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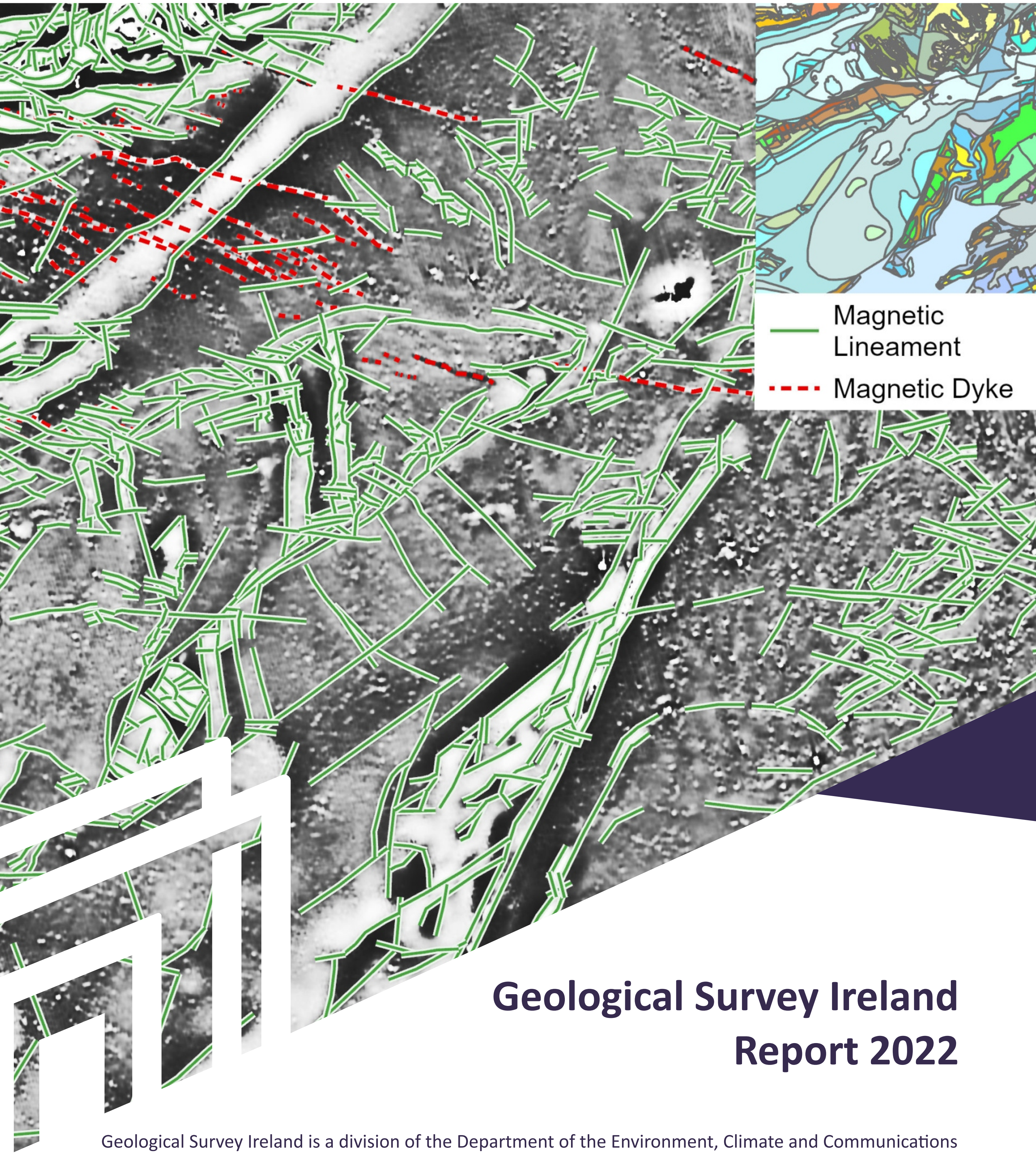
Northwest MPM Project: Structural Lineament Maps Derived from Tellus Airborne Projects



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The Tellus Project

Tellus is a national programme to gather geochemical and geophysical data across the island of Ireland. The survey examines the chemical and physical properties of our soils, rocks and waters to inform the management of Ireland's environment and natural resources. The project is managed by Geological Survey Ireland and is funded by the Department of Environment, Climate and Communications (DECC).

For more information on the Tellus Project please visit www.gsi.ie/tellus.

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1. Summary

Structural lineaments have been picked in Tellus airborne geophysical maps across the Northwest Mineral Prospectivity Mapping (NW MPM) project area (Figure 1.1). The area is approximately 21,500 km^2 in size and lies in the northwestern region of Ireland. Two geophysical datasets were utilised, magnetics and electromagnetics (EM), and in each case several different numerical filters were applied to the geophysical maps to enhance or emphasise different structural features present in the data. Both geophysical datasets provide certainty that the lineaments identified and picked are located in bedrock (i.e., the structures are not associated with variations and patterns present in Quaternary sediments and overburden). The maximum depth of sensitivity (investigation) provided by the electromagnetic data is of the order of ~100 m, and for the magnetic data is, in places, as deep as several kilometers.

The approach adopted in picking lineaments in the maps was to focus exclusively on "structural" lineaments (inferred to be associated with faults and fractures) and to avoid lineaments most likely associated with sedimentary or igneous stratigraphy (layering) or unconformities. The distinction between the two is not always unambiguous in the geophysical maps and, in cases of ambiguity, an element of interpretive judgement was required to avoid picking sedimentary/igneous layering (based on available 1:100K and 1:50K geological mapping and the shape and form of the geophysical anomalies themselves).

The airborne survey geometry, with a flight line orientation of N15°W, is associated with a systemic bias against lineaments oriented N15°W. While some lineaments with this orientation are retained in the geophysical maps (for example, faulted edges of larger geological bodies), the lineament maps produced are characterised by a relatively small number of lineaments oriented on or close to N15°W. The Tellus flight line orientation of N15°W was chosen as it runs perpendicular to the main Caledonian trends which dominate over much of the island of Ireland.

The output of the work consists of three separate sets of picked structural lineaments that are delivered in a file geodatabase (.gdb) and as separate Esri shapefiles (.shp). Maps of each set of lineaments are shown in Appendices 1 – 3.

(i) Magnetic lineaments (picked with the intention of excluding unambiguous igneous dykes)

File: [NW_MPM_magnetic_dykes.shp]

(ii) Magnetic dykes (where the observed lineaments are unambiguously associated with dykes)

File: [NW_MPM_magnetic_lineaments]

(iii) Electromagnetic (resistivity) lineaments

File: [NW_MPM_em_lineaments.shp]

File Geodatabase

File: [NW_MPM_Geophysical_Lineaments_Vector_Data.gdb]

A range of magnetic and electromagnetic map images (Table 2.1), which formed the basis of the lineament picking, are also provided as an output, in georeferenced tiff (.tif) format, to facilitate comparison and interrogation of the lineaments and structural patterns against the original source data. It is recommended that users of the lineament datasets refer to the geophysical map images when using or considering the lineament patterns.

