NGU REPORT 2024.038

Drone-borne aeromagnetic survey in Sortland, Vesteralen

GEOLOGY FOR SOCIETY
SINCE 1858

GEOLOGICAL SURVEY OF NORWAY
- NGU -

NGU REPORT 2024.038

Drone-borne aeromagnetic survey in Sortland, Vesteralen

GEOLOGICAL SURVEY OF NORWAY
- NGU -

NGU REPORT

Geology for society

Geological Survey of Norway
P.O. Box 6315 Torgarden
NO-7491 Trondheim, Norway
Tel. +47 73 90 40 00

Report no.: 2024.038
ISSN: 0800-3416 (print)
ISSN:2387-35150 (digital)
Grading: Open

Title: Drone-borne aeromagnetic survey in Sortland, Vesteralen
Authors: Florent Szitkar
Client: NGU
County: Nordland
Municipality: Sortland

Map-sheet name (M=1:250.000):
Map-sheet name (M=1:50.000):
Deposit name and grid-reference: WGS84 UTM32N 450000E, 6600000N
Numbers of pages: 17
Price (NOK):

Map enclosures:
Fieldwork carried out: July 2024
Date of report: September 19th 2024
Project no.: 407900
Person responsible: Vikas Baranwal
Keywords: Geophysics, Graphite, magnetics, drone

Summary: As part of an NGU-funded project led by V. Baranwal, a drone-based aeromagnetic survey was conducted in three areas around Sortland (Vesterålen, northern Norway) to produce high-resolution magnetic maps of known magnetic lows associated with graphite deposits. This region has a historical significance in graphite production and is still known for manufacturing pencils. This report outlines the acquisition, processing, and visualization of the datasets collected during the survey, presenting the results in the form of detailed maps. The three geophysical surveys covered a total area of 10 km², comprising 114, 170, and 152 flight lines, respectively and were conducted in July 2024. The first area was fully surveyed, but the second and third were smaller than anticipated due to a mechanical failure of the drone, which caused two consecutive crashes.

The NGU employed a DJI M300 multipurpose drone equipped with a Sensys MagDrone R3, a three-component fluxgate magnetometer securely mounted to the drone's landing gear. With a sampling rate of 200 Hz and a sensitivity of 150 pT, the magnetometer is optimized for detecting weak magnetic anomalies, making it ideal for this high-resolution geophysical survey. The system weighs only 1 kg, enabling easy integration with the drone. The surveys were conducted at a flight speed of 5 m/s, with a route spacing of 30 meters. The distance between parallel flight lines was adjusted according to the altitude during data acquisition. UGcS software was used for topographic draping, allowing the drone to maintain a constant altitude of 35 meters above ground level. This altitude was selected to ensure clearance from the tallest trees and to accommodate the steep terrain. A total of 75 flights were required to cover the three areas. On the second day of surveying, the drone had a hard landing due to a mechanical issue, though it remained functional, allowing the survey to continue as planned. However, it crashed again one week later, forcing an early termination of the survey.

The raw magnetic data were processed using proprietary software, which compensates for the drone's magnetic interference and generates a clean magnetic dataset. Custom codes were used for data processing, and the results were gridded and visualized using GMT software. Topographic data with a 10-meter resolution were sourced from the Hoydedata.no website.

Table of contents

1. Introduction 5

2. Survey specifications 8
   2.1 Airborne survey parameters 8
   2.2 Airborne survey logistics summary 11

3. Data processing and presentation 12
   3.1 Standard processing procedure 12
   3.2 Temporal corrections 12
   3.3 Magnetic data processing, gridding and presentation 13

4. Conclusion 15

5. References 16

Appendixes 15

Database description 15

1. INTRODUCTION

In autumn 2020, NGU acquired a DJI M300 multi-purpose drone, which flew its survey over the Sortland area in July 2024 as part of a project led by V. Baranwal, with F. Szitkar also involved (both researchers at NGU) and Jonas Eriksen (student at NTNU). The drone completed 436 flight lines overall divided in three polygons, covering an area of approximately 10 km², as shown in Figure 1 and Figure 2.

