Macmillan Pass 2019 Geophysics – Gravity Survey

NTS 105O/01, 02 Yukon, Canada

Prepared for:

FIREWEED ZINC

Report prepared by:

Aurora Geosciences Ltd.

AURORA GEOSCIENCES

2019 FIELD REPORT
GRAVITY SURVEY
MACMILLAN PASS
YUKON, CANADA

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1 SUMMARY

This geophysical report describes the gravity survey completed in the summer of 2019 by Aurora Geosciences Ltd. (AGL) for Fireweed Zinc Ltd. (Fireweed) on their Macmillan Pass property. The survey was conducted to assist in locating SEDEX ore deposits over the Fertile Corridor and Boundary Target areas of the property.

The Macmillan Pass project is located in Yukon (Canada), around 175 km north-east of the community of Ross River, from which a direct road access to the property and camp is available via Yukon Highway 6 (Canol Road). Air access is also available via the Macmillan Pass airstrip (Macmillan airstrip), located on the property.

The field work took place between June 25th and July 9th, 2019. A five person AGL crew carried out two geophysical surveys: gravity, described in this report, and passive seismic, described in a separate report *(FWZ-20200520-Mac_Pass_2019_Passive_Seismic_Survey-Field_Report)*. A sixth worker was present as an onsite processor, also assisting field work as needed. One field person was rotated out on July 3rd and replaced by a new worker *the* same day. Mobilisation to and from camp was accomplished by airplane between Whitehorse and Macmillan airstrip on chartered flights, on June 24th and July 10th. All AGL personnel stayed in Fireweed's Tom Camp, located approximately 2.5km south-east of the Canol Road and Macmillan airstrip.

The field crew were transported to and from the survey areas by helicopter and travelling between the stations was done on foot.

In the digital archives appended with this report are merged gravity survey results for 2018 and 2019 programs, presented as a gridded image of Bouguer Gravity in *pdf* format. Also included are raw instrument dump files, processed data in both ASCII (*.xyz) and Geosoft (*.gdb, *.grd, *.map) formats, and processor's notes (*.txt). No interpretation or modelling of the gravity data is included with this report. The 2018 gravity program results were presented in the report *FWZ20181027_Gravity Survey at Mac Pass.pdf*

2 CREW AND EQUIPMENT

Table 1: AGL Personnel

Name	Position	Date on site
Alexandar Jelenic	Geophysicist / Project Manager	June 24 to July 3, 2019
Davin Hofmann	Geotechnician / Crew Chief	June 24 to July 10, 2019
Brent Kazamel	Geotechnician	June 24 to July 10, 2019
Heather Neufeld	Geotechnician	June 24 to July 10, 2019
Adam Bouchama	Geotechnician	June 24 to July 10, 2019
Felix Gagne	Onsite Processor / Geotechnician	June 24 to July 10, 2019
Rupert Duke	Geotechnician	July 3 to July 10, 2019

Table 2: Geophysical Instruments and Equipment

Gravimeters:	1	Scintrex CG-5 Autograv™ (s/n 1368) & accessories
	1	Scintrex CG-6 Autograv™ (s/n 99) & accessories
Global Navigation Satellite System (GNSS) instruments	2	Leica RTK Systems & accessories: 2 × CS15 Controllers 2 × GS14 Antennas (Base + Rover) 2 × GS15 Antennas (Base + Rover) 2 × Rover Poles 2 × Base Tripods 2 × Radio Tripods
	2	Pacific Crest Radios/Repeaters
Passive Seismic:	2	Moho Tromino® (s/n 340 & 341) & accessories: supplied by Fireweed
Miscellaneous:	3	Laptops with Oasis montaj™, Gravred and Grilla installed
	2	Iridium satellite phones
	3	inReach® units
	6	Garmin handheld GPS
	6	Bear spray and bear banger kits

3 SURVEY LOCATIONS

Fireweed's Macmillan Pass Project is located in the eastern central part of Yukon (Canada), less than 10 km from the Northwest Territories boundary, and around 175 km from the community of Ross River, YT. The property covers areas of both Mayo and Watson Lake mining districts of Yukon. The Canol Road crosses the property, which offers a seasonal direct road access from Ross River. The Macmillan airstrip is also located on the property, along the Canol Road and near the camp site.

The 2019 gravity surveys are located in two areas: Fertile Corridor and Boundary Target.

