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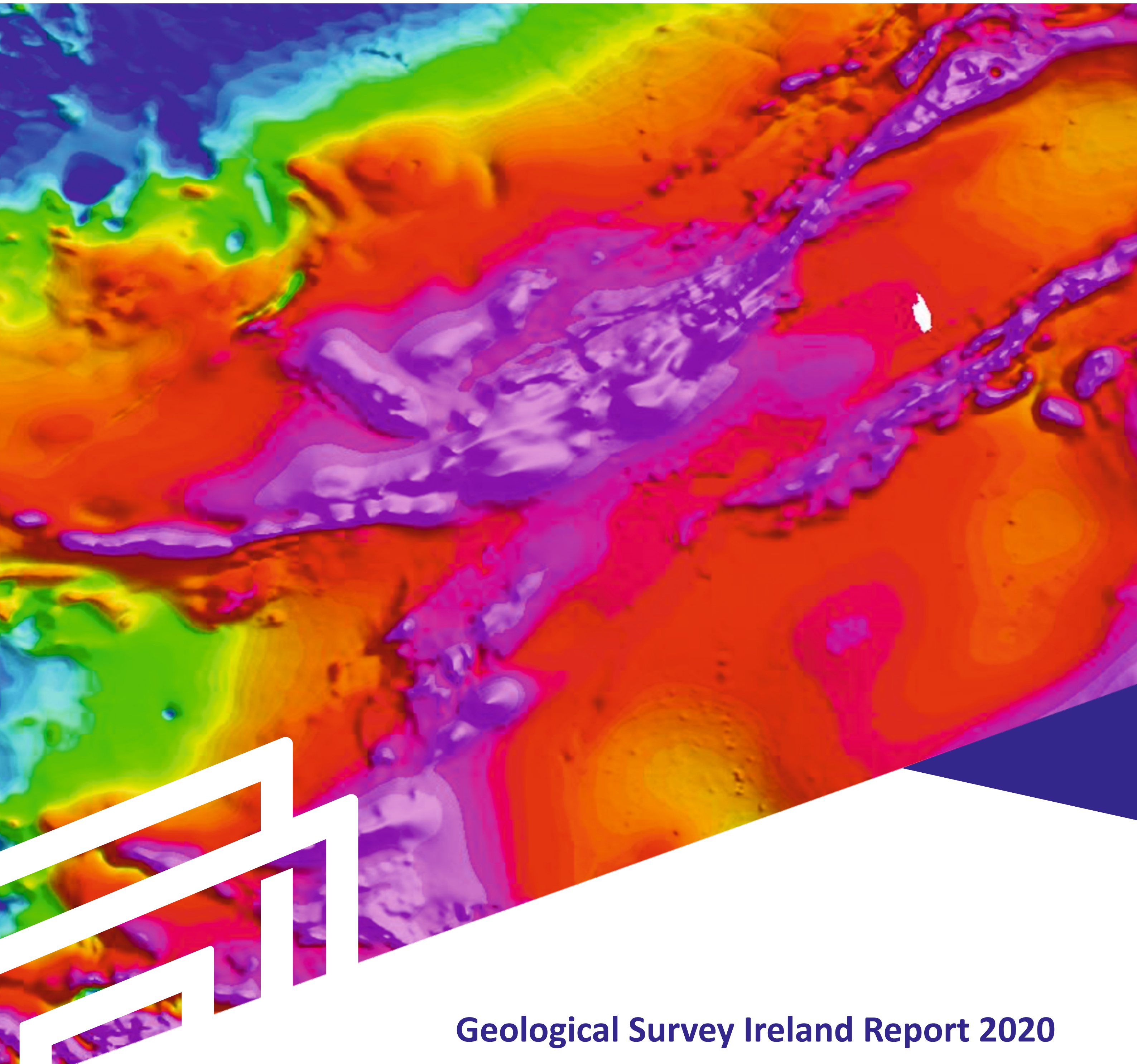
A simple Guide to Tellus Geophysical Products