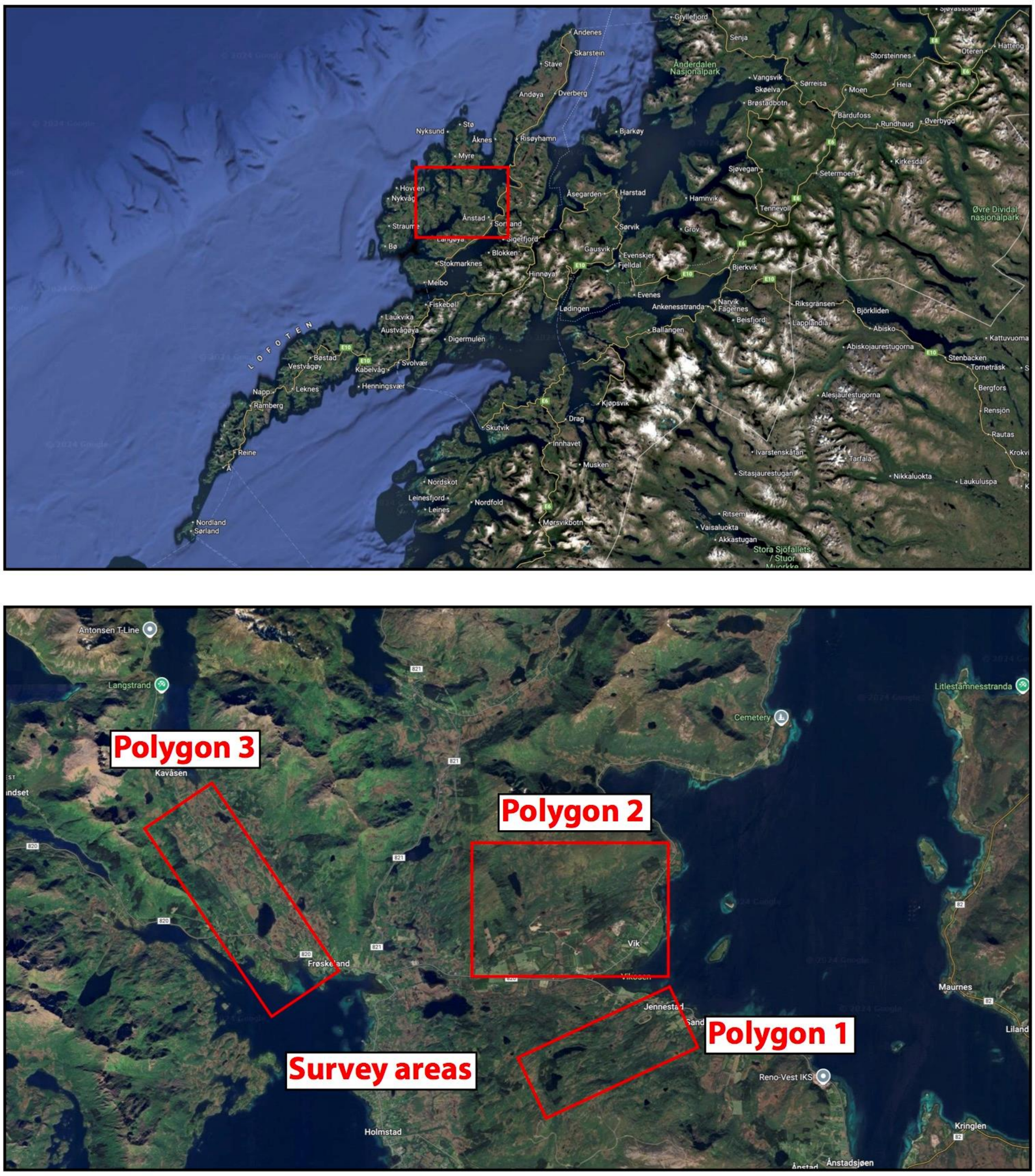
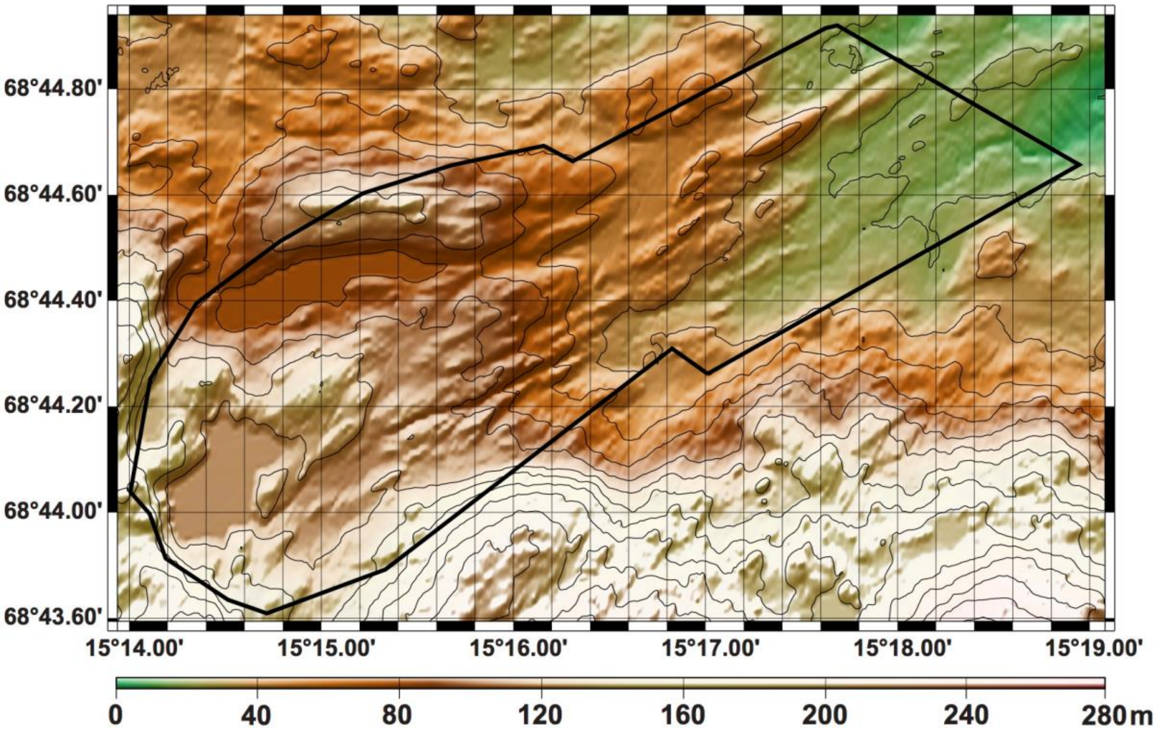
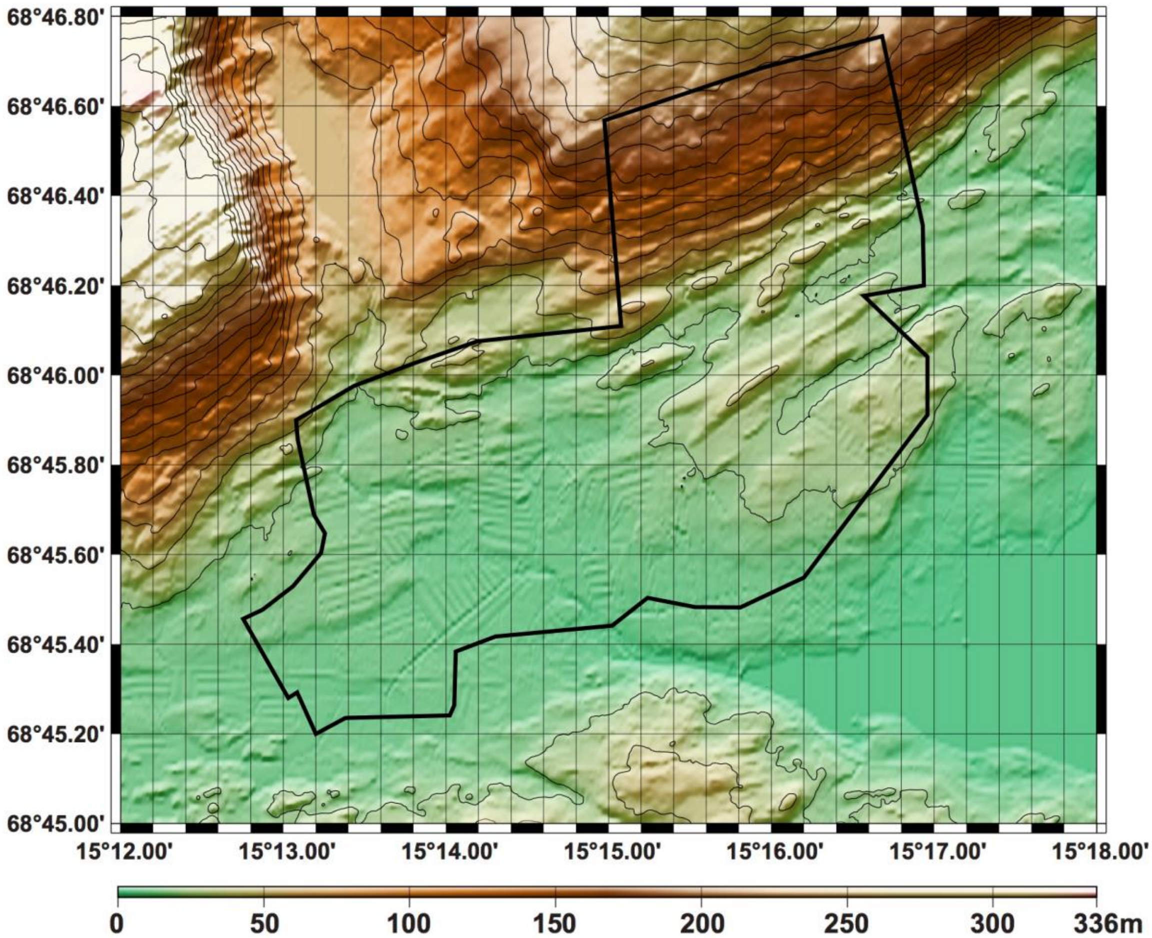