- The Fertile Corridor grid comprises 687 gravity stations on 21 lines orientated NNE *(N021°)* and spaced 200 metres apart. These lines are an extension of the 2018 gravity survey, at the western edge of End Zone.
- The Boundary Target area consists of 44 gravity stations on two north-south lines *(N000°)*, 200 metres apart. The area is around 4 kilometres WNW of the western limit of the Fertile Corridor 2019 survey area.

Figure 1 shows the locations of the areas of the gravity survey conducted in 2019, along with 2018 gravity survey coverage for reference. The passive seismic survey is scattered over the same areas, with a lower density of measurements.

The geographic datum used for all coordinates in this report is NAD83, Canadian Spatial Reference System (CSRS), in either the UTM Zone 9N projection or latitude/longitude, and the elevations are recorded as orthometric heights using the CGVD28 Geoid (HT2_2010v70).

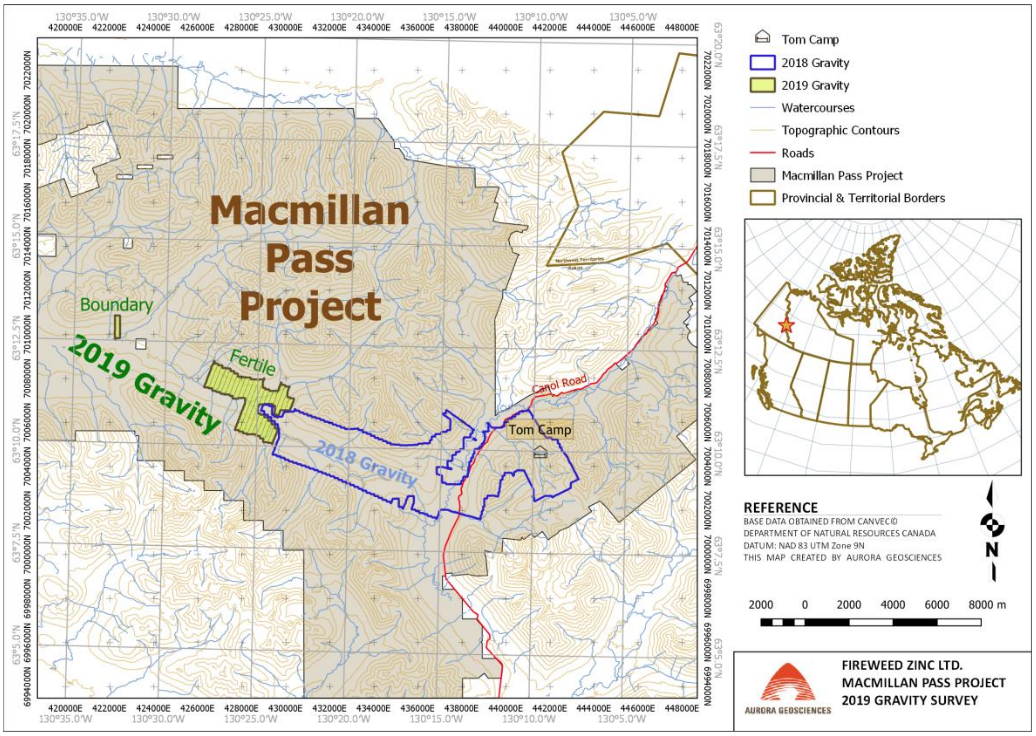


Figure 1: Location of Fireweed's Macmillan Pass Project

4 SURVEY SPECIFICATIONS

4.1 Gravity Survey Specifications

The proposed stations were uploaded to handheld Garmin GPS units, which were used to navigate to the stations and locate them. The reading site was cleared of soft moss and organics or preferentially located on a rock outcrop, a low boulder or other solid foundation.

Table 3: Gravity Survey Specifications

Gravimeter preparation:	All gravimeters are warmed up and levelled on a concrete floor in Aurora's warehouse in Whitehorse. The instruments are cycled for up to 48 hours; taking 60-second readings at 5 Hz (CG-5) / 10 Hz (CG-6) to determine the remnant instrument drift and adjust their drift constant. Tilt offset and tilt sensitivity constants are also adjusted to improve accuracy on softer, less stable ground, or on melting permafrost. The instruments remain under power at all times throughout the survey operation. The cycle data for the CG-5 gravimeter is provided in the digital archive appended to the report under "Raw Data\Gravimeter Cycling". The CG-6 adjustment is calculated internally upon completion of the cycling, as detailed in the CG-6 manual at pages 3–22 and following.

