessed the glacier by both the left-hand side (climbing up on lateral moraine), and by the centre (walking along the proglacial area and climbing up onto the glacier, following the golden-coloured medial moraine). Accessing via. the centre of the glacier was much easier. This is annotated in Fig. 2.
Camping logistics were similarly easy here. We camped beside the hydroelectric power facility and flew long range drones from this area.

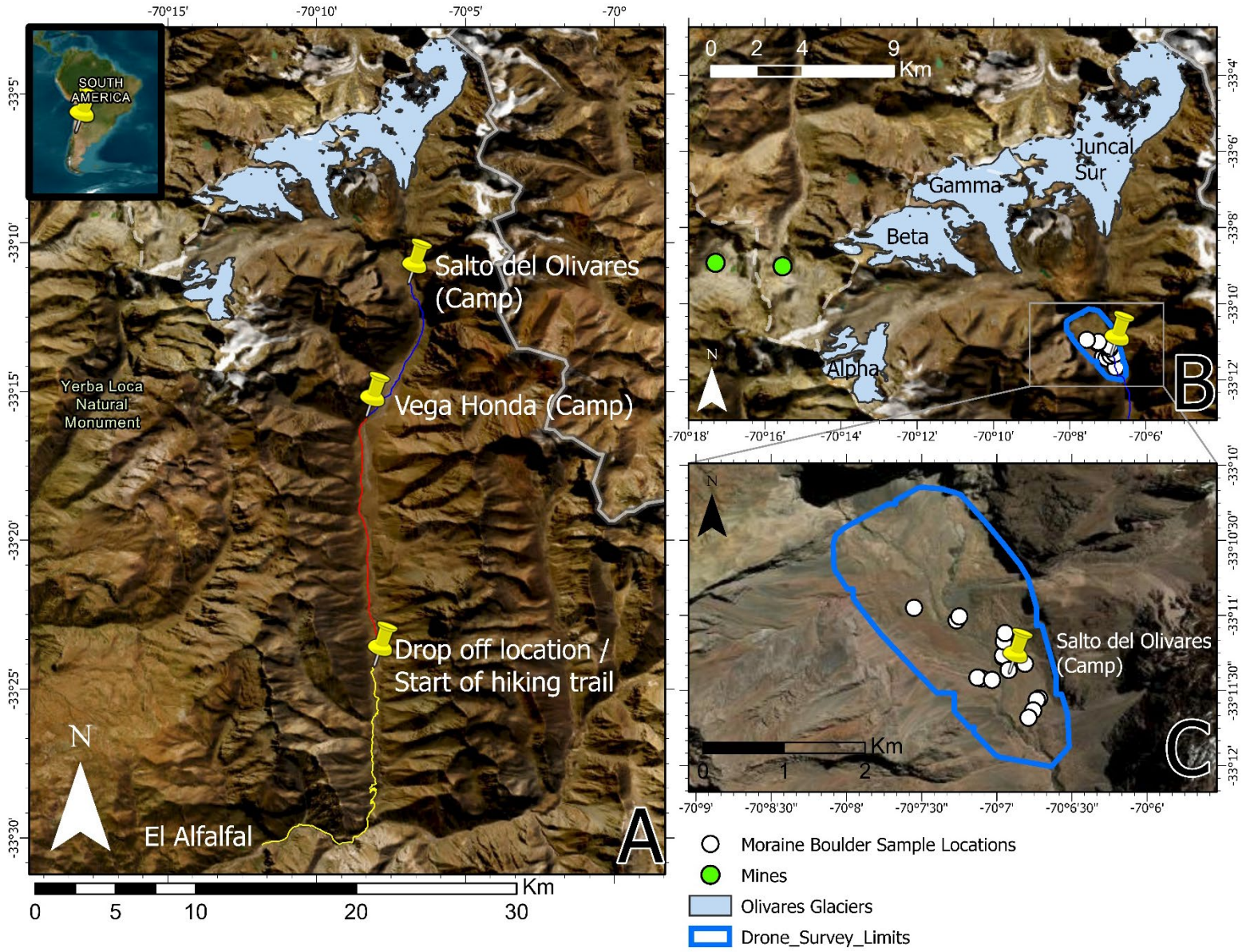


Figure 1 showcases (a) the general overview of the glacier basin, with our hiking route annotated, (b) a closer view of the Salto del Olivares and upper Olivares Basin and (c) our moraine boulder sampling and drone survey limits (Mavic-3E mapping)