Figure 1: Location of the survey areas, north of Sortland (red rectangles).


68°44.80'
68°44.60'
68°44.40'
68°44.20'
68°44.00'
68°43.60'
15°14.00'
15°15.00'
15°16.00'
15°17.00'
15°18.00'
15°19.00'
0
40
80
120
160
200
240
280m


68°46.80'
68°46.60'
68°46.40'
68°46.20'
68°46.00'
68°45.80'
68°45.60'
68°45.40'
68°45.20'
68°45.00'
15°12.00'
15°13.00'
15°14.00'
15°15.00'
15°16.00'
15°17.00'
15°18.00'
0
50
100
150
200
250
300
336m

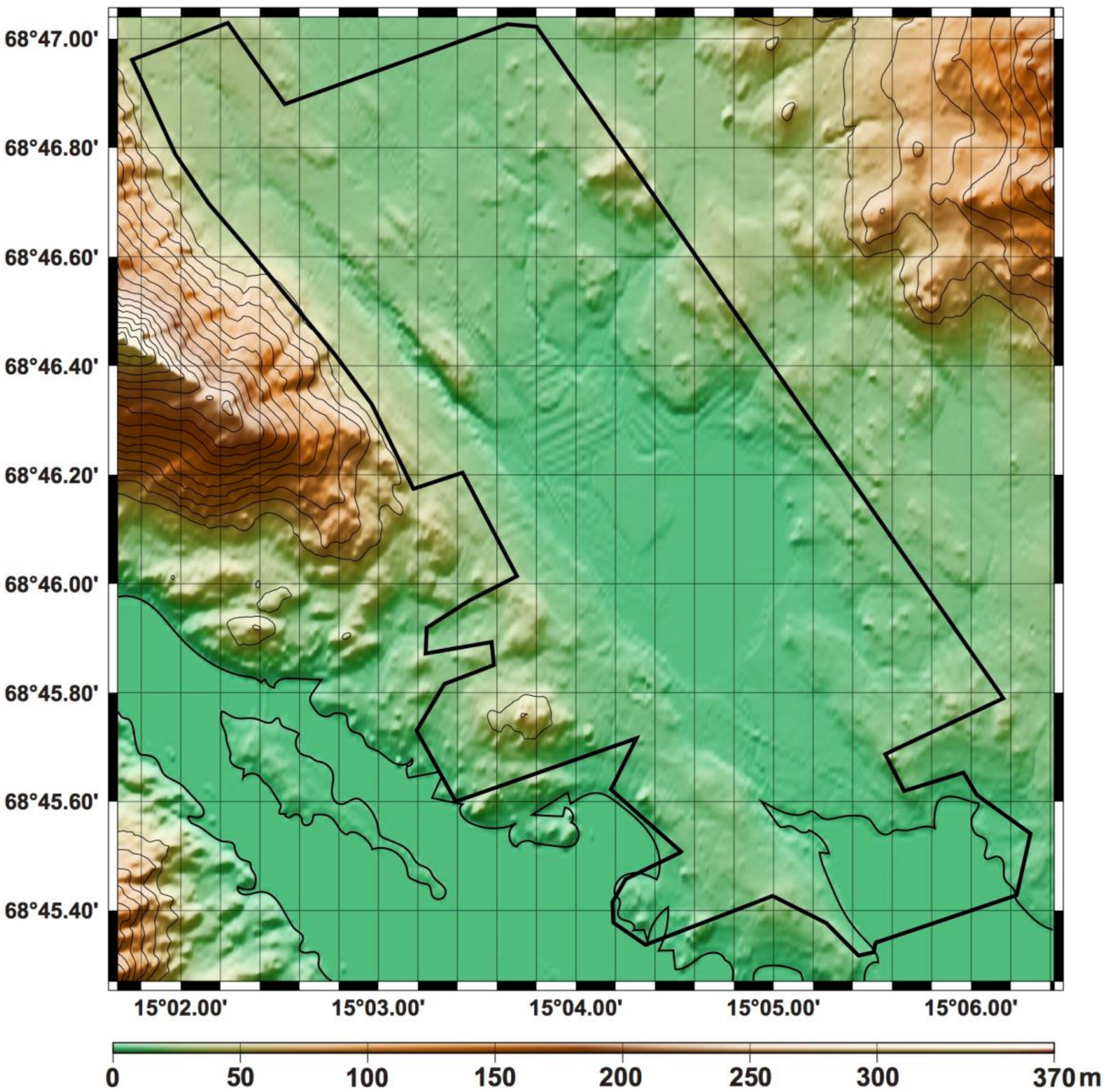


Figure 2: Topographic map of the three survey areas. The black contour corresponds to the limits of the magnetic surveys.

The primary objective of the airborne geophysical survey was to collect a dense, high-resolution magnetic dataset over a significant graphite deposit. This data can be utilized to map geological contacts, structural features, and variations in the bedrock geology within the surveyed area.

The survey used a three-component vector magnetometer, the Magdrone R3 from Sensys GmbH (Germany), mounted between the landing gear of the drone. The magnetometer is equipped with an integrated GPS, further enhanced by a real-time kinematic (RTK) GPS installed on the DJI M300 drone. Collecting all three components of the magnetic field is crucial due to the fixed attachment of the magnetometer to the drone, which records both the drone's magnetic influence and the target magnetic anomalies. Capturing magnetic data along all three axes allows for accurate quantification and removal of the drone's magnetic interference, ensuring precise results.