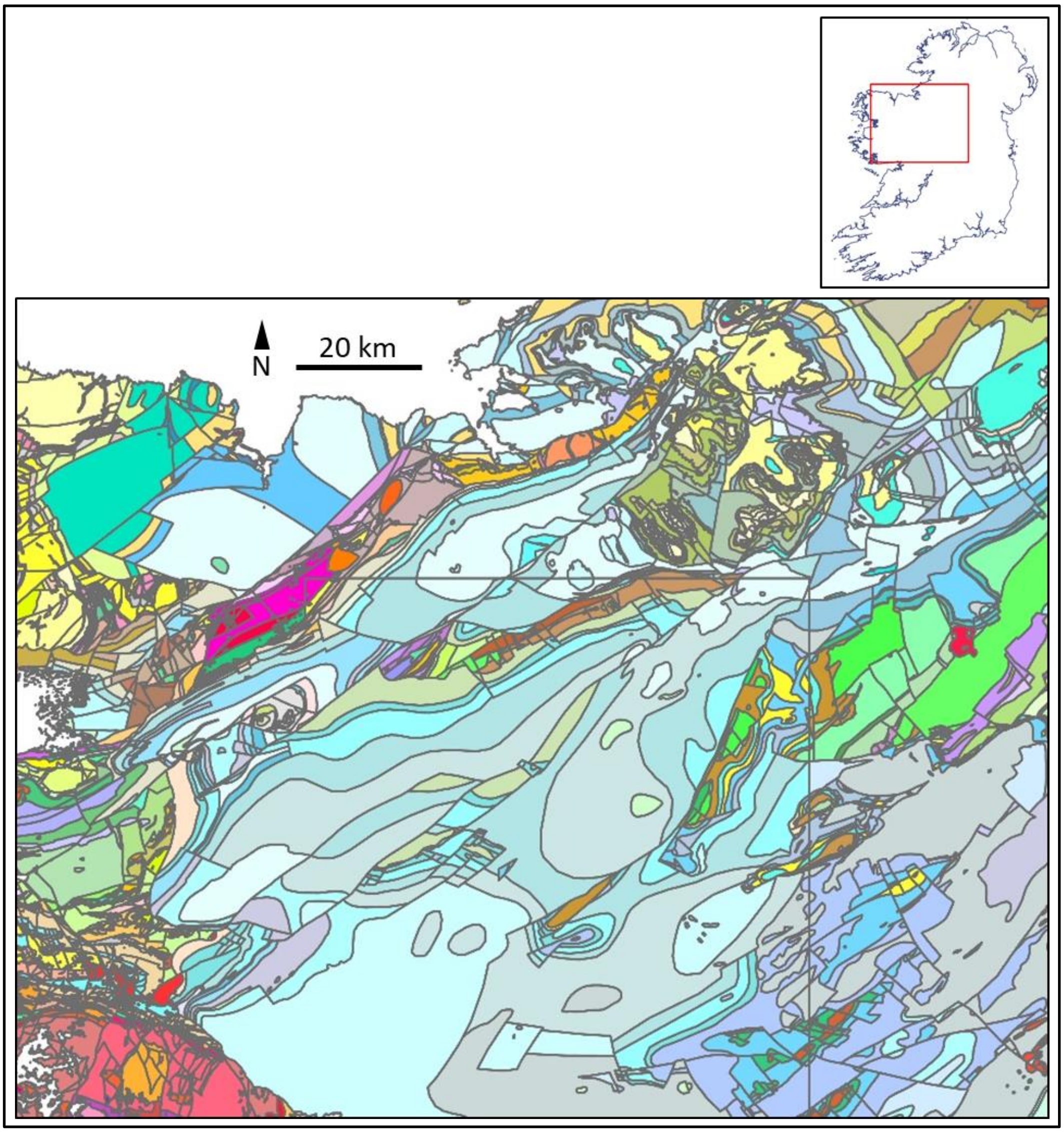


Figure 1.1: Inset map: Location of Northwest Mineral Prospectivity Mapping (NW MPM) project area (red polygon). Main map: Bedrock geology of NW MPM area, taken from GSI 1:100K and 1:50K North Midlands geology maps (note polygon boundary around the 1:50K map, occupying the southwestern quadrant of the area).

2. Geophysical Maps

Structural lineaments have been picked in airborne geophysical maps from the Tellus Programme. The Tellus programme is a national airborne geophysical survey and ground geochemical survey managed by Geological Survey Ireland. Geophysical data, comprising magnetics, electromagnetics and gamma-ray spectrometry, are collected on an annual basis in a series of discrete survey blocks that are subsequently merged together on completion of each block.

Airborne magnetic and electromagnetic (resistivity) maps, with a range of different filters applied, provided the basis for the structural lineament picking. The primary map products used are summarised in Table 2.1 and are delivered as a supplementary output, to provide opportunity to examine the lineaments with respect to the source maps and to potentially refine them if and as needed.

Table 2.1: Summary of primary geophysical map products used for lineament picking.

Map No.	Map Description [filename in brackets]	Comment
	MAGNETICS	
1	**Total Magnetic Intensity (TMI)**, Reduced-to-Pole, Low-Pass filter (reject wavelengths < 250 m), equal area colour distribution in colour. [MAG_MERGE2021_RTP_LP_COL.tif]	Colour map provides visibility of lineaments associated with long-wavelength, deep-seated features.
2	**Vertical Derivative (order = 0.5, by Fourier transform)** of TMI Map 1, equal area colour distribution in colour. [MAG_MERGE2021_RTP_LP_VD05_COL.tif]	Low-order (moderate) vertical derivative enhances resolution and clarity of anomalies and lineaments in the map, without significantly subduing long-wavelength, deep-seated features.
3	**Vertical Derivative (order = 1, by convolution)** of TMI Map 1, equal area colour distribution in grey-scale. [MAG_MERGE2021_RTP_LP_VD1C_BW.tif]	Vertical derivative enhances resolution and clarity of anomalies and lineaments in the map, but with some loss of imaging of long-wavelength, deep-seated anomalies. Grey-scale palette reveals a wide

		range of variation in texture and tone in the map.
4	**<u>Vertical Derivative (order = 1.5, by Fourier transform)</u>** of TMI Map 1, equal area colour distribution in grey-scale. [MAG_MERGE2021_RTP_LP_VD15_BW.tif]	Intermediate strength vertical derivative further enhances resolution of lineaments, and retains significant textural and tonal variations across the map.
5	**<u>Vertical Derivative (order = 2, by convolution)</u>** of TMI Map 1, equal area colour distribution in grey-scale. [MAG_MERGE2021_RTP_LP_VD2C_BW.tif]	High-order (strong) vertical derivative further enhances resolution of lineaments, but subdues textural and tonal variations across the map. Magnetic response of deeper-sourced anomalies is increasingly attenuated as strength of vertical derivative is increased (from order = 0.5 to order = 2) and is absent in order = 2 map.
	ELECTROMAGNETICS	
6	**<u>3 kHz resistivity</u>**, equal area colour distribution in grey-scale. [2F_RES3_MERGE_2019B_IDW.tif]	Depth of sensitivity in maps estimated ~30 – 100 m. Grey-scale palette reveals a wide range of variation in texture and tone in the map.
7	**<u>12 kHz resistivity</u>**, equal area colour distribution in grey-scale. [2F_RES12_MERGE_2019B_IDW.tif]	Depth of sensitivity in maps estimated ~20 – 50 m. Grey-scale palette reveals a wide range of variation in texture and tone in the map.
8	**<u>Vertical Derivative (order = 0.25, by Fourier transform)</u>** of 3 kHz Map 6, equal area colour distribution in grey-scale. [ZD025_2F_RES3_MERGE_2019B_IDW.tif]	Low-order (moderate) vertical derivative enhances the resolution and clarity of anomalies and lineaments in the map.
9	**<u>Vertical Derivative (order = 0.25, by Fourier transform)</u>** of 12 kHz Map 7, equal area colour distribution in grey-scale. [ZD025_2F_RES12_MERGE_2019B_IDW.tif]	Low-order (moderate) vertical derivative enhances the resolution and clarity of anomalies and lineaments in the map.

10	**<u>Vertical Derivative (order = 0.75, by Fourier transform)</u>** of 3 kHz Map 6 with Low-Pass filter (reject wavelengths < 250 m), equal area colour distribution in grey-scale. [ZD075_BWLP250_2F_RES3_MERGE_2019B_IDW.tif]	Higher-order vertical derivative further enhances resolution of lineaments, but subdues the textural and tonal variations across the map.
11	**<u>Vertical Derivative (order = 0.75, by Fourier transform)</u>** of 12 kHz Map 7 with Low-Pass filter (reject wavelengths < 250 m), equal area colour distribution in grey-scale. [ZD075_BWLP250_2F_RES12_MERGE_2019B_IDW.tif]	Higher-order vertical derivative further enhances resolution of lineaments, but subdues the textural and tonal variations across the map.