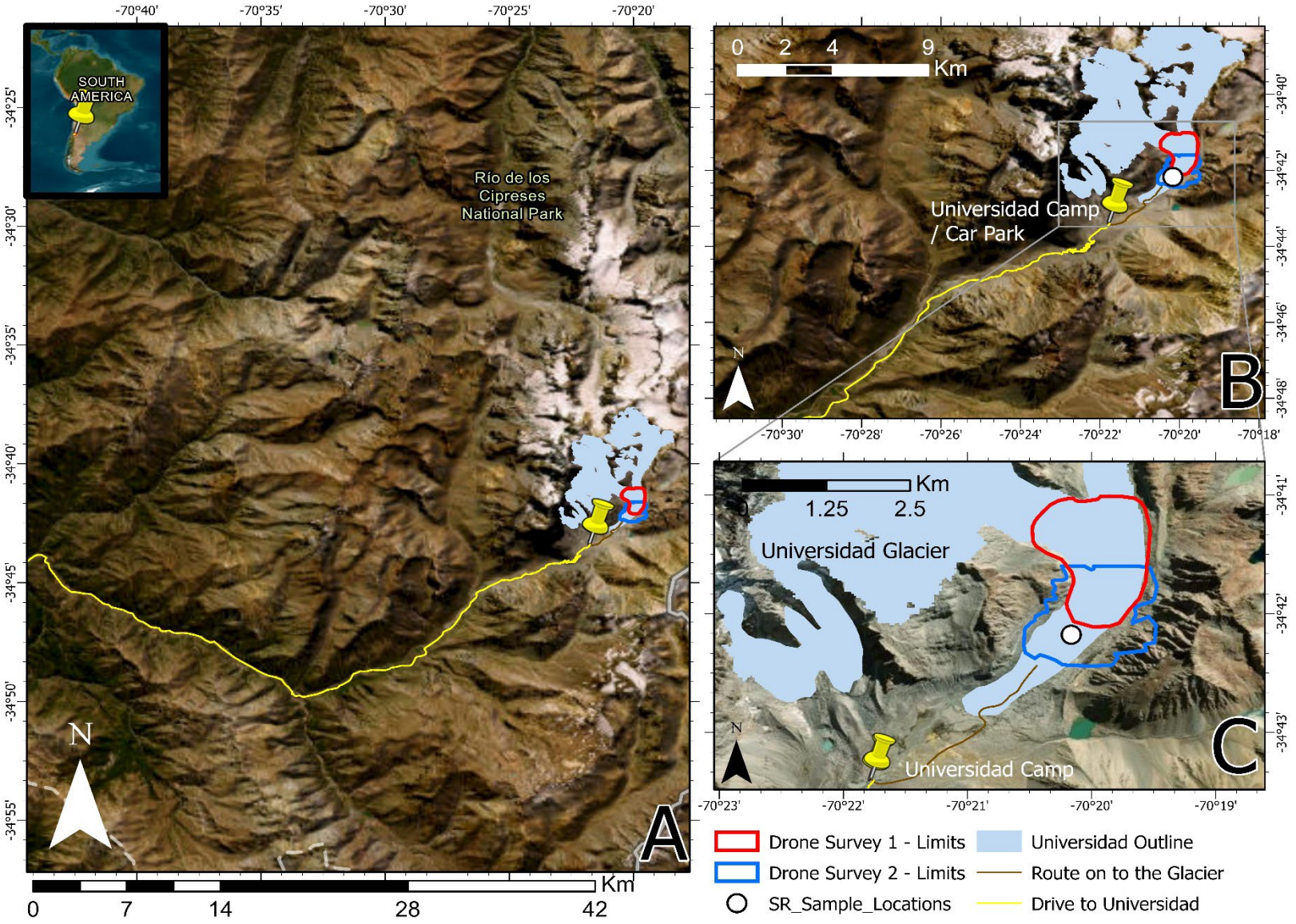


Figure 2 showcases (a) the general overview of the glacier basin, with our access routes annotated, (b) a closer view of the Universidad Glacier basin and (c) location of our surface reflectance measurements and drone survey limits (both Mavic-3E mapping (Survey 1) and Wingtra Multispectral (Survey 2))