The survey was carried out with the assistance of a spotter, who also measured the magnetic susceptibility of rocks in several areas. The three surveyed areas presented varying technical challenges. Polygon 1, located over Jennestad, was the easiest to navigate, while the other two areas, near Vik and Froskeland, featured both flat and steep terrain. To maximize data collection while minimizing risk, the strategy was to first survey the "easier" flat areas before moving on to the more difficult, steeper zones. Ironically, the final drone crash occurred in a steep area, though it was unrelated to the challenging topography and instead caused by a mechanical failure in the drone itself.

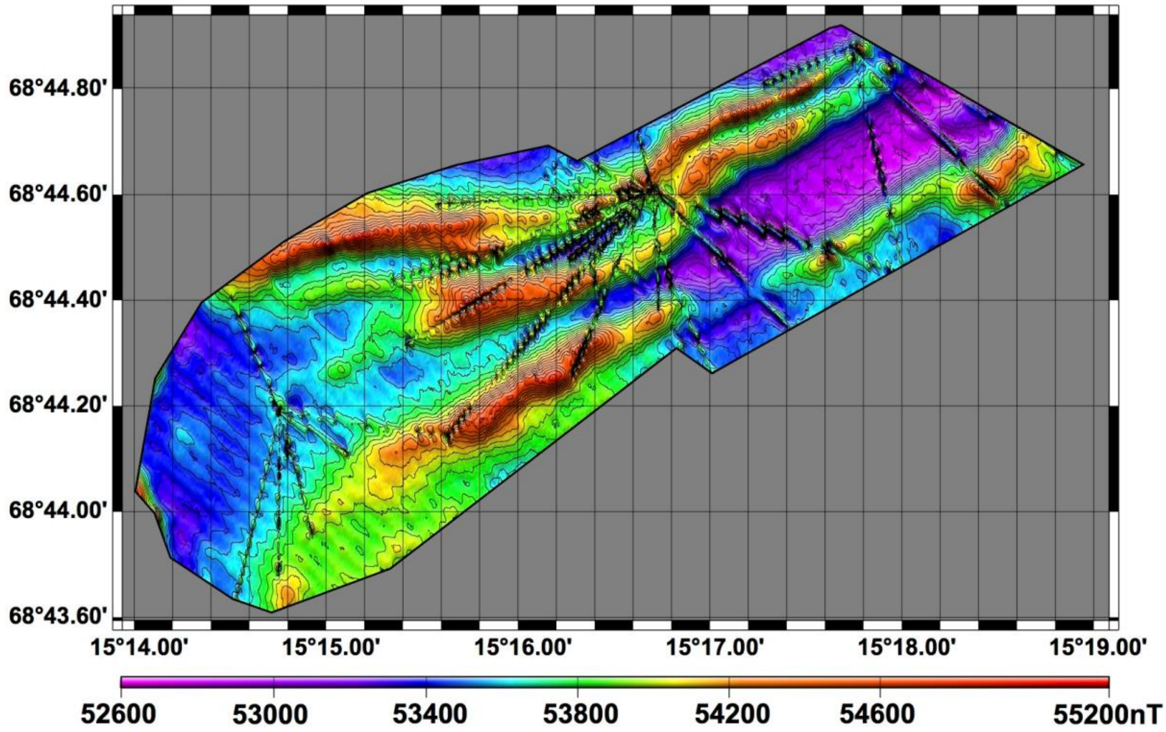
2. SURVEY SPECIFICATIONS

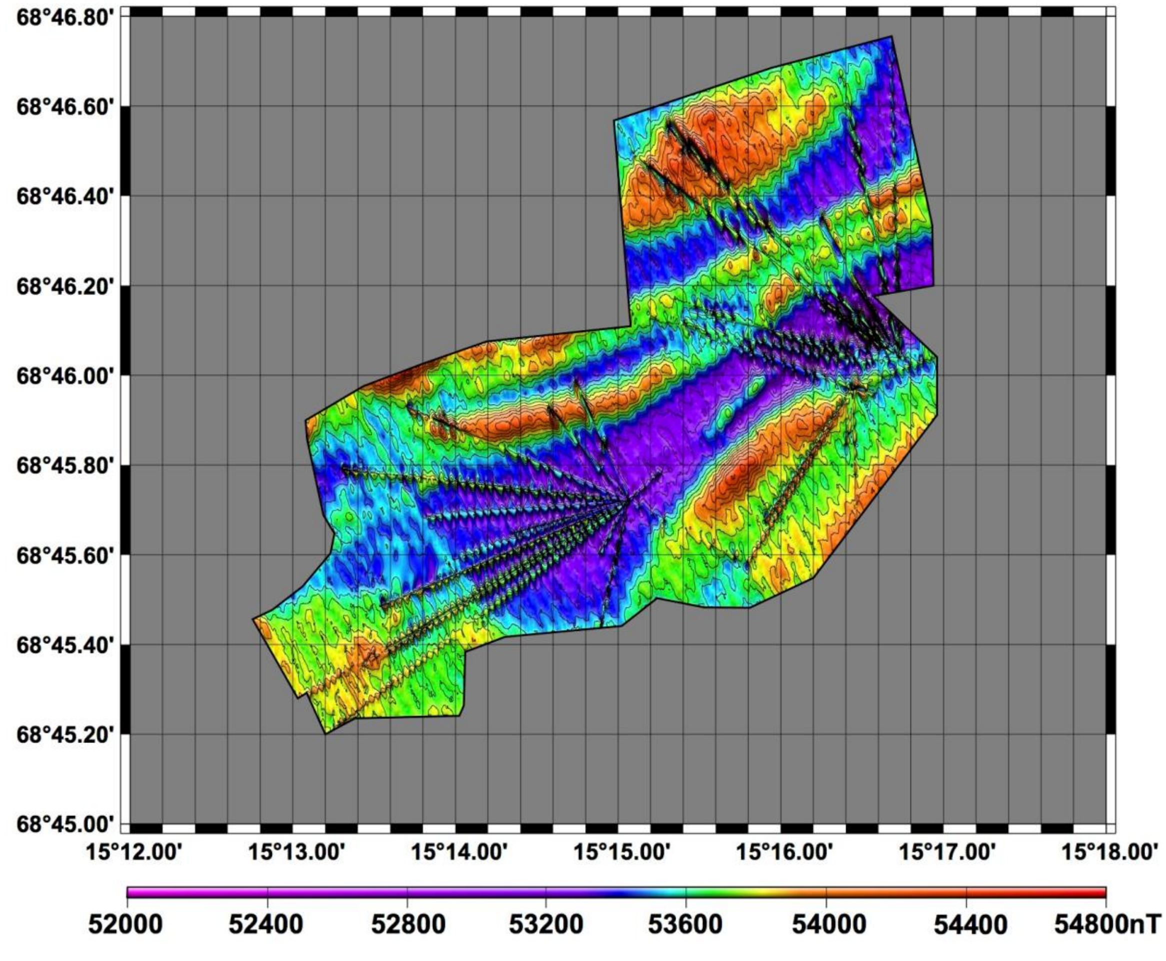
2.1 Airborne survey parameters

NGU used the Sensys magnetometer to collect low-altitude, slow-speed, high-resolution airborne magnetic data. Since this magnetometer is a third-party instrument (i.e., not produced by DJI), it operates independently from the drone's power supply, with its own dedicated battery taped directly to the magnetometer. As previously mentioned, the magnetometer was securely mounted between the drone’s landing gear legs (see Fig. 3). The entire magnetic data acquisition system weighs approximately 1 kg. This lightweight design is crucial, as drones are engineered to carry limited payloads, and even a small increase in weight significantly reduces flight time.