As the NW MPM area straddles a number of Tellus survey blocks (Northern Ireland, Tellus Border, Cavan, North Midlands, A1, A2 and A3), the available merged magnetic (2021) and EM (2019B) datasets were used, clipped to the boundaries of the NW MPM area (Figure 2.1).

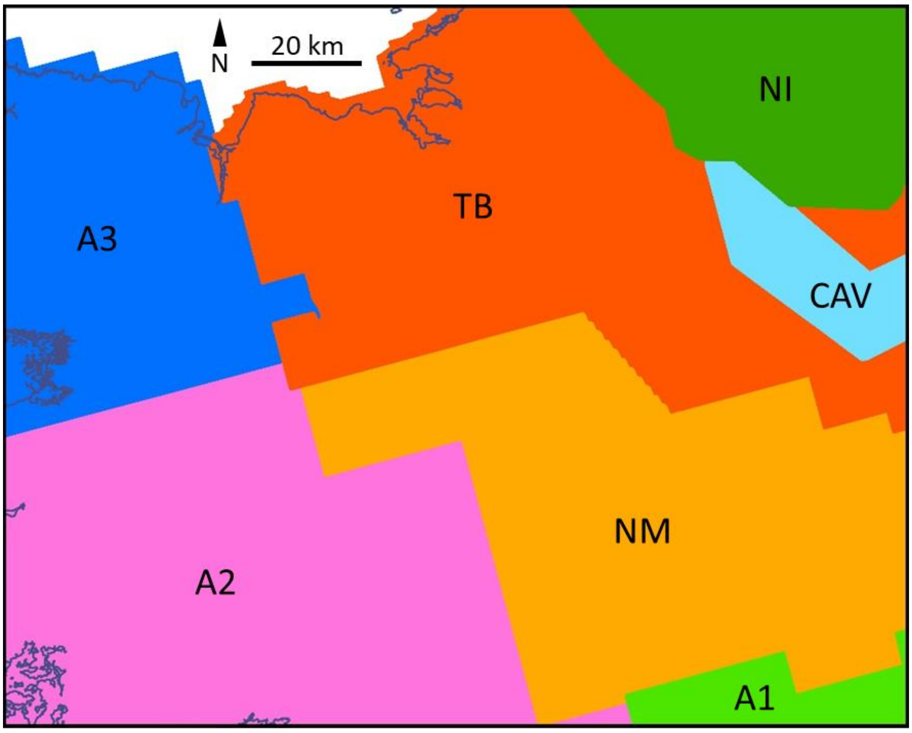


Figure 2.1: Northwest MPM project area – Tellus airborne survey blocks providing geophysical data coverage of the area: Northern Ireland (NI, dark green), Tellus Border (TB, red), Cavan (CAV, light blue), North Midlands (NM, orange), A1 (light green), A2 (purple) and A3 (dark blue). Irish coastline shown (dark grey lines).

While the EM resistivity data were clipped to the coastline (as no geological signal is recorded from beneath seawater in EM data), the full extents of the offshore magnetic data were retained as magnetic anomalies imaged offshore provide good constraints when picking lineaments in the vicinity of the coastline on the northwestern and western edges of the MPM area. Data in the EM resistivity maps are also blanked where flight altitude is greater than 150 m above ground level, to remove unreliable resistivity estimates due to low EM signal strengths at high flight altitudes.

Magnetic Maps

Total Magnetic Intensity (TMI) data were gridded to a 50 x 50 m cell mesh (Minimum Curvature algorithm), reduced-to-the-pole and low-pass filtered (wavelengths < 250 m rejected) to produce the initial magnetic map for the lineament analysis (Map 1, Table 2.1). All subsequent maps were derived from this TMI map. The reduction-to-the-pole filter has the effect of re-positioning magnetic anomalies symmetrically and directly over their causative subsurface bodies, allowing lineaments to be picked with a more accurate spatial association with edges and boundaries of bodies in the subsurface. The low-pass filter removes very short wavelength features, generally associated with cultural (man-made) noise in the TMI grid, and is a necessary data pre-conditioner prior to the application of derivative (sharpening) filters. The TMI map is most useful for identifying the edges of deep-seated magnetic bodies that are characterised by long-wavelength anomalies (responses).

A number of vertical derivative (gradient) filters, of increasing order (strength), were applied to the TMI grid to produce maps in which the resolution and clarity of magnetic anomalies and lineaments is enhanced, particularly for shallower magnetic bodies (Maps 2, 3, 4 and 5, Table 2.1, for derivative orders = 0.5, 1, 1.5 and 2 respectively). Visibility of subtle magnetic features, not readily apparent in the TMI map, is greatly improved in the derivative maps. The magnetic response of deeper-sourced anomalies is, however, increasingly subdued as the strength of the derivative filter is increased (from order = 0.5 to order = 2).

The position of anomalies with respect to their subsurface causative features remains unchanged by the application of vertical derivative filters. The filters also do not generate any directional bias in the enhancement of lineaments and features in the magnetic maps (in contrast, for example, with horizontal directional derivative filters, which preferentially enhance features striking perpendicular to the direction of filter application).

Two example magnetic map products covering the NW MPM area are shown in Figure 2.1.

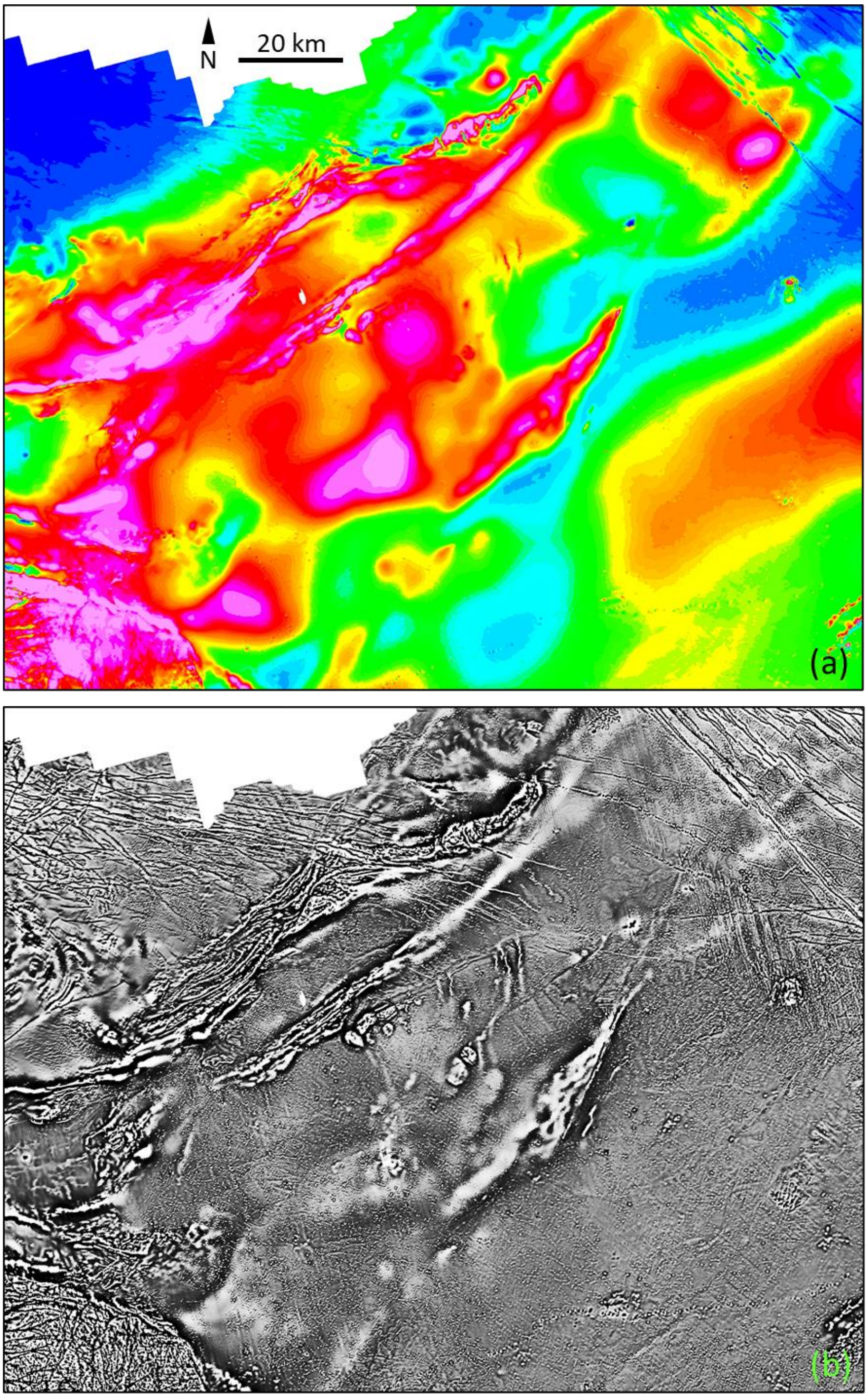


Figure 2.1: Northwest MPM project area – magnetic data. (a.) Total Magnetic Intensity (Map 1, Table 2.1), colour-scale with negative values = blue and positive values = red. (b) Vertical derivative (order = 1.5) of TMI (Map 4, Table 2.1), grey-scale with negative values = black and positive values = white.