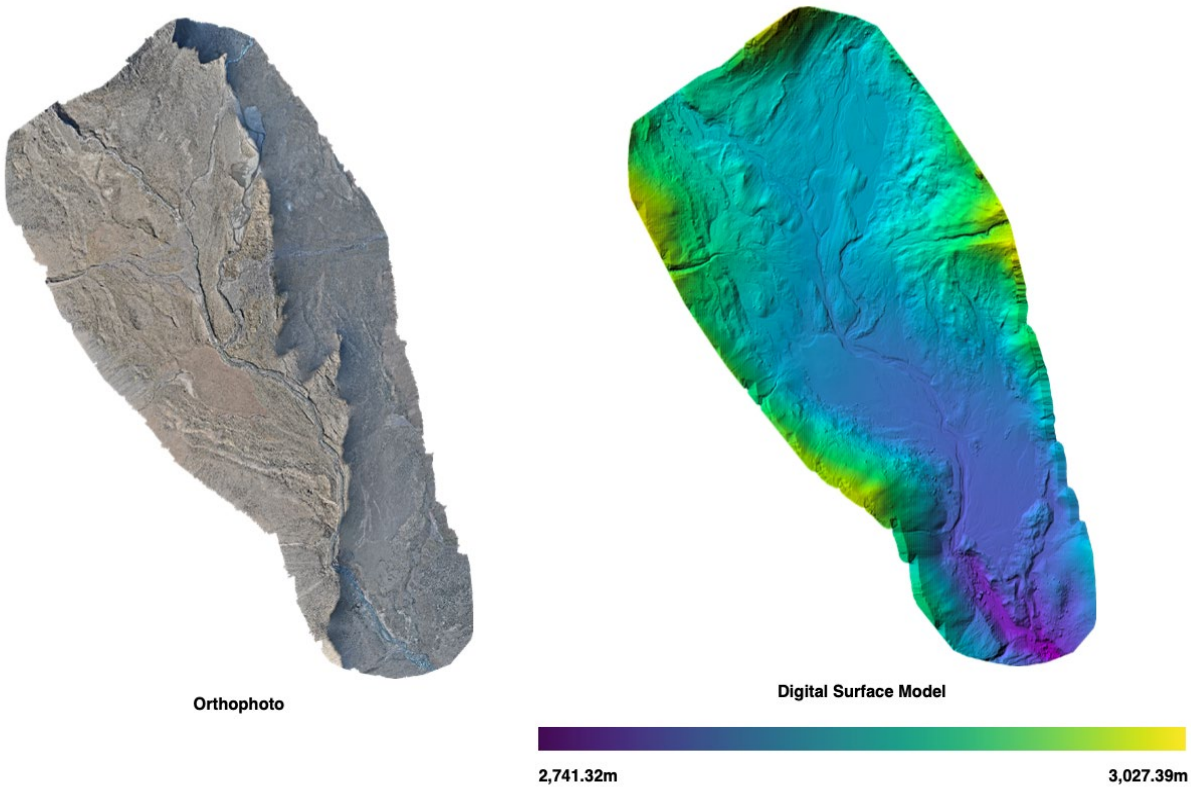
Expedition Evaluation and Data Produced

Objective 1)

Collect moraine boulder crest samples that are representative of glacier change since the Last Glacial Maximum and during the Holocene for cosmogenic nuclide exposure-age dating at the Salto del Olivares.

We were able to successfully complete this objective. We collected 16 samples in total and collected over 60 kg of rock to ensure that we had sufficient mineralogical content for dating. We sampled across several glacier moraines that had been mapped remotely prior to going to the field. We hope to obtain cosmogenic nuclide ages for these samples in the next 6 months, and we are currently (August 2023) organising the first stage of sample processing at SUERC, East Kilbride.

In addition to our moraine boulder samples, we obtained a high-resolution orthophoto and digital elevation model (DEM) of the area from a Mavic-3E drone survey. This has greatly improved the quality of the geomorphological map produced of the area, and will prove vital in aiding our Holocene reconstruction of the area.



Revised Objective 2)

Gather surface reflectance measurements across different surface types on Universidad Glacier to assess spatial variability in albedo at a glacier site not affected by the supraglacial deposition of mining dust.