It is important to note that the magnetometer’s battery does not last for an entire day of fieldwork. Under normal conditions, a small green light on the side of the magnetometer blinks to indicate sufficient battery power. However, when the battery level becomes low, the light switches to a red blinking pattern before shutting off entirely. Unfortunately, the duration of the red blinking phase is shorter than a typical drone flight. If the light begins blinking red shortly after takeoff, the pilot may not notice it, and the drone could complete a significant portion of its flight without collecting any data. To avoid this issue, it is essential to replace the magnetometer’s battery halfway through the workday to ensure uninterrupted data collection.

Figure 3: DJI M300 shortly before landing after a flight over the Fen area. The vector magnetometer is installed on the horizontal bar between the two legs forming the landing gear.


68°44.80'
68°44.60'
68°44.40'
68°44.20'
68°44.00'
68°43.60'
15°14.00'
15°15.00'
15°16.00'
15°17.00'
15°18.00'
15°19.00'
52600
53000
53400
53800
54200
54600
55200nT


68°46.80'
68°46.60'
68°46.40'
68°46.20'
68°46.00'
68°45.80'
68°45.60'
68°45.40'
68°45.20'
68°45.00'
15°12.00'
15°13.00'
15°14.00'
15°15.00'
15°16.00'
15°17.00'
15°18.00'
52000
52400
52800
53200
53600
54000
54400
54800nT

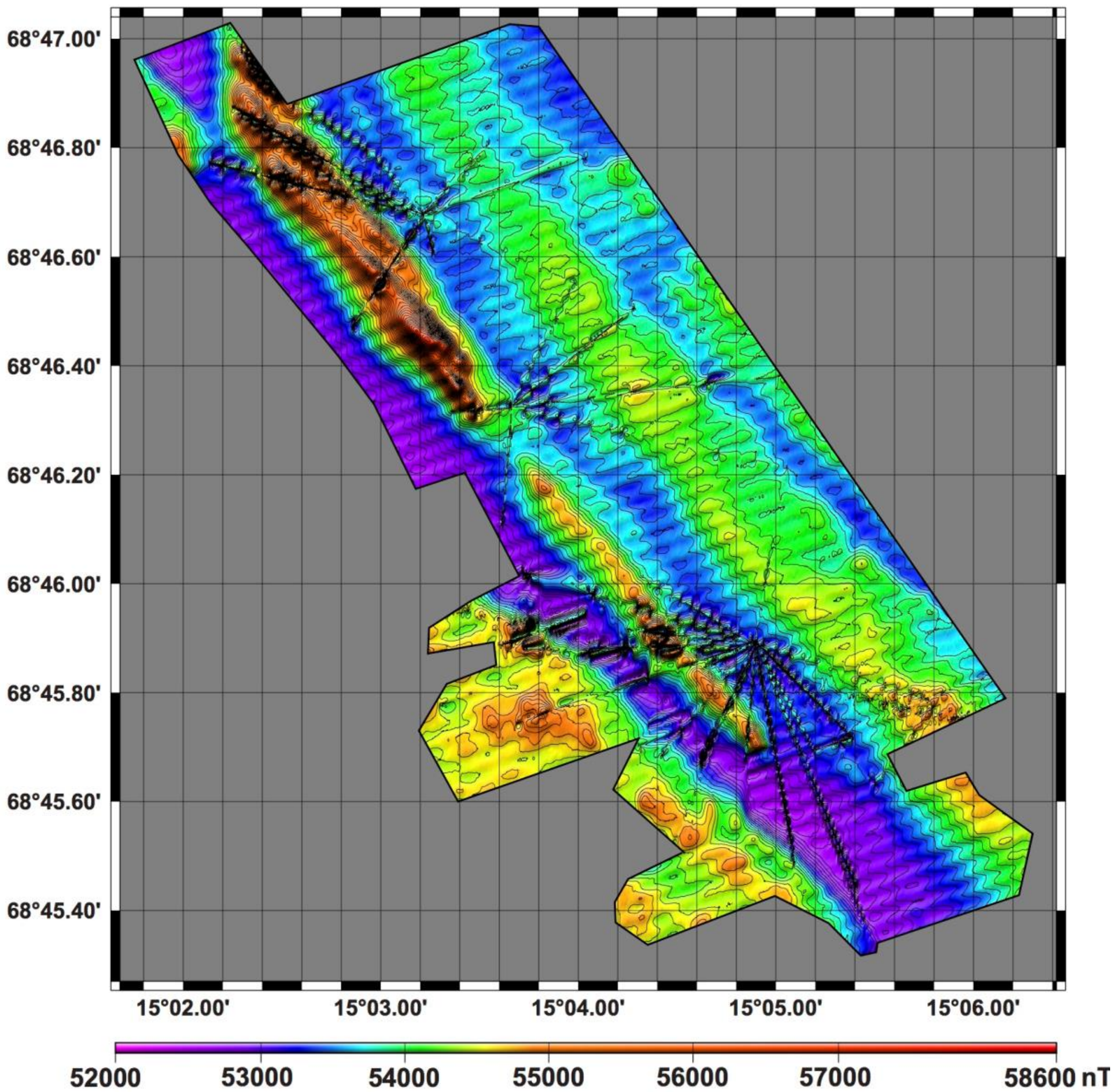


Figure 4: Magnetic maps (before processing) of the three survey areas. The elongated lines correspond to the transits between the take off point and the survey areas, both at the beginning and end of each flight.