Electromagnetic Resistivity Maps

Resistivity data at 3 and 12 kHz were gridded to a 50 x 50 m cell mesh (Inverse Distance Weighted algorithm), to produce two initial resistivity maps for the lineament analysis (Maps 6 and 7, Table 2.1). All subsequent maps were derived from these two resistivity maps. The 3 and 12 kHz data are preferred for the lineament analysis for both practical and technical reasons. From a practical perspective, these are the only two frequencies recorded in Northern Ireland and therefore able to provide complete coverage over the NW MPM area. Technically, of the other two EM frequencies available in the Republic, the deeper-imaging 0.9 kHz data are characterised by greater cultural (man-made) noise levels and weaker geological signal strengths and provide a poorer basis for lineament picking, and the shallower-imaging 25 kHz data are likely, particularly for low subsurface resistivities, to be sensitive to features in the Quaternary sediments and overburden, rather than bedrock.

Sensitivity analysis of resistivity models produced by formal inversion of the Tellus EM data (in A5, A6 and Waterford blocks) suggests that lineaments picked in the resistivity maps at frequencies of 3 and 12 kHz can be regarded as broadly reflecting geological structures found in the depth range 20 – 100 m.

Similar to the treatment of the magnetic data and with the same objective of enhancing the resolution and clarity of resistivity anomalies and lineaments, two vertical derivative filters, of increasing order (strength), were applied to the resistivity maps at each frequency (Maps 8, 9 and 10, 11, Table 2.1, for filter orders = 0.25 and 0.75 respectively). As the vertical derivative filter, particularly at higher orders, has the effect of simultaneously enhancing short-wavelength noise in the maps, a noise-rejection low-pass filter (wavelengths < 250 m rejected) was applied prior to application of the order = 0.75 vertical derivative filter.

Two example resistivity map products covering the NW MPM area are shown in Figure 2.2.

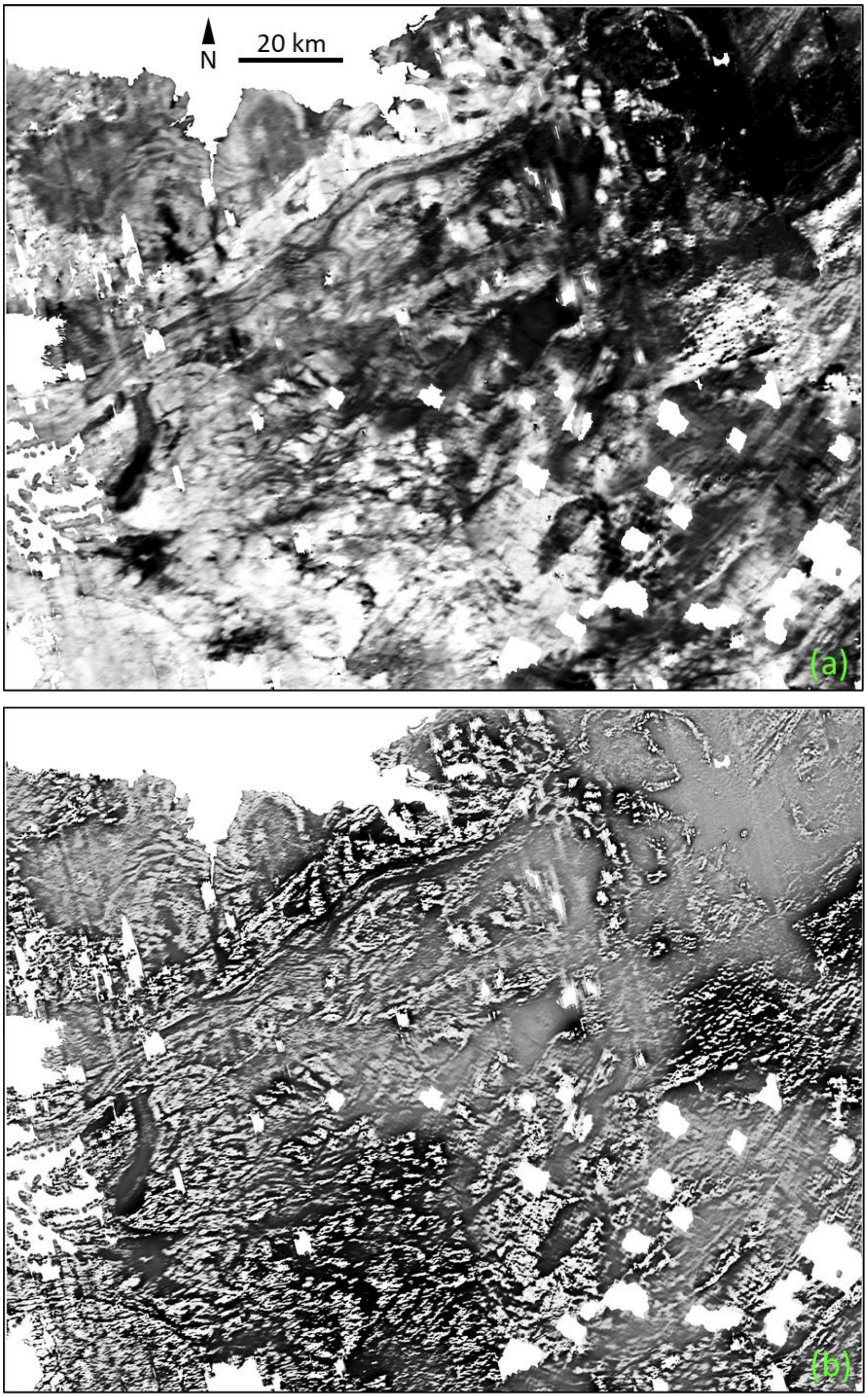


Figure 2.2: Northwest MPM project area – electromagnetic resistivity data at 12 kHz. (a.) Resistivity (Map 7, Table 2.1), grey-scale with low values = black and high values = white. (b) Vertical derivative (order = 0.75) of resistivity (Map 11, Table 2.1), grey-scale with low values = black and high values = white. Blank areas, located away from seawater, correspond with areas where survey altitude was greater than 150 m, where resistivity estimates are generally unreliable and have been removed.

3. Lineament Picking

The objective in picking lineaments in the geophysical maps has been to identify exclusively "structural" lineaments (inferred to be associated with faults and fractures) and to avoid lineaments most likely associated with sedimentary or igneous stratigraphy (layering) or unconformities. The distinction between the two is not always unambiguous in the geophysical maps. In cases of ambiguity, an element of interpretive judgement (based on available 1:100K and 1:50K geological mapping and the shape and form of the geophysical anomalies themselves) was required to avoid picking sedimentary/igneous layering as far as possible. While the 1:100K and 1:50K bedrock geological maps provides a good basis for identifying stratigraphic layering in the case of the resistivity (electromagnetic) maps and in areas characterised by shallow-sourced magnetic anomalies, it provides no constraint on the origin of magnetic anomalies located beneath or within the Carboniferous sedimentary basins in the MPM area. Evidence in the magnetic maps indicates that there is little intrinsic magnetisation associated with the Carboniferous limestone and sandstone lithologies themselves.