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Introduction

The Tellus airborne geophysical survey collects three data types: Magnetic, Electromagnetic and Radiometric (also referred to as Gamma-Ray spectrometry). The different datasets are processed to produce a range of different grids (i.e., map) based products; listed below;

Magnetic Data

1. Total Magnetic Intensity
2. Reduced-to-Pole
3. Upward Continuation
4. First Vertical Derivative
5. Second Vertical Derivative
6. Analytical Signal
7. Tilt Derivative

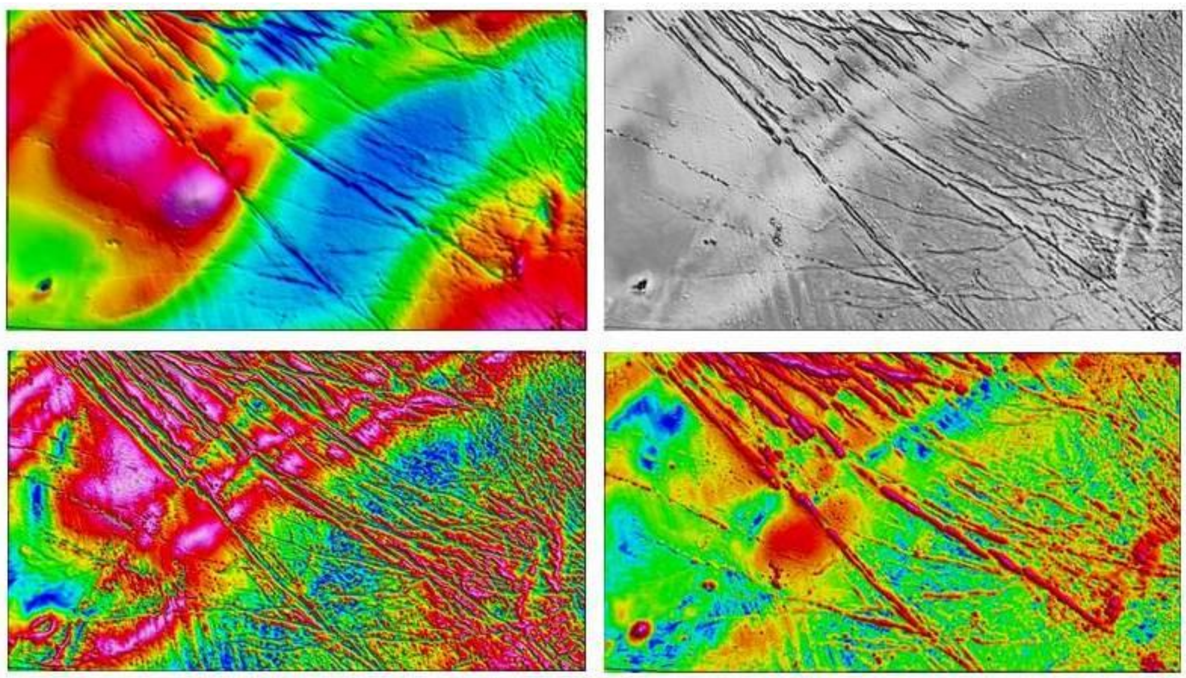
Electromagnetic Data

1. Single-frequency resistivity grids at 0.9, 3, 12 and 25 kHz
2. Resistivity depth slices derived by interpolation of single-frequency resistivity data.
3. Resistivity depth grids derived by formal inversion of four-frequency EM responses
4. Fractional vertical derivatives (of order ~0.25

Radiometric Data

1. Potassium Concentration
2. Equivalent uranium concentration
3. Equivalent thorium concentration
4. Ternary map of %K–eTh–eU concentrations
5. Other products
6. (see details)

A generalized description of each geophysical product is given. A summary table of all products is provided in Appendix 1.



Magnetic Data

1. **Total Magnetic Intensity – TMI.** TMI data record the magnetic signal (or magnetic field) of rocks from surface to 10 – 50 km depth. The TMI data are derived by subtraction of the International Geomagnetic Reference Field (IGRF) from the magnetic data recorded by the aircraft sensors, thus removing the magnetic field generated in the Earth's deep interior and isolating the magnetic signal of crustal rocks.