The airborne survey commenced on July 14th, 2024, and continued until July 21st, 2024. The drone launched from several locations depending on the polygons.

Flying at a constant altitude of 35 meters above the ground, the drone used UGcS software to follow the terrain topography. Flight paths were oriented perpendicularly to the primary directions of the graphite deposits. The total magnetic anomaly results for the three polygons are shown in Figure 4.

Magnetic data were recorded at 5 ms intervals, producing a high-resolution dataset with a spatial sampling increment of 1.5 cm. While this sampling frequency is not adjustable, it was significantly higher than necessary. Therefore, the data were later down-sampled to a rate of 1 acquisition per second, equating to approximately every 3 meters for the main survey. This down-sampling greatly reduced noise levels in the data.

The magnetometer is equipped with two sensors, enhancing data reliability. This redundancy allows cross-checking to ensure data consistency, even if one sensor were to fail. Both datasets from the two sensors are included in the databases, although only one is plotted in this report as they are essentially identical.

A base magnetometer was installed near the take-off point to monitor diurnal variations in the magnetic field, which were accounted for during the final data processing.

The navigation system utilized a combined GPS/GLONASS/BEIDOU satellite tracking system, integrated into the DJI M300 drone, to provide real-time WGS-84 coordinates at 1-second intervals. The system's accuracy was further enhanced by a real-time kinematic (RTK) station, positioned near the take-off point, which constantly triangulated the drone’s position.

For safety, the drone's flight parameters were continuously monitored and displayed on the remote control screen during each flight. These parameters included horizontal distance from the pilot, flight altitude, return-to-home point, wind speed and direction, pitch and roll, and battery levels.

2.2 Airborne survey logistics summary

A summary of the survey specifications is shown in Table 1.

Vesteralen surveys	
Traverse (survey) line spacing	30 m
Traverse line directions	160/340, 160/340 and 90/270
Total distance	380 km
Average aircraft ground speed	5 m/s
Altitude range over the topography	35
Magnetometer sampling rate	5 ms
Magnetometer GPS positioning	5 ms

3. DATA PROCESSING AND PRESENTATION

3.1 Standard processing procedure

Since the magnetometer is rigidly attached to the drone, the magnetic measurements are significantly influenced by the UAV's metallic components. To isolate the magnetic anomaly, the drone's magnetic interference must be estimated and removed from the data.

Typically, the magnetic susceptibility tensor (a 3x3 matrix) and the remanent magnetization vector (comprising three coefficients) are quantified by performing a calibration at the start of the flights. This calibration occurs when the drone is far enough from the ground and any geological targets so that the magnetic measurements collected at this time should correspond to those predicted by the International Geomagnetic Reference Field (IGRF, Thebault et al., 2015). Any deviation from the IGRF is thus attributed to the drone's magnetic influence.

To remove the drone's magnetic influence from the data, a method developed by Isezaki (1986) is employed. This correction can be performed manually (often the case for vector magnetometers mounted on Autonomous Underwater Vehicles) or automatically.

In this case, the magnetometer is equipped with proprietary software from Sensys that automatically removes the drone's magnetic interference from the signal. While this automated approach simplifies the data processing, it also limits the user's control and understanding of the algorithm's workings. Additionally, there is no way to optimize the process if residual noise remains.

3.2 Temporal corrections

Temporal fluctuations in Earth's magnetic field, known as diurnal variations, can affect the total magnetic field readings recorded during the airborne survey. These fluctuations are typically corrected by using a stationary reference magnetometer, which records the Earth's magnetic field simultaneously with the airborne sensor at short time intervals.

In this survey, diurnal variations were measured using a GEM GSM-19 magnetometer, borrowed from the nearby helicopter survey, as ours was not operational.

The theory is explained below:

The recorded data are merged with the airborne data and the diurnal correction is applied according to equation (1).

$$(1)\quad \mathbf{B}_{Tc} = \mathbf{B}_T + \left(\overline{B}_B - \mathbf{B}_B\right)$$

Where:

$\mathbf{B}_{Tc}$ = Corrected airborne total field readings

$\mathbf{B}_{T}$ = Airborne total field readings

$\overline{B}_{B}$ = Average datum base level

$\mathbf{B}_{B}$ = Base station readings

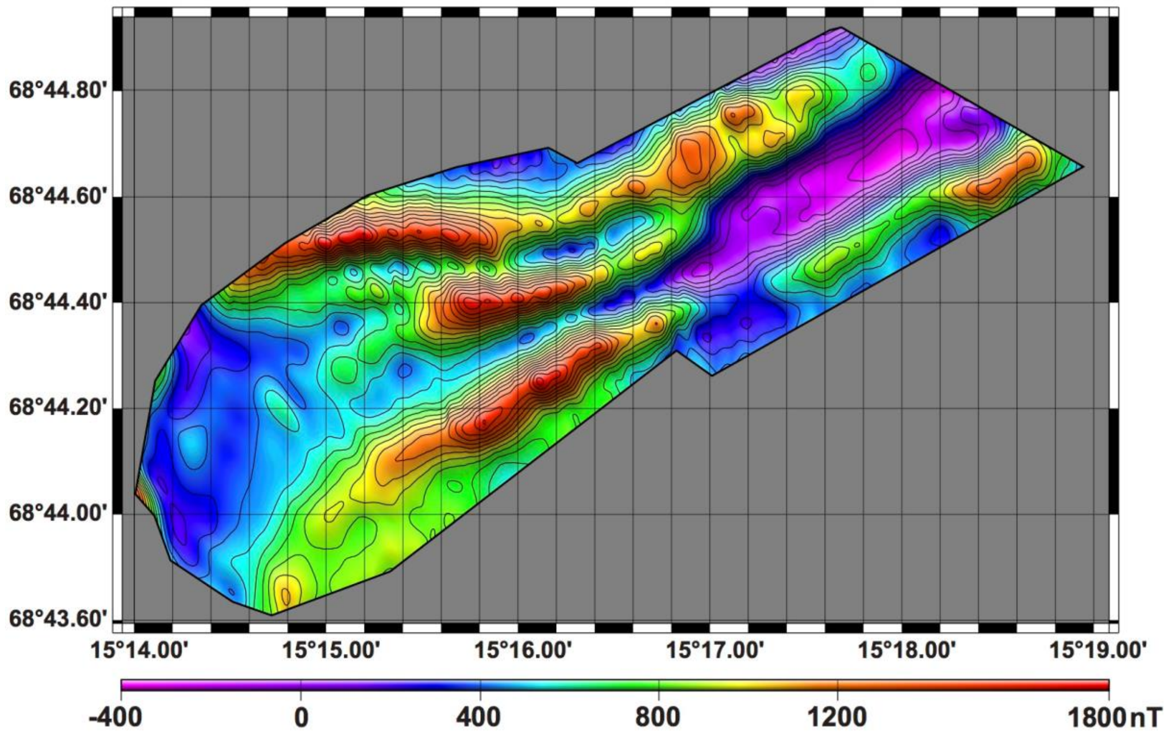
3.3 Magnetic data processing, gridding and presentation