The majority of magnetic anomalies (and hence lineaments) within the areas of the Carboniferous basins are inferred to originate either (i) in the basement beneath the Carboniferous sediments or (ii) within the Carboniferous sediments and possibly corresponding with blind (sub-cropping at depth) igneous dykes or structures carrying magnetic minerals. Depths to magnetic sources within the basement to the Carboniferous have not been estimated as part of this lineament study, but could be addressed by formal modelling of the magnetic anomalies in future work.

Whether picked magnetic lineaments within the areas of the Carboniferous basins correspond with deep magnetic basement structures or with shallower magnetic features located within the Carboniferous sediments, can be assessed by comparing the lineaments with the magnetic TMI map (Map 1, Table 2.1). If a lineament is observed to demarcate the edge of a long-wavelength anomaly in the TMI map, it can be taken as indicating a structure located in the magnetic basement to the Carboniferous sediments. The possibility of such a deep lineament/structure extending upwards into the overlying Carboniferous sediments is not precluded – it is just that the upward development of the structure, if present, is not visible in the magnetic data. Lineaments that are visible as fine features in the magnetic vertical derivative maps, but are not visible in the TMI map, are most likely to correspond with structures located within the Carboniferous sediments.

Grey-scale images have been preferred for lineament picking for all the maps, with the exception of the magnetic TMI and order = 0.5 vertical derivative maps (Maps 1 and 2, Table 2.1) where a colour palette was found best in highlighting the edges of deep-seated magnetic bodies that are characterised by long-wavelength anomalies. A grey-scale palette reveals a wide range of variation in geophysical (and hence geological) texture and tone in the maps, allowing different types of lineaments to be identified and mapped. Lineaments, which may be straight-line or curved to varying degrees, generally express themselves in the following ways (with reference to examples shown in Figures 3.1 – 3.5):

(i) Lineaments associated with igneous dykes (magnetic data only) (Figure 3.1). Thin dykes correspond with distinct, narrow, linear, high-amplitude magnetic anomalies. The anomalies may be positive or negative in polarity. Negative anomalies indicate strong remanent magnetisation corresponding with reverse polarity of the Earth's magnetic field at the time of dyke emplacement. Positive anomalies may indicate either strong induced magnetisation aligned parallel with the Earth's present day magnetic field or strong remanent magnetisation corresponding with normal polarity of the Earth's magnetic field at the time of dyke emplacement, or a combination of the two.

Two significant, largely reverse (negative) polarity, dyke swarms are present in the NW MPM area. The first is located in the northeastern corner of the area, with a predominant NW – SE strike orientation. The second is in the northwestern corner, with a predominant WNW – ESE trend, becoming more W – E or NW – SE in places, with several perpendicular dykes (oriented NNE – SSE) present in the northwestern-most corner. Dykes in the second swarm are observed to become normal (positive) polarity towards the eastern-most extremity of the swarm.

Magnetic lineaments unambiguously associated with dykes, as described above, have been picked separately from all other magnetic lineaments and may be found as a stand-alone set of lineaments in the database file [NW_MPM_magnetic_dykes.shp].

No visible expression of the dykes is found in the electromagnetic maps, indicating that the dykes are very narrow or provide little resistivity contrast with their host rocks, or both.

(ii) Lineaments associated with the disruption of a series of anomalies along the length of a fault/fracture (Figure 3.2). The disruption may or may not be associated with a clearly resolved offset of the anomalies across the lineament.

(iii) Lineaments associated with sharp and distinct, straight or curved edges to anomalies (Figure 3.3), inferred to correspond with faulted boundaries to geological units.

(iv) Lineaments in an otherwise uniform resistivity or magnetic host "background" (Figure 3.4). These lineaments are typical, in resistivity data, of conductive fractures/faults in resistive limestone or resistive igneous intrusions or, in magnetic data, of non-magnetic fractures/faults in magnetic igneous intrusions.

(v) An arrangement or geometry of juxtaposed anomalies with different orientations, which suggests the presence of a fault between the anomalies (Figure 3.5). In cases, the alternative possibility that the geometry might be satisfied by an unconformity cannot be ruled out, based on available knowledge.

Longer, regional lineaments may be associated with several forms of expression along their length. For example, an alternation between forms (ii) and (iii) above, along the length of longer lineaments, is fairly typical in the data.

Lineaments oriented parallel to the flight line direction (N15°W) are poorly imaged and resolved in the geophysical maps. Fine geophysical anomalies oriented N15°W will generally be removed by the levelling processes applied to the airborne data to (intentionally) remove line-to-line variations arising from the data acquisition geometry (e.g., small line-to-line altitude variations). While lineaments associated with the edges of larger geological bodies (form (iii) above) that are aligned N15°W will be retained in the geophysical maps, the lineament maps are characterised by a relatively small number of lineaments oriented N15°W.

While moderate differences exist in the depths of imaging of the 12 and 3 kHz EM resistivity maps (estimated ~20 – 50 m and ~30 – 100 m respectively), these two frequencies have been used interchangeably, with lineaments picked in the map providing the best resolution and clarity of particular features. Given the 50 m spatial resolution of the maps and the regional scale of the investigation, any lateral shifts in the location of lineaments between the two different frequency (and therefore depth) maps, resulting from potential dip of the structures, are felt to be negligible.