   The maximum depth of magnetic sources in the subsurface is spatially variable and depends on the depth at which the Curie Temperature (~580^{o}C) is exceeded. Above this temperature, rocks no longer maintain coherent magnetization.

   TMI data are the primary magnetic data produced by Tellus and all additional products are derived by further processing of the TMI data.

   TMI data are often designated by "MAG" or "TMI". Data units are in nanoTesla (nT).

2. **Reduced-to-Pole – RTP.** The shape of the magnetic signals (anomalies) associated with magnetized subsurface bodies in the TMI data depends on the location (particularly latitude) of the measurements with respect to the Earth's magnetic poles. Away from the magnetic poles, the Earth's magnetic field is non-vertical and induces magnetic anomalies in rocks that are dipolar in shape (with both positive and negative peaks) and are asymmetrically positioned over the boundaries of the causative magnetic bodies. At magnetic poles, where the Earth's magnetic field lines are vertical, the anomaly shapes consist of single positive peaks, unless negatively remanently magnetized, and anomalies are positioned symmetrically over magnetic bodies.

   Reduction-to-the-Pole is a process of correction applied to TMI data that numerically transforms the data to an observation location at the magnetic pole, simplifying the shape and position of anomalies with respect to subsurface magnetic causative bodies and assisting interpretation. RTP data are often little different to TMI data at high latitudes such as in Ireland (but are significantly different at low latitudes).

   Often designated as "RTP". Data units are in nT.

3. **Upward Continuation.** Upward continuation is a numerical process operating on the TMI (or RTP) data in which the magnetic data are simulated at an elevation higher than that at which they were originally collected. The process (effectively recording the data at a higher elevation) has the effect of smoothing the magnetic anomalies in the data and removing short-wavelength features associated with shallow magnetic bodies. Magnetic anomalies associated with deep-seated magnetic bodies

are thus enhanced. It is also very useful for removing cultural noise in airborne data, although with the drawback that any near surface geological signals will also be smoothed and attenuated. Upward continuation can be applied to both magnetic and gravity datasets.

Often designated as "Up100" (where the number indicates the height in metres by which the data have been upward continued). Data units are nT.

4. **First Vertical Derivative – 1VD or FVD.** The vertical derivative operator computes the rate of change of the magnetic field strength in a vertical direction, i.e., it computes the difference between the magnetic field measurement at the aircraft elevation and at an elevation 1 m above that. The derivative operator is typically applied to TMI data that have been reduced-to-pole and upward continued by 100 m.

   Short-wavelength anomalies, relating to shallow magnetic bodies, are significantly sharpened and enhanced in FVD data. The positions of anomaly peaks and troughs remain unchanged and the sharpening of anomalies often allows near superimposed anomalies in the TMI data to be distinguished separately. The FVD is useful in defining the locations of shallow dolerite dykes and faults and in highlighting textures and fabrics within highly magnetic rocks. This FVD operator can be applied to both magnetic and gravity datasets.

   Often designated "1VD" or "FVD". Data units are nT/m.

5. **Second Vertical Derivative – 2VD or SVD.** The SVD is in effect the (vertical) derivative of the first vertical derivative. It retains the characteristic of the FVD that the positions of anomaly peaks and troughs remain unchanged, but provides further sharpening and discrimination of short-wavelength anomalies associated with shallow magnetic bodies. Cultural noise in the magnetic data may be accentuated in SVD data. Significant differences, in the resolution of shallow features, between the FVD and SVD data are not always observed. The tilt derivative (TDR, described below) may provide a better or alternative option for highlighting small, shallow features.

   Often designated "2VD" or "SVD". Data units are nT/m^2.