Gravity tie readings:	Prior to and after daily surveying, readings are taken at a control station. Control stations are established at various locations, as detailed below in Table 4 (Section 4.2). Readings are stacked for a minimum of sixty seconds and were repeated until three readings produced values within 0.01 mGal. Sites are selected to be solid and stable, to allow for quick, stable and repeatable setups as well as long-term use.
Station locations:	Stations are located with non-differential GPS receivers. Site location is preferably close to the planned location, but if more suitable sites, flatter, more solid and/or better sheltered, are found 15 or 20 metres away, they may be selected.
Gravity readings:	Readings are stacked for a minimum of 30 seconds. The full sample is internally corrected for Earth tides, tilt of the instrument, and sensor temperature. The standard deviation (SD) in the set of individual readings is kept to less than 0.05 mGal when possible. When this is not possible, readings are repeated at least 3 times to ensure that the data are repeatable within 0.015 mGal. On the CG-5, the seismic filter is engaged to remove seismic noise and wind noise.

4.2 Gravity Control Points

The datum for each control point is established by drift correcting their measured values with daily check-ins at Tom Camp (8888) by the CG-6 gravimeter s/n 99, whose daily drift has been observed to be minimal and stable throughout the job (except on July 2nd, discussed further in this section).

Table 4: List of Gravity Control Points (Gravity Check-ins)

Point ID	UTM East (m)	UTM North (m)	Orthometric Height (m)	Dates used (in 2019)	Gravity Datum (mGal)
8888 (Tom Camp)	N/A	N/A	N/A	June 25 – July 9	7314.300
6666 (Fertile)	N/A	N/A	N/A	June 26 – June 28	7363.498
5555 (Fertile)	N/A	N/A	N/A	June 29	7367.864
4444 (Fertile)	N/A	N/A	N/A	June 30 – July 3	7367.508
3333 (Fertile)	428466.974	7008028.932	1319.177	July 3 – July 6	7335.710
6666 (Fertile)	N/A	N/A	N/A	July 4	7363.498
2222 (Fertile)	427588.972	7007102.365	1127.108	July 5	7377.834
2223 (Fertile)	427441.241	7007274.919	1121.399	July 6 – July 7	7378.533
1111 (Fertile)	N/A	N/A	N/A	July 7 – July 8	7347.324
-17200/1800 (Fertile)	426875.272	7007492.554	1116.294	July 8	7379.654
7777 (Boundary)	423801	7010087	1169	July 9	7372.619
1112 (Boundary)	422456	7010895	1319	July 9	7348.405

The data obtained at control points allow the drift correction of the gravity readings and the calculation of the average drift velocity during daily operations for each gravimeter. They also provide a tool to quickly notice and address possible issues such as unnoticed gravimeter spring tares. Figure 2 and Figure 3 show the average daily drift velocity calculated for respectively the CG-6 and CG-5 gravimeters.