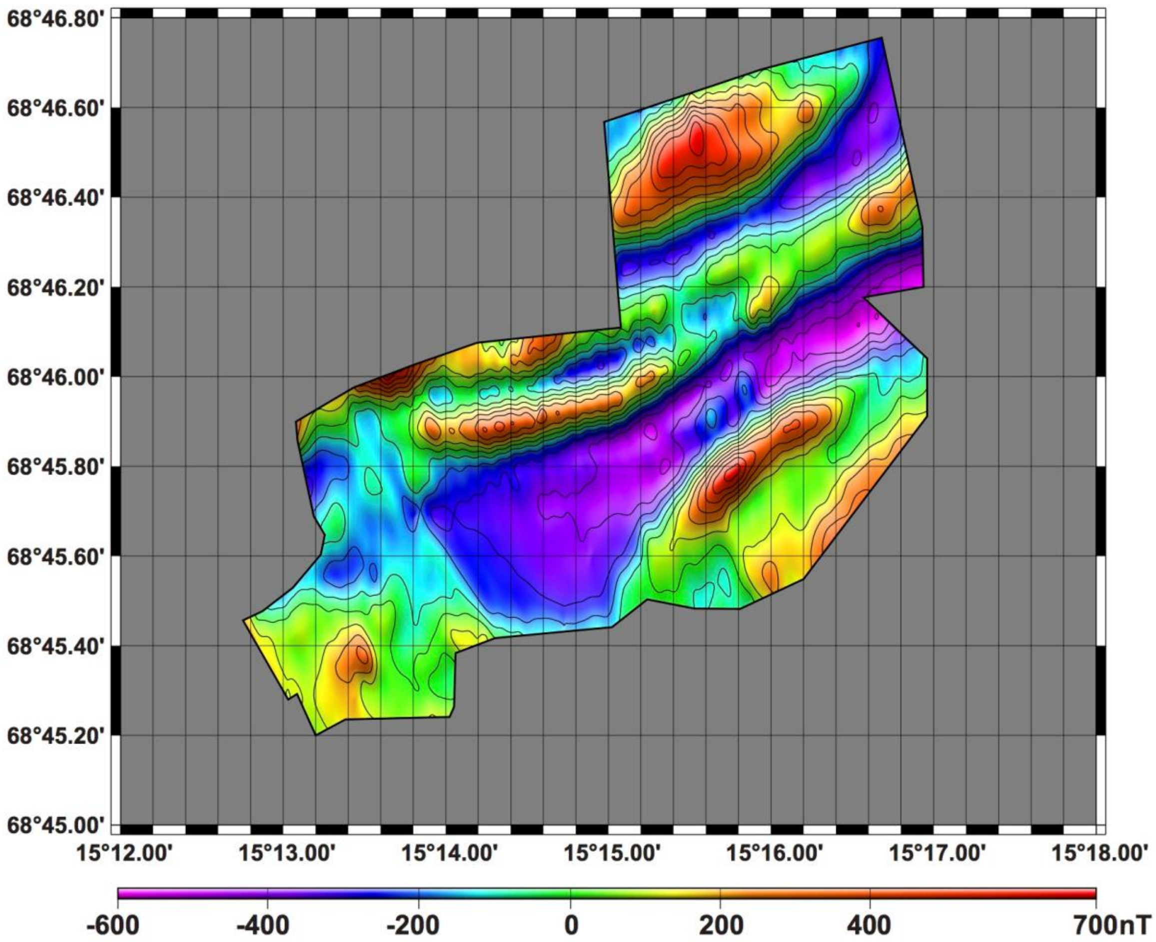
The total field magnetic anomaly data were calculated from the temporal corrected data after subtracting the IGRF for the surveyed area calculated for the data period (eq.2)

$$\mathbf{B}_{TA} = \mathbf{B}_{Tc} - IGRF \quad (2)$$

IGRF 2015 model was employed in these calculations, to ensure that the total data set would match the previously processed and earlier published surrounding data sets.

The total field anomaly data were split into lines and then were gridded using a minimum curvature method with a grid cell size of 10 meters. This cell size is a third of the 30 meters average line spacing for the main survey area. For the high-resolution data, the cell size is exactly half of the route spacing. The micro-leveled data were later gridded using minimum curvature algorithm (Figure 6A; B and C).





68°46.80'
68°46.60'
68°46.40'
68°46.20'
68°46.00'
68°45.80'
68°45.60'
68°45.40'
68°45.20'
68°45.00'
15°12.00'
15°13.00'
15°14.00'
15°15.00'
15°16.00'
15°17.00'
15°18.00'
-600
-400
-200
0
200
400
700nT