6. **Analytic Signal – AS.** The AS is defined as the square root of the sum of the squares of the vertical and the two horizontal derivatives of the total magnetic field (the TMI data). The two horizontal derivatives (in x and y grid directions) define the rates of change of the magnetic field strength in these directions. Peaks of the AS correlate directly with their magnetic causative bodies and are positioned symmetrically over them, regardless of the magnetization direction in the bodies. The AS therefore has an advantage over reduction-to-the-pole, which is unable to center anomalies over causative bodies where the bodies are remanently magnetized.

In addition, the AS has characteristics similar to the vertical derivative in that short-wavelength anomalies, relating to shallow magnetic bodies, are sharpened and enhanced. It is very sensitive to the edges of causative magnetic bodies and is therefore useful for mapping the boundaries of lithological units.

Often designated "AS". Data units are nT/m.

7. **Tilt Derivative – TDR.** The TDR is computed as the arctangent of the ratio of the vertical derivative of the total magnetic field (numerator) to the total horizontal derivative (denominator). The total horizontal derivative is defined the square root of the sum of the squares of the two horizontal derivatives in the x and y grid directions. As the TDR is an angle, it is often referred to as the *"tilt angle"* or *"local phase"* of the magnetic field.

   As the TDR is based on derivative computations, short-wavelength anomalies, relating to shallow magnetic bodies, are sharpened and enhanced. It offers several advantages in the interpretation of magnetic anomalies. Firstly, weakly magnetic bodies are weighted the same as strongly magnetic bodies - providing a relative enhancement of subtler features present in the TMI data. Secondly, the TDR has a very simple form over simple bodies, e.g., for vertical geological contacts the TDR = 0° contour corresponds with the boundaries of causative magnetic bodies. TDR values are always positive over the bodies themselves and negative away from them. The lateral distance between the TDR = 0° and 45° contours also provides an estimate of the depth to the magnetic body.

   Often designated "TDR". Data units are degrees or radians (where 1 degree = $\pi/180$ radians or 1 radian = $180/\pi$ degrees).

Electromagnetic data

1. **<u>Single-frequency resistivity grids at 0.9, 3, 12 and 25 kHz</u>.** EM responses at each of the four frequencies transmitted by the airborne system are transformed separately and independently to provide ground resistivity values at each measurement location (~ 6 m apart along the flight lines). Resistivity data are subsequently gridded to provide grids/maps at each frequency.

   While there is no explicit depth information contained in these resistivity grids, the lowest (0.9 kHz) and highest (25 kHz) frequency data provide the deepest and shallowest geological sensitivity and imaging respectively (the depth of imaging is inversely proportional to the square root of the transmission frequency). Furthermore, as depth of imaging is also proportional to the square root of the ground resistivity itself, in any one frequency map, resistive and conductive structures are imaged at greater and shallower depths respectively.

   Two different sets of single-frequency resistivity grids are provided by Tellus, with a different method of resistivity computation used in each case:

   (i) **Contractor derived resistivity grids, provided separately for each Tellus survey block.** Contractor Sander Geophysics Limited (SGL) use a nomogram (look-up table) approach to identify a single resistivity value at each measurement location and for each EM frequency independently. Data grids are nulled where flight height exceeds 120 m, to remove potentially poor resistivity solutions.

   Filename convention used: "ExtendedResXX", where XX defines the frequency in kHz (09, 3, 12 or 25).

   (ii) **GSI derived, merged resistivity grids.** Merged resistivity grids (for all contiguous data blocks flown to date) are derived by GSI using formal inversion (Geosoft *HEM* software): a single resistivity value is determined at each measurement location and for each EM frequency independently. Data grids are nulled where flight height exceeds 150 m, to remove potentially poor resistivity solutions.

   Filename convention used: "TELLUS_RESXX_4F_MERGE_YYYY_Coast_Clipped", where XX defines the frequency in kHz (09, 3, 12 or 25) and YYYY defines the dataset year.

   As both methods above provide a resistivity value under the assumption that the Earth consists of a single, homogeneous resistivity medium, these resistivity values are often referred to as *"apparent" resistivities*.

Unit of measurement is ohm.metres (Ω.m).