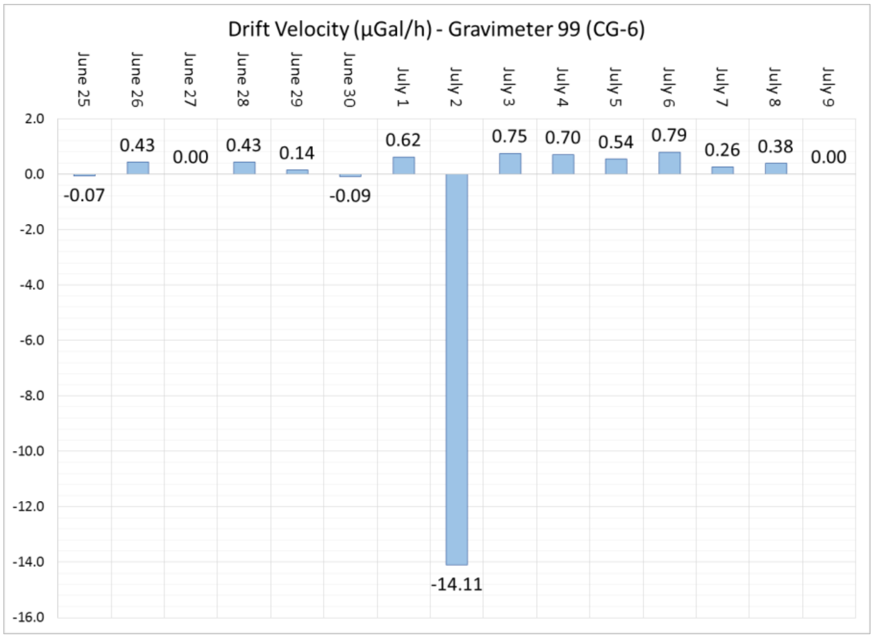


Figure 2: Average Drift Velocity for CG-6 s/n 99

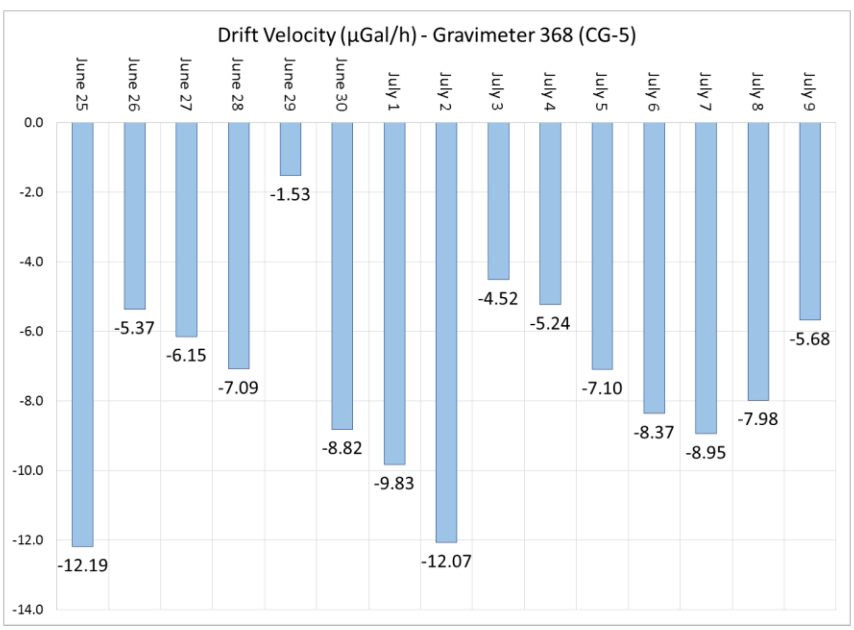


Figure 3: Average Drift Velocity for CG-5 s/n 1368

The average drift velocity for the CG-6 gravimeter on July 2nd stood in stark contrast with the values calculated up to then (and also with those that would later be observed until the end of the project), so a tare was suspected. To remedy this, a close analysis of the daily path, GPS tracks and gravimeter time stamps was conducted by the onsite processor with the members of the field crew, who could remember specific details of their day and helped narrow the likely moment of the tare event to a few stations only. It was decided that four stations should be re-surveyed the following day, which resolved the issue by allowing the identification of the exact station where the tare occurred. The values of the duplicated measurements permitted the calculation of tightly constrained virtual check-in values and times, which were added to the tie file. This enable the calculation of the proper drift correction of the data acquired by gravimeter CG-6 on July 2nd.

4.3 RTK Survey Specifications

Accompanying the gravity survey is an RTK survey, to provide the spatial control — including the critical vertical positioning requirements — for the gravity reductions described in *Section 0*. RTK readings are taken in identical locations as the gravity readings. The specifications for the RTK survey are detailed in *Table 5*.

Table 5: RTK Survey Specifications

Geographic datum:	NAD83 (CSRS)
Geographic projection:	UTM Zone 9N projection
Elevation datum:	Heights above ellipsoid are measured. They are later converted to ortho-metric heights, or metres above Mean Sea Level, using the CGVD28 Geoid.
Satellites used:	GPS and Glonass
RTK base:	The base stations are established in conjunction with the gravity control stations (detailed in Section 4.2). The base Leica GNSS antenna logs data continuously at one-second epochs, broadcasting them over an RTK radio. Each occupied base station position has a corresponding raw data set that was submitted to CSRS-PPP for processing. CRS-PPP is an online application for GNSS data post-processing allowing users to compute higher accuracy positions from their raw observation data.[1]
RTK rover:	The GNSS rover antenna is placed on the gravity survey station and elevations corrected for the rover antenna height. For all GPS locations, an RTK link is established and a minimum of ten one-second epochs with the base are measured.
RTK point ID:	The ID reflects the local grid line and station values of the site being measured.