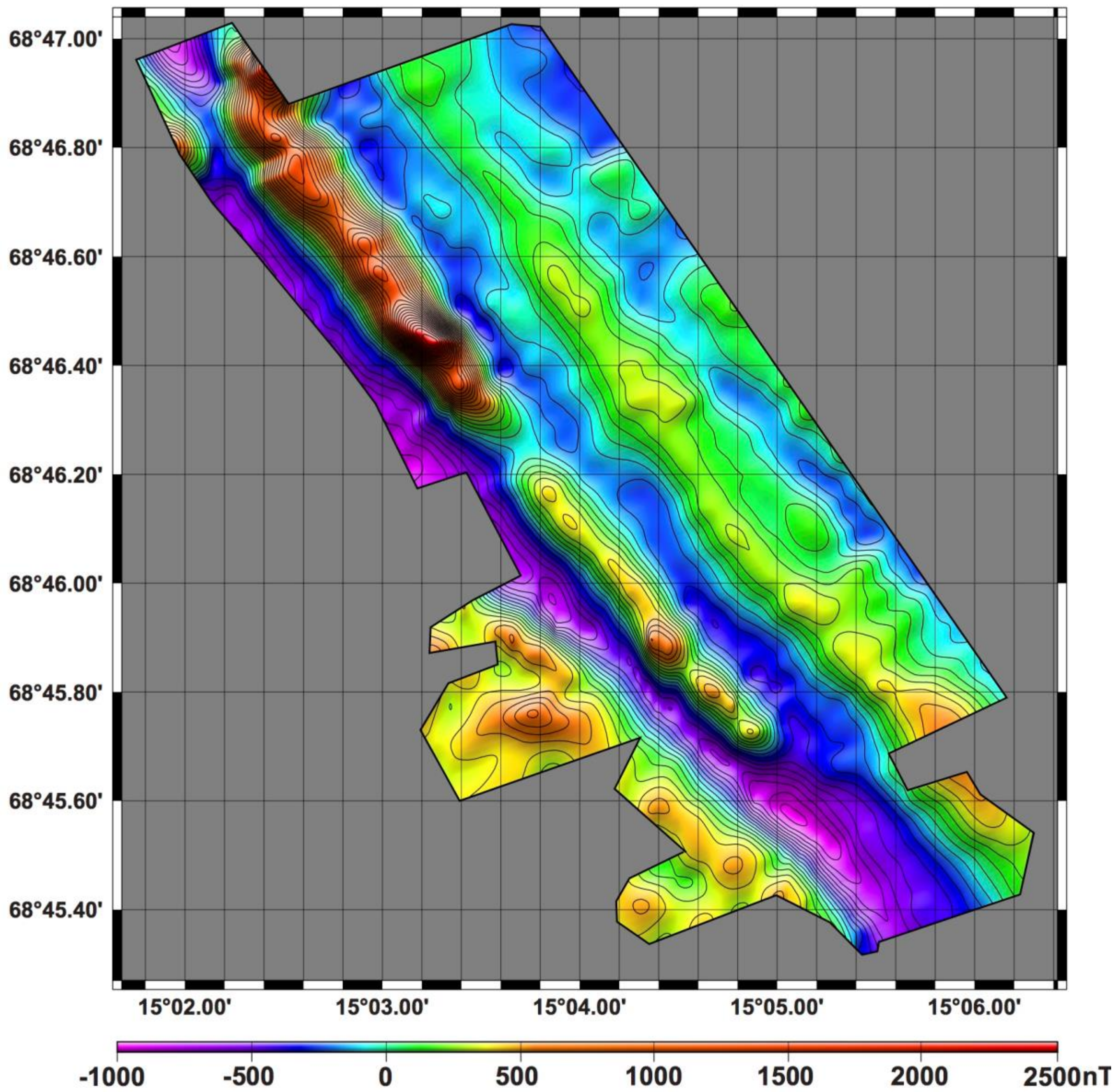


Figure 5: Processed magnetic anomaly maps of the survey area. The graphite deposits are associated with the large magnetic anomaly lows visible on the three maps.

4. CONCLUSION

This drone-based aeromagnetic survey was part of a larger project led by V. Baranwal (NGU), and this report will contribute to a comprehensive publication once the overall project is completed.

The survey was conducted using UGcS software, which enabled topographic draping and allowed the drone to maintain a constant altitude above the complex terrain. Without this software, navigating the rugged landscape would have been impossible. Unfortunately, the drone suffered two crashes, both resulting from mechanical failures that caused one of the propellers to stop mid-flight. Although it remains unclear which specific propeller malfunctioned, it is likely that both crashes were caused by the same issue, indicating the presence of an intermittent mechanical fault. Fortunately, after the first crash, despite damaged legs, the drone remained operational, allowing the survey to continue. After the second crash, the drone was sent to DJI's repair center in the Netherlands for inspection and repairs.

However, this experience highlighted the importance of conducting drone fieldwork sessions with two drones, one serving as a backup. While drones are incredibly useful, they are also delicate and prone to damage, especially when used extensively in challenging conditions. If a critical failure occurs early during fieldwork—especially in remote locations—it can lead to significant financial loss. For example, following the crash in Vesterålen, a drone rental was necessary to continue with other planned surveys. Moving forward, it is crucial to discuss the best strategy for future operations: whether to purchase an additional drone equivalent to the DJI M300 or rely on rentals. This incident has emphasized the need for greater foresight and preparedness when conducting drone-based surveys.

REFERENCES

Thebault, E. *et al*. (2015) International Geomagnetic Reference Field: The 12th generation. *Earth, Planets and Space* 67, https://doi.org/10.1186/s40623-015-0228-9.

Appendix A1: Flow chart of magnetic processing

Meaning of parameters is described in the referenced literature.

Processing flow:

1. Quality control.
2. Visual inspection of airborne data and manual spike removal
3. IGRF removed.
4. Splitting flight data by lines
5. Gridding
6. Microlevelling

Databases description:

Database_Database_Vesteralen1_Intermediate.txt, Database_Vesteralen2_Intermediate.txt and Database_Vesteralen3_Intermediate.txt: Lat, Long, General Index, Magnetometer Index, Date, GPS Time, Lat (UTM), Long (UTM), Topo (m), Drone altitude agl (m), Drone altitude amsl (m), Sensor 1 X component, Sensor 1 Y component, Sensor 1 Z component, Sensor 1 Total field, Sensor 2 X component, Sensor 2 Y component, Sensor 2, Z component, Sensor 2 Total field, IGRF, Diurnal variations, Sensor 1 Total field – IGRF, Sensor 2 Total field – IGRF.

Database_Vesteralen1_Final.txt, Database_Vesteralen2_Intermediate.txt and Database_ Vesteralen3_Intermediate.txt: Lat, Long, General Index, Magnetometer Index, Date, GPS Time, Lat (UTM), Long (UTM), Topo (m), Drone altitude agl (m), Drone altitude amsl (m), IGRF, Temporal variations, Sensor 1 X component, Sensor 1 Y component, Sensor 1 Z component, Sensor 1 Total field, Sensor 1 Total field - IGRF, Sensor 1 Total field Final microleveled, Sensor 2 X component, Sensor 2 Y component, Sensor 2, Z component, Sensor 2 Total field, Sensor 2 Total field - IGRF, Sensor 2 Total field Final microleveled.

Note: In the processed database, only useful data have been kept, i.e., transit flights from and to the take-off point have been removed, as well as all the time the magnetometer was recording data but the drone was standing idle on the ground for battery changing.

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/