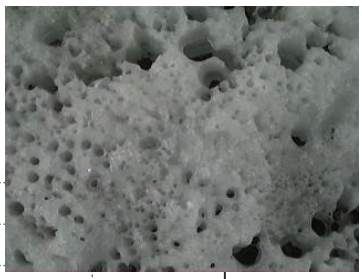
As we were unable to carry out our original Objective at Olivares Alfa, we revised and applied it at Universidad Glacier. Due to weather constraints, we were only able to stay for two full days at Universidad Glacier, as the day we were due to leave was forecast to bring a large storm which may have triggered local landslides and blocked our exit access.

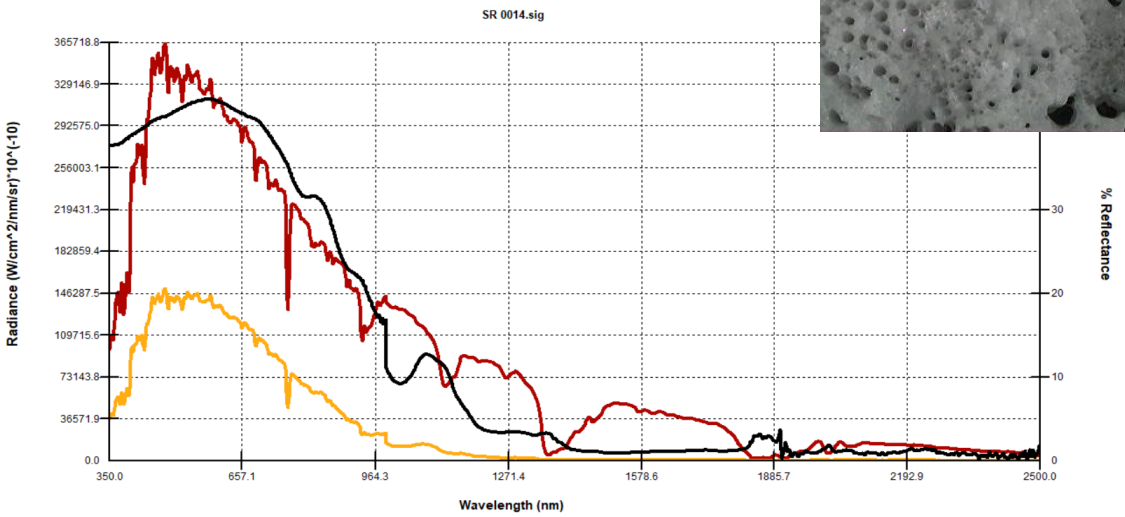
In addition, the weather limited the time window when we could record surface reflectance measurements, as we needed a completely clear and cloudless sky to measure one hour either side of solar noon. As a result, we only had one two-hour window to record measurements, but even within this window there were only a few clear-sky intervals where clouds were not blocking the sun. Given these conditions and constraints, we focused on measuring surface types which were unique to Universidad Glacier, and that would be hard to record elsewhere. This was primarily the ogives, which are ridges on a glacier surface that can be visualised by darker and lighter bands. We measured the lighter and the darker bands with the spectrometer, to quantify the range in reflectance values that exist across this surface type.

We collected 16 measurements on cleaner ice ogive bands and 7 measurements on the darker ice band, with each measurement being derived from averaging hundreds of wavelength recordings captured over a small time-window. We used a Spectra Vista Corporation SVC HR-1024i Field Spectrometer, on loan from the NERC Field Spectroscopy Facility in Edinburgh. Examples of our measurements and results are displayed below:

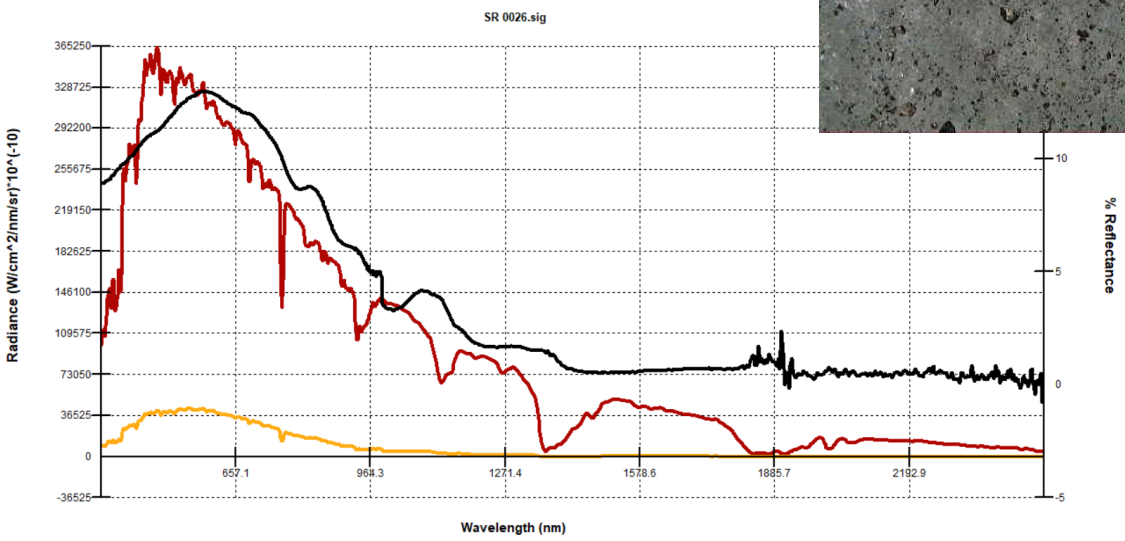
Scan 00014: Lighter Ogive Band

Yellow line = radiance of target
Red line = radiance of white standard
Black line = % Reflectance





Scan 00026: Darker Ogive Band



We plan to use the point-based surface reflectance data in conjunction with the data derived from Objective 4, to demonstrate how point-based and UAV-based reflectance data varies. In addition, we plan to incorporate our surface reflectance products as input albedo into our glacier model, where we plan to compare this site with the Olivares Basin and assess the impact of a changing surface albedo on glacier mass balance. The surface reflectance supplementary data is available at https://www.sciencedirect.com/science/article/pii/S0048969722021611

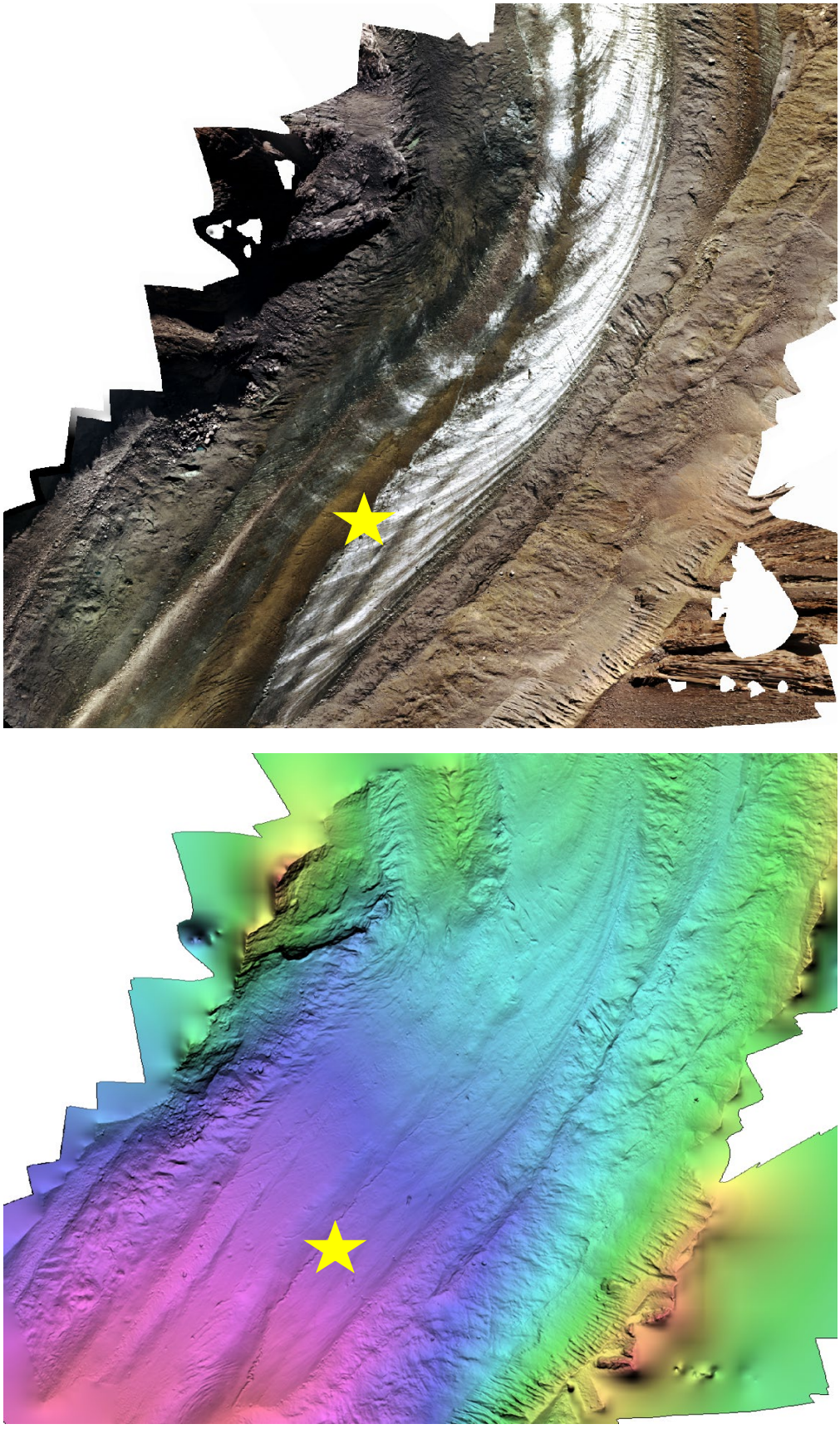
Objective 3)
Collect sediment samples from the surface of Olivares Alfa Glacier for geochemical analysis to identify the contributions of dust from the Andina and Los Bronces mines, relative to mineral dust eroded from the surrounding landscape.