Table 6: List of RTK Base Locations

Point ID	UTM East (m)	UTM North (m)	Orthometric Height (m)	Dates used (in 2019)
Fertile PPP	429231.433	7006885.340	1194.554	June 25 – June 29
GRAV 5555	429166.931	7006177.196	1168.849	June 30 – July 2

[1] https://www.nrcan.gc.ca/maps-tools-publications/tools/geodetic-reference-systems-tools/tools-applications/10925#ppp

Point ID	UTM East (m)	UTM North (m)	Orthometric Height (m)	Dates used (in 2019)
Fertile PPP [A]	429231.449	7006885.347	1194.595	July 3
Fertile 3	428469.559	7008028.534	1319.160	July 4 – July 6
Fertile 4	427113.188	7008573.105	1280.533	July 7 – July 8
Fertile 5	423776.048	7010085.557	1185.564	July 9

[A] Reoccupation of the station. The new coordinates are from a PPP solution for this second occupation

5 DATA PROCESSING

5.1 RTK Processing

The Leica system stores the RTK data in two formats: .m00 & .xml. The .m00 files contain raw GPS, required for post processing.

The base station raw GPS data are recorded in .m00 files, which are then converted to RINEX format using Leica Geosystems software, and then submitted to the Precise Point Position (PPP) geodetic application from Natural Resources Canada[2] (NRCan) to obtain the PPP solution.

The rover raw GPS data are not recorded on .m00 format. However, the measurements and other data are recorded, and can be exported in various formats. Projects can be exported as .xml files that contain the rover RTK measurements, along with metadata such as error of measurements, identification and parameters of the active GPS base station, number of epochs for each RTK measurement, and more. Simpler exports are possible in the form of generic delimited ASCII files that include point ID along with UTM coordinates and heights above ellipsoid. RTK data are downloaded daily in the camp from the Leica controllers. Data are inspected and unique line-station coordinates matching the gravity and passive seismic measurements are attached. When PPP solutions are obtained, adjustment values are determined and applied to all concerned measurements.

The PPP solution certificates are appended to this report in the digital archive, under the folder "Processed Data\PPP Solutions". The final RTK data is also included in the "Processed Data/ASCII" folder.

5.2 Gravity Processing

Gravimeters are downloaded daily in the camp and processed using the proprietary software package Gravred 3.2. The raw gravity data downloaded from the gravimeters are already corrected for Earth tides, instrument tilt, and sensor temperature. Gravred merges gravity data with spatial data, and corrects for drift, latitude, free-air, Bouguer slab, Bullard-B, and a suite of terrain corrections. Repurposing some of its modules also allows an emulation of the overburden correction described *in* Caron 2018[3]. All corrections except overburden are performed onsite on a daily basis. Final corrections, which required LiDAR survey elevations and an overburden model, are still pending at the time of this report.

[2] https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en
[3] Correcting airborne gravity data for overburden thickness: a case study from the Nechako interior plateau, British Columbia, Caron et al., 2018, dx.doi.org/10.1139/cjes-2017-0209

The LiDAR data acquisition was just starting at the end of AGL 2019 field program. The construction of the overburden digital model relies substantially on passive seismic data collected by AGL alongside gravity. The passive seismic data must first be processed then presented as sections prior to analysis and interpretation. The analysis of the passive seismic data is to be conducted by Fireweed, and the final results with overburden depths are not available at the time of this report. However, as mentioned in the Summary section of this report, the logistical report for the 2019 Seismic Survey is available.

The value of each individual correction is added to the raw gravity, yielding a complete Bouguer anomaly. Complete Bouguer anomaly values calculated using a host rock density of 2.67 g/cm³ are produced for the 2019 gravity survey and merged with 2018 data. The resulting dataset is gridded and presented on Geosoft maps included with this report, along with their exports as Portable Document Files (.pdf) and Geotiff files (.tif).

5.2.1 Drift Correction

The drift correction removes the effect of the internal gravimeter drift, assumed to be linear in time between successive occupations of control points. The datum of all control points (as presented in Table 4) are adjusted to be at a common level, by drift-correcting several occupations of each using the gravity control point 8888, at Tom Camp, which was the first and last site occupied every day by both gravimeters.

Tie files used for the drift correction are in the digital archives appended with this report, in their respective daily folder under "Processed Data\GravRed".