2. **<u>Resistivity depth slices derived by interpolation of single-frequency resistivity data</u>.** Contractor SGL use half-EM-skin-depth to estimate approximately the subsurface imaging depth for each resistivity data point at each frequency and, through a process of lateral and vertical interpolation of depth-resistivity pairs taken from each of the four frequencies, produce resistivity depth-slices at 10 m, 30 m, 60 m and 100 m depths. Data grids are nulled where flight height exceeds 120 m, to remove potentially poor resistivity solutions.

   Filename convention used: "ExtendedResSliceZZ", where ZZ defines the depth in m (10, 30, 60 or 100). Unit of measurement is ohm.metres (Ω.m).

3. **<u>Resistivity depth grids derived by formal inversion of four-frequency EM responses</u>.** GSI invert the four EM frequency data simultaneously (using aempy software) to derive 20-layer resistivity depth models at each measurement location along each flight line. As a smooth-model inversion scheme is used, resistivities smoothly transition from one layer to the next with increasing depth. Resistivity model data for each depth layer are gridded to provide resistivity depth grids at depths between 1.0 and 62.6 m, with layer thickness increasing logarithmically with increasing depth. Data grids are nulled where the model solutions fail a set of three quality control criteria.

   Filename convention used: "ResDZZ_Z_ohmm_IDW", where ZZ_Z defines the depth in m. Unit of measurement is ohm.metres (Ω.m).

4. **<u>Fractional vertical derivatives (of order ~0.25)</u>.** Any of the resistivity grids listed above may benefit from the application of a fractional vertical derivative operator (of order ~0.25) to sharpen up boundaries between different resistivity units and to enhance subtler features in the grids. While higher order vertical derivatives, such as orders 1.0 and 2.0 (which correspond with the FVD and SVD operators referred to above with respect to magnetic data) can be used, they are often found to over-amplify noise in the data with respect to the geological signal and therefore may not always provide benefit for interpretation.

Radiometric data

1. **Total Counts - TC.** The Tellus airborne gamma-ray spectrometer records gamma radiation, in counts/second, across a 1024-channel energy spectrum extending from 0 – 3.0 MeV. The total count data record the count rate (counts/second) within the energy window between 0.40 – 2.81 MeV, and sum together, without discrimination, the gamma radiation from the three radio-nuclides potassium, uranium and thorium.

   Often designated "TC" or "TOT". Unit of measurement is counts/second (cps).

2. **Potassium concentration – %K.** The recorded count rate in the potassium (^{40}K) spectral energy window, extending from 1.37 – 1.57 MeV, is converted to potassium concentration using experimentally derived calibration coefficients.

   Often designated "%K" or "Pot". Unit of measurement is percentage (%).

3. **Equivalent Uranium concentration – eU.** The recorded count rate in the uranium (^{214}Bi) spectral energy window, extending from 1.66 – 1.86 MeV, is converted to uranium concentration using experimentally derived calibration coefficients. The derived concentration is generally described as "equivalent Uranium" as it is inferred from the gamma-ray radiation of daughter element ^{214}Bi.

   Often designated "eU" or "Ura". Unit of measurement is parts-per-million (ppm).

4. **Equivalent Thorium concentration – eTh.** The recorded count rate in the thorium (^{208}Tl) spectral energy window, extending from 2.41 – 2.81 MeV, is converted to thorium concentration using experimentally derived calibration coefficients. The derived concentration is generally described as "equivalent Thorium" as it is inferred from the gamma-ray radiation of daughter element ^{208}Tl.

   Often designated "eTh" or "Tho". Unit of measurement is parts-per-million (ppm).

5. **Ternary map of %K–eTh–eU concentrations.** Ternary images provided by Tellus are typically generated using an RGB colour palette (equivalent to a CMY inverted palette) with the colours respectively assigned to concentrations of K, Th and U.

   The ternary maps are helpful in visualizing variations in the relative abundances of the three radionuclides in bedrock geology and in superficial deposits.

6. **Other products.** While the products listed above are the "standard" Tellus radiometric products