Unfortunately, we were unable to address this objective as it was location-specific due to the mining dust component.

Revised Objective 4)
Carry out a drone survey to classify the variation in albedo across Universidad glacier.

We flew a Wingtra Gen II drone with a RedEdge-P multispectral camera over the ablation area of Universidad glacier on the 27th of April 2023. The drone survey was post-processed with RINEX base station GPS data, and the georeferencing was accurate to approximately 3 cm in the X and Y measurements. We did this alongside measuring the surface reflectance (RO2) of the glacier, to see how the two (point based and UAV) compare.

Initially we had concerns regarding the overlap between our drone survey limits and where the surface reflectance measurements were taken, as we had some unexpected drone battery/ early return-to-home issues. Fortunately, we managed to have all three of our drone flights overlap to create one dataset/ large survey area, which additionally overlaps with the location of our point-based spectral reflectance (Figure 2).
The orthophoto and digital surface model produced from the survey are illustrated below. The yellow star indicates the approximate area where surface reflectance measurements were taken.



Orthophoto (top) and Digital Surface Model (bottom) derived at Universidad Glacier

The immediate research from these data and early results are currently in progress, and publications derived from and/or incorporating the findings of this field campaign are forthcoming.

We anticipate three key themes out of our data:

1. Reconstruction on the Holocene evolution of the Olivares Basin
2. The impact of mining on glaciers in the Olivares Basin
3. Large-scale glacier modelling of the Central Chilean Andes

We propose that these three themes will be published across open-access academic journals in the next 12-18 months. These papers will form a large proportion of Charlotte Curry's PhD thesis.

The first set of results (geomorphological map of the Salto del Olivares and reconstruction of Holocene evolution) will be presented at The British Society of Geomorphology meeting in Edinburgh in September 2023.

Food and waste disposal

We disposed of food by keeping all our rubbish in a rubbish bag, which was carried back down the mountains and disposed of when we returned to Santiago. During Phase 1 and Phase 2, human waste was discretely buried away from water sources, in accordance with the El Ministerio de Bienes Nacionales regulations.

Details of any injury or illness to expedition members and/or porters

Out of those who were funded by this grant or helped carry out the research objectives, no one was seriously ill or injured.

Expedition Accounts (including carbon offsetting)

Charlotte Curry's costs are itemised below:

Item	Income	Expenditure
MEF Research Grant	£3,000	
RGS Geographical Club Award	£1,000	
RTSG University of Sheffield	£1,368	
Travel (international flights, travel to/from airport in UK, car hire, fuel, taxis in Santiago)		£2,164.77
Accommodation		£1,035.87
Subsistence		£250
Arriero (full cost)		£1,090.02
Excess baggage		£330
Offsetting (full cost)		£165.21
Medications – high altitude and water purification		£32.32
Spectrometer equipment – total incurred costs including travel, accommodation, insurance, return DHL shipping to Edinburgh		£420.36

Christiaan Diemont, Claudio Bravo and Benjamin Robson's participation was funded by The University of Bergen (GEO_Ann Rowan). Costs in excess of above income were also covered by The University of Bergen.

The team are exceptionally grateful to The Mount Everest Foundation, The Royal Geographical Society, The University of Sheffield and The University of Bergen (in particular, Dr. Ann Rowan) for supporting this work.

08/05/2023

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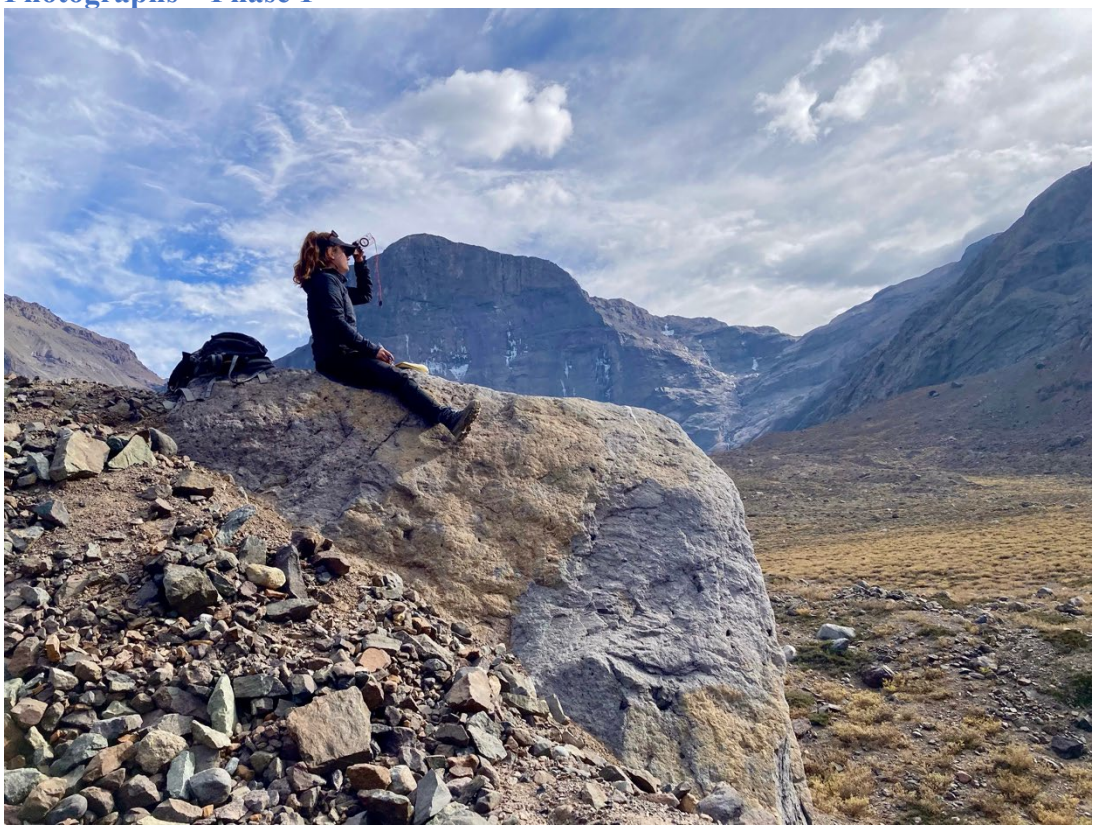
Photographs – Phase 1



Charlotte Curry taking topographic shielding measurements on a moraine boulder in the Salto del Olivares

Charlotte Curry flying a Mavic-3E drone in the Salto del Olivares, Chile

Christiaan Diemont and Claudio Bravo collecting moraine boulder sample in the Salto del Olivares, Chile

Chisels used to exploit natural fractures in moraine boulder.

Photographs – Phase 2

Charlotte Curry collecting spectral reflectance values on Universidad Glacier, Chile

Spectrometer set-up with white standard

Proglacial area in front of Universidad Glacier (glacier in background)

Benjamin Robson setting up the Wingtra drone for flight at Universidad Glacier

Drone images of Universidad Glacier

Drone images of Universidad Glacier terminus