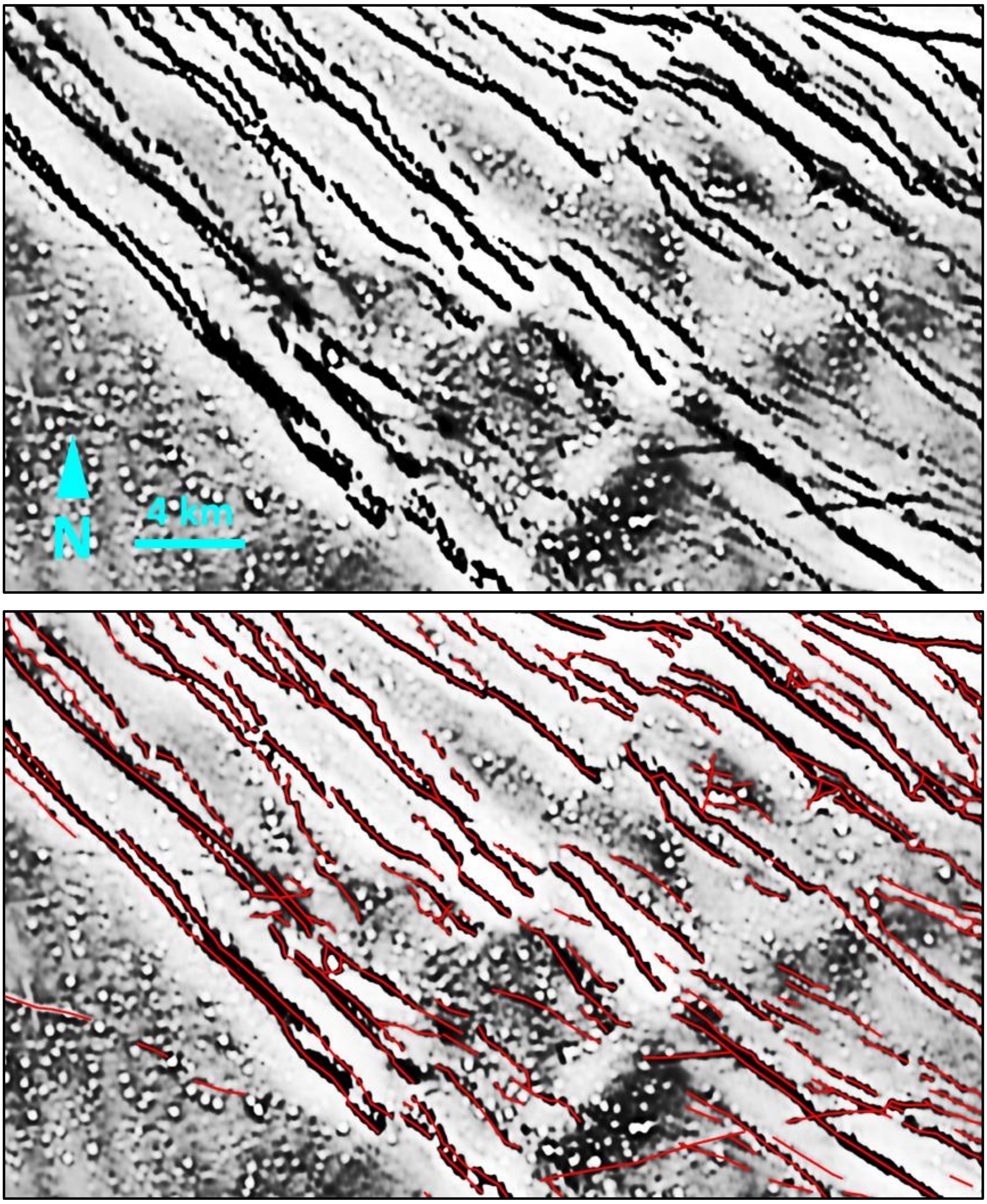


Figure 3.1: Portion of vertical derivative (order = 1) of Total Magnetic Intensity (Map 3, Table 2.1), grey-scale with negative values = black and positive values = white. Lineaments (red lines, in lower figure) correspond with igneous dykes that, in this area, are characterised by strong reverse (negative) polarity. White spots or blobs in the image correspond with cultural (man-made) magnetic noise.

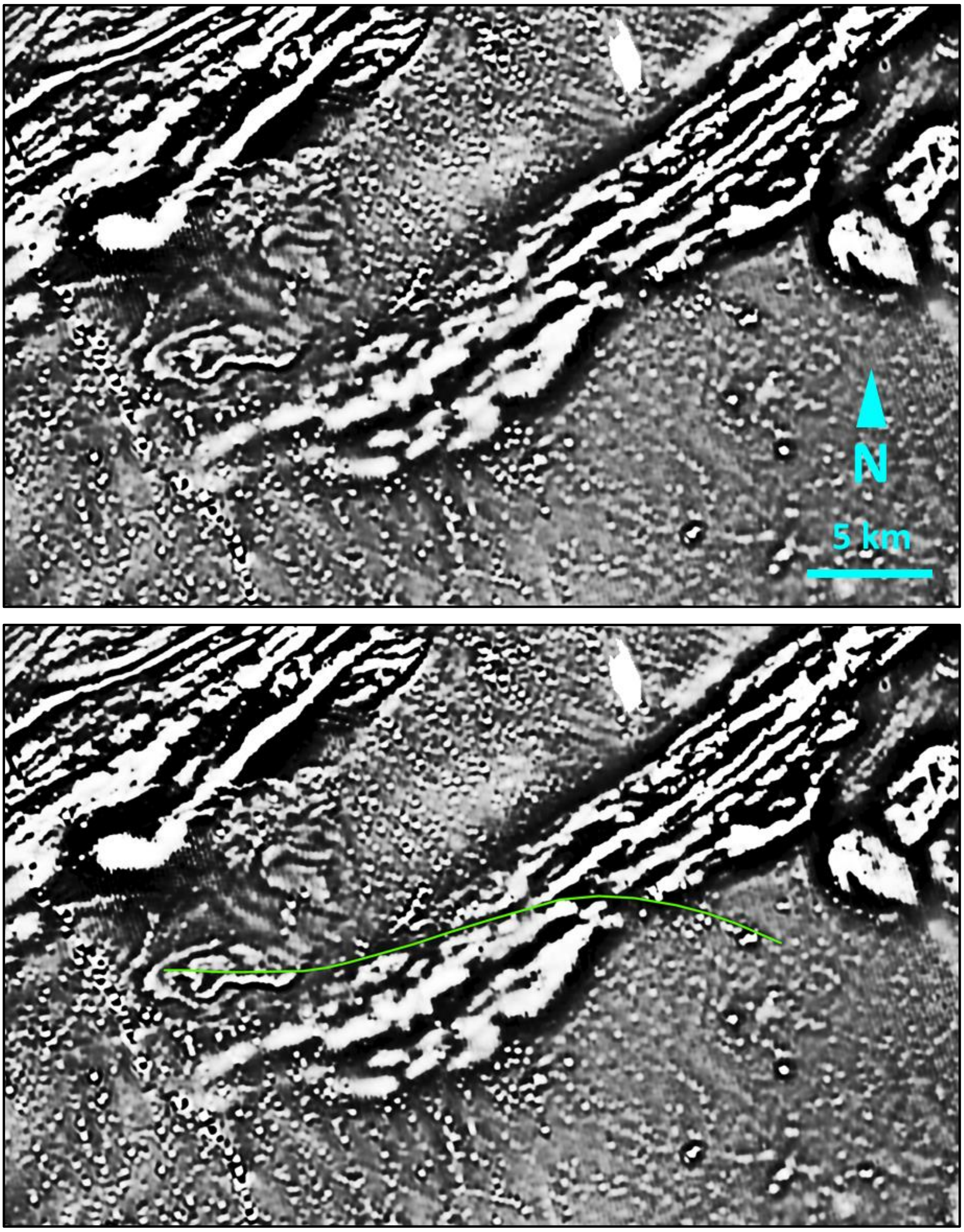


Figure 3.2: Portion of vertical derivative (order = 1.5) of Total Magnetic Intensity (Map 4, Table 2.1), grey-scale with negative values = black and positive values = white. The single illustrative lineament (green line, in lower figure) tracks through the disruption of a series of anomalies along the length of the fault/fracture.