5.2.2 Latitude Correction

The latitude correction removes the effect of varying latitude between the gravity stations. The latitude, UTM Easting and Northing and the local UTM declination at or near the centre of the grid are the parameters used to calculate this correction. The values used on this project are carried over from 2018, in order to facilitate the merging of the data (mostly adjacent locations).

Table 7: Latitude Correction Parameters

Center Latitude	Centre UTM East	Center UTM North	UTM Declination
63.2° N	436500	7002500	-1.2°

5.2.3 Elevation Corrections: Free-Air, Bouguer Slab, Bullard-B

The free-air correction corrects for the change in distance from the centre of the Earth. A datum of 0 m (sea level) is used, and the correction brings the gravity value down to that datum.

The Bouguer slab corrects the gravity for a uniform slab, of thickness equal to the elevation, and of density equal to the expected average rock density of the area.

The Bullard-B correction accounts for the curvature of the Earth in the Bouguer slab.

5.2.4 Near Terrain Correction (NTC)

Near-station terrain correction compensates for the effect of local differences in topography. It is applied for the area located between 2 and 20 metres from the gravity reading, using a model generated by field measurements at every gravity station.

The government supplied digital elevation models (DEM) usually have cells on the order of 10 m, and therefore details close to the station, where they have the greatest effect on the gravity reading, can be too fine to capture with a DEM. Also, the DEM elevations can be locally off from the measured RTK by up to a couple of metres, creating improper geometry for the terrain correction. To compensate for this, the gravity operators collect near-station correction measurements at each station. These consist of six slope readings representing an average slope within each of the six 60^{o} sectors of the 20-metre radius around the reading site. The slopes are converted to elevation differences, and these differences are used in the sector equation for the gravitational effect of a vertical cylinder. The individual results are added together to return the value of the NTC correction.

The original slope data collected and used for the NTC correction are in the digital archives appended with this report, in their respective daily folder under “Processed Data\GravRed”.

5.2.5 Far Terrain Correction

The far-station correction compensates for terrain effects from the exclusion distance (20 metres) to the extents of the digital elevation models.

The far terrain corrections are calculated using two digital elevation models: a denser inner DEM — 5-metre cell size — that extends at least 1 kilometre beyond the survey area; and a coarser outer DEM – 20-metre cell size — that starts at the perimeter of the inner and extends out to 8 kilometres from the survey area. The two DEMs are made using the Arctic DEM data[4].

The flat top prism algorithm is used to calculate the corrections of both the inner and the outer DEM.

5.2.6 Overburden Correction

The overburden correction compensates for the effect of surficial material, whose density is expected to be lower than that of bedrock, creating a lack of mass in the volume it occupies. The calculations are similar in some respect to the far terrain correction. The exclusion distance, however, is set to 0 metres, as there is no near-station overburden model, and in contrast with terrain correction reducing down to near-zero values when closing in at the station location (elevation differences become negligible), the overburden layer, when present, does have a significant gravitational effect at the exact station location. In order to preserve the geometric configuration of the gravity measurements (gravimeter sitting just above the overburden layer, and not some metres above or below its upper extent), the elevation of each gravity reading is set to exactly the elevation of the DEM node on which it sits.

The overburden correction requires an overburden DEM for the bottom of the layer, which is currently not available. Therefore, no overburden correction has been applied to the data.

5.3 QA/QC

In order to identify potential mislabels RTK data are processed to get line and station estimations based solely on their UTM locations. Outliers are examined separately and relabelled if required.

In April 2020, Fireweed also provided a comparison of the corrected RTK data elevations with their 1m cell-sized LiDAR survey produced DEM of the property. The differences are distributed in a regular bell curve, with the RTK data generally being lower than the LiDAR, which is consistent with gravity survey requiring pits to be dug to ensure the stability of the instrument. This significantly increased the confidence in the

[4] https://www.pgc.umn.edu/data/arcticdem/

RTK dataset, and allowed the identification of a suspicious reading, which was investigated and is now suspected of being a bad RTK initialization. The overall results are shown in Figure 4, and results split by RTK base setup in

Figure 5Figure 5.

Details on the QA/QC are appended to this report in the “Processed Data/QAQC” folder.

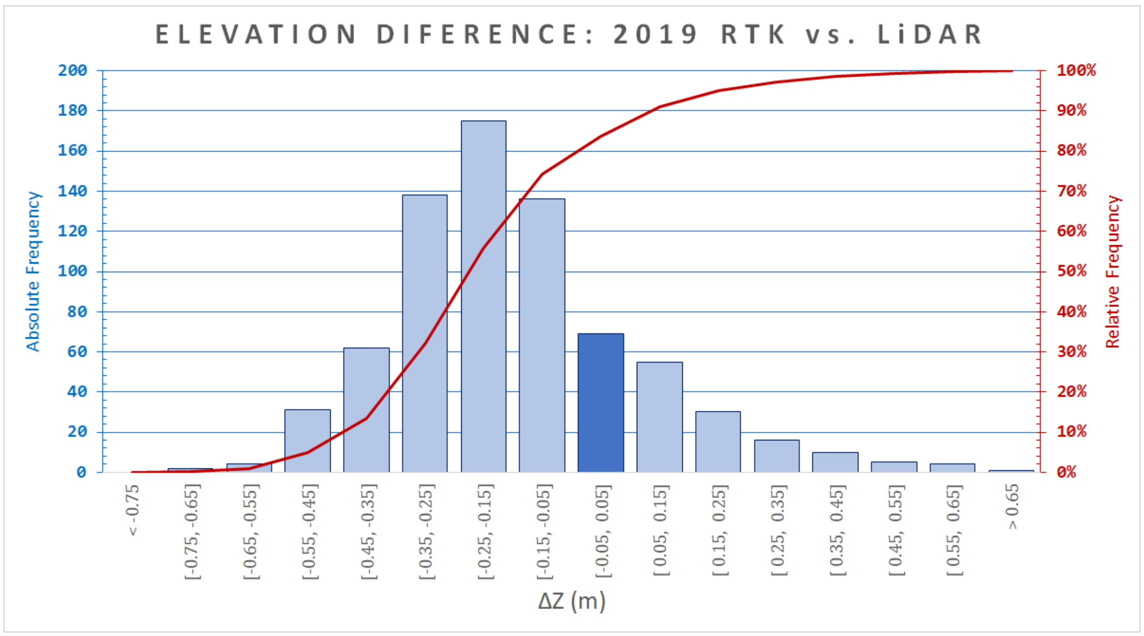


Figure 4: Elevation difference between RTK and LiDAR

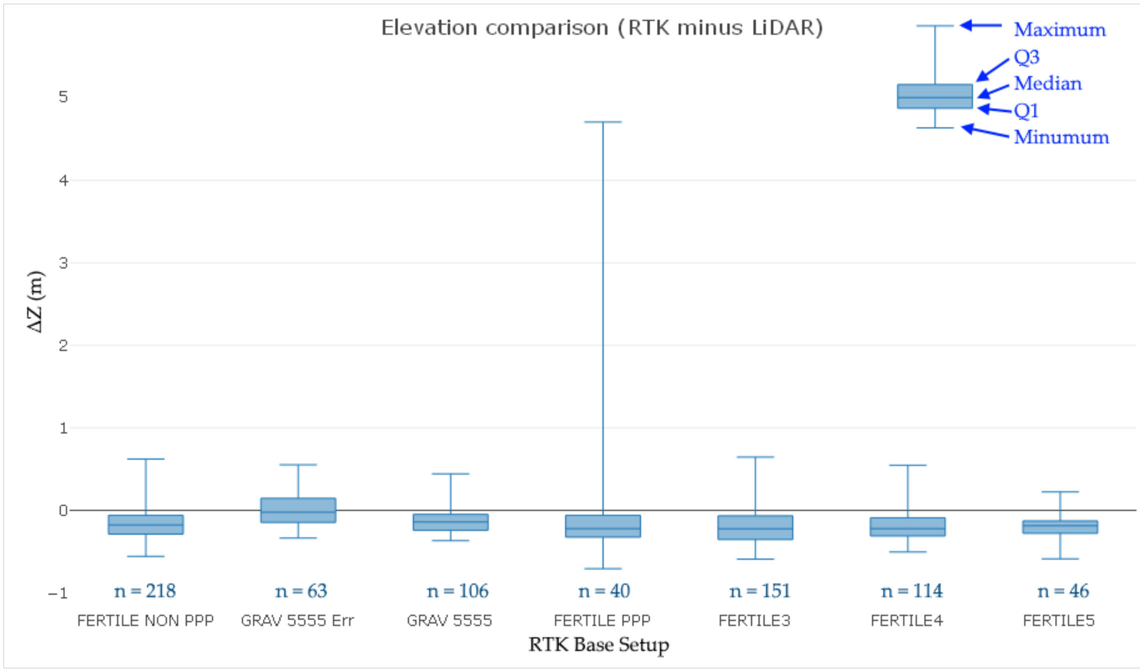


Figure 5: Elevation difference between RTK and LiDAR *(per RTK base setup)*

6 PRODUCTS

Table 8: Files included with the digital version of this report

Folder	Description of Contents
Processed Data\Geosoft Databases	FWZ-20200504-Gravity_2018-2019.gdb
Processed Data\Geosoft Grids	FWZ-20200504-Gravity_2018-2019.grd: Bouguer Gravity FWZ-20200504-Gravity_2018-2019_{1,2}TR.grd: Bouguer Gravity, {first, second} order trend removed, using Geosoft's GRIDTRND.gx FWZ-20200504-Gravity_2018-2019_hp_{0750,1000,1250, 1500,1750,2000}.grd: High-Pass Filtered Bouguer Gravity, cutoff wavelength = {750,1000,1250,1500,1750,2000}m, applied on the Bouguer gravity gridded data
Processed Data\Geosoft Maps	FWZ-20200504-Gravity_2018-2019.map: plan map that includes elevation contours and the gravity grids.
Processed Data\Geosoft Polygons	FWZ-20200429-2019_Survey_Outline.ply: outline of the 2019 survey areas
Processed Data\QAQC	QAQC documents in ASCII format
Final Products\Geotiff	Geotiff (.tif) exports of the plan map (one per grid)
Final Products\PDF	PDF (.pdf) exports of the plan map (one per grid)

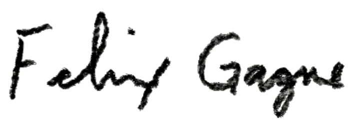
Folder	Description of Contents
Logistical Report\Appendices\Crew Log	PDF of the crew log, production log, and logistical log
Logistical Report\Appendices\Instrument Specifications	CG-5, CG-6 and Leica Geosystems Instrument Specifications (various formats)
Raw Data\	Daily archive of instrument and GPS track files, organized into folders for each day

Table 9: Gravity database channel descriptions

Channel	Description	Units	Format
Line	Line coordinate of the local grid (nominal)	m	
Station	Station coordinate of the local grid (nominal)	m	
UTME	East coordinate, NAD83 (CSRS), UTM projection Zone 9N	m	
UTMN	North coordinate, NAD83 (CSRS), UTM projection Zone 9N	m	
Elevation	Orthometric height, CGVD 1928 Geoid (HT2_2010v70 transform)	m	
Date	Date of collection of the gravity measurement (local)		yyyy/mm/dd
Time	Time stamp of the gravity measurement, in local time (Pacific Time Zone, Daylight Savings, UTC – 7)		hh:mm:ss (24-hour clock)
Model	Model of the gravimeter (shortened to either CG-5 or CG-6)		
Serial	Last 3 digits of the serial number		
Operator	Initials of the operator of the gravimeter		
RawGrav	Value of the gravimeter measurement (includes internal corrections for Earth tides, instrument tilt, and sensor temperature)	mGal	
SD	Standard deviation of the individual measurements (whose average resulted in the value indicated in **Grav_Raw**)	mGal	
Drift	Value of the drift correction	mGal	
Latitude	Value of the latitude correction	mGal	
FreeAir	Value of the free-air correction	mGal	
Bouguer_267	Value of the Bouguer slab correction (ρ = 2.67 g/cm^3)	mGal	
BullB_267	Value of the Bullard-B correction (ρ = 2.67 g/cm^3)	mGal	
NearStn_267	Value of the near terrain correction (ρ = 2.67 g/cm^3)	mGal	
Inner_267	Value of the far terrain correction, using the 5m-cell-sized inner DEM (ρ = 2.67 g/cm^3)	mGal	

Channel	Description	Units	Format
Outer_267	Value of the near terrain correction, using the 20m-cell-sized outer DEM (ρ = 2.67 g/cm^3)	mGal	
Adjust_to_8888	-0.100 for 2019 measurements: 2 values were mentioned for 2018 data, which varied by 0.100mGal. The initial value transferred to process 2019 data was later found to be incorrect. This adjusts for the mistake.	mGal	
Reject	A numerical value entered causes the rejection of the reading (suspicious or incorrect data identified)		
FinalGrav	Final gravity value, corrected and levelled.	mGal	

Respectfully Submitted,



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