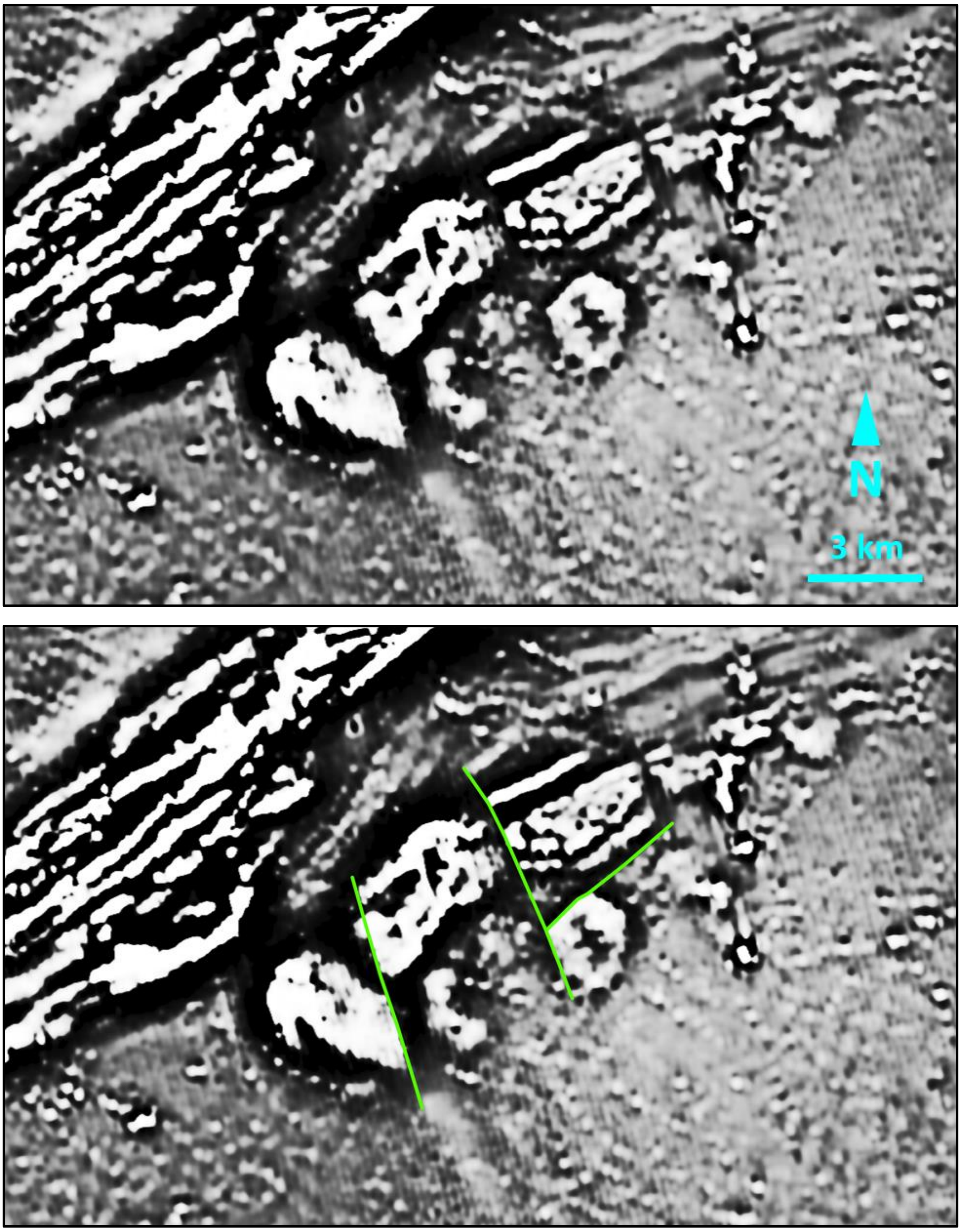


Figure 3.3: Portion of vertical derivative (order = 1.5) of Total Magnetic Intensity (Map 4, Table 2.1), grey-scale with negative values = black and positive values = white. Several illustrative lineaments (green lines, in lower figure) track sharp and distinct edges to anomalies, inferred to correspond with faulted boundaries to geological units.

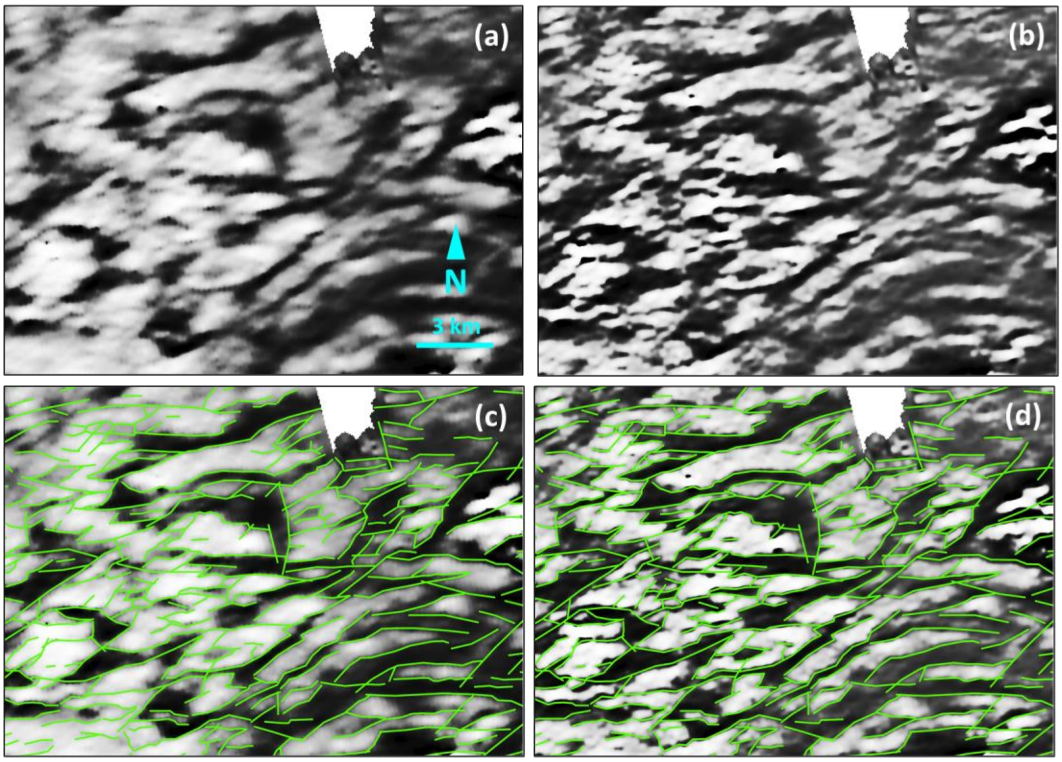


Figure 3.4: Portion of 12 kHz resistivity data with (a.) vertical derivative (order = 0.25) (Map 9, Table 2.1) and (b.) vertical derivative (order = 0.75) (Map 11, Table 2.1), grey-scale with low values = black and high values = white. (c. and d.) Lineaments (green lines) track conductive features interpreted to correspond with fault and fracture patterns within highly resistive Carboniferous limestone lithologies. The white area on the northern edge of the map consists of data nulled above 150 m flight altitude.

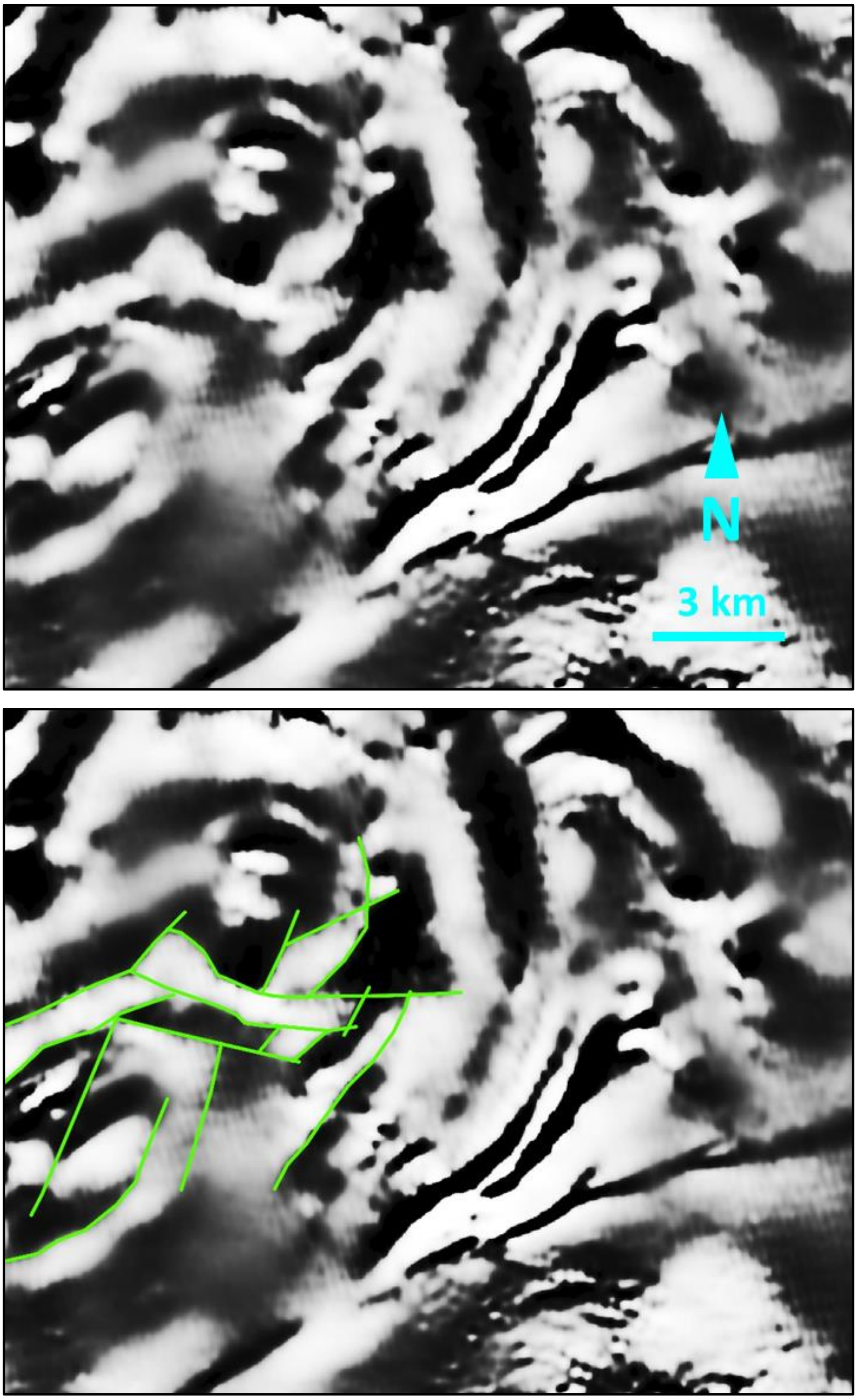
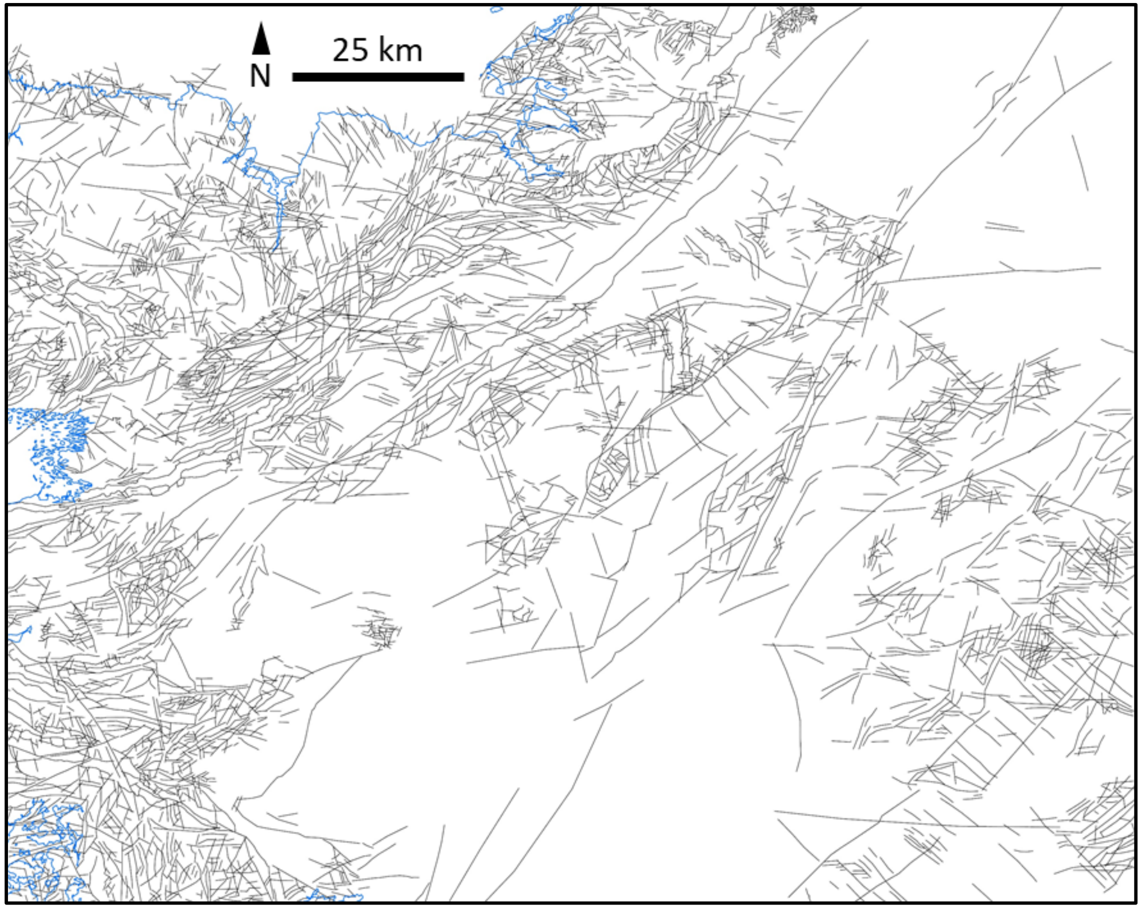
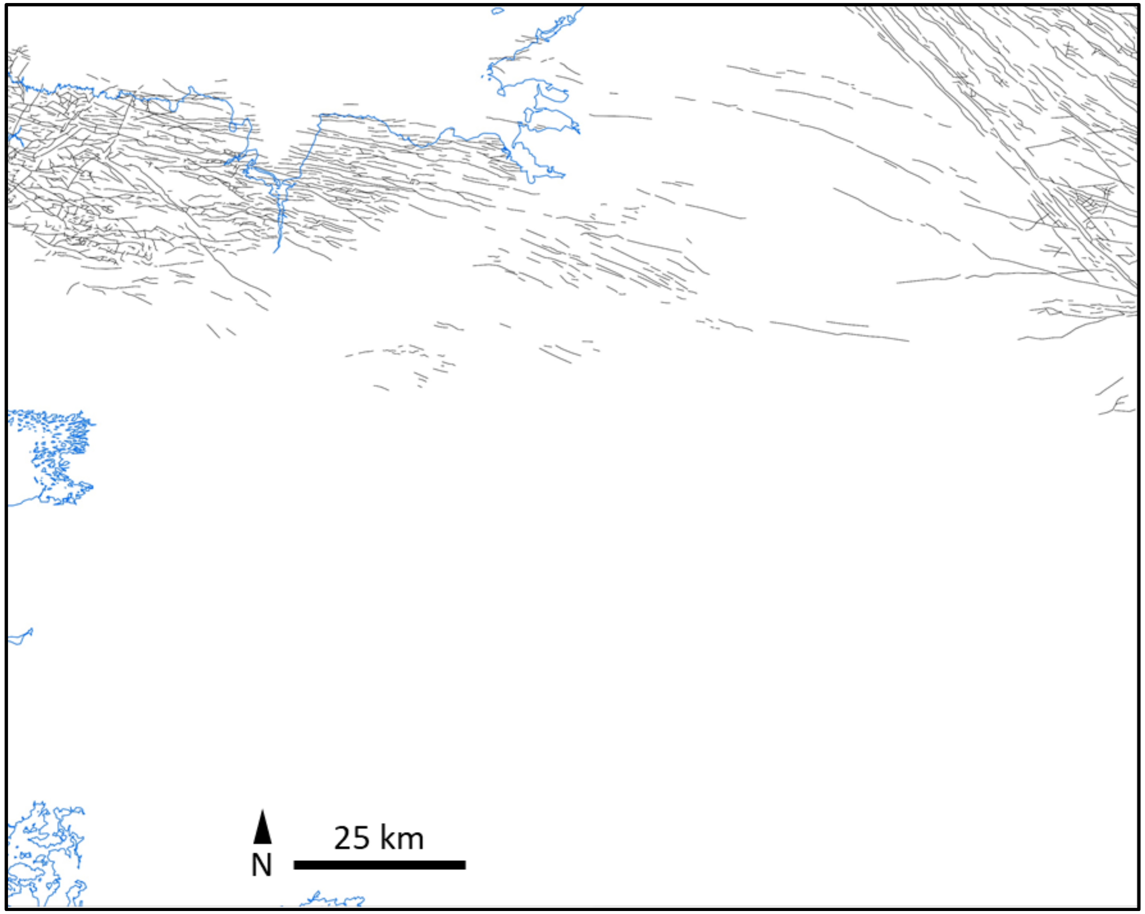


Figure 3.5: Portion of vertical derivative (order = 1) of Total Magnetic Intensity (Map 3, Table 2.1), grey-scale with negative values = black and positive values = white. Several illustrative lineaments (green lines, in lower figure), inferred to be faults, are drawn to accommodate the geometry of juxtaposed magnetic anomalies with different orientations (as well as tracking sharp edges of anomalies, c.f., Figure 3.3 above).

Appendix 1: Map of Magnetic Lineaments. File: [NW_MPM_magnetic_lineaments]



Appendix 2: Map of Magnetic Dykes. File: [NW_MPM_magnetic_dykes.shp]



Appendix 3: Map of EM (Resistivity) Lineaments. File: [NW_MPM_em_lineaments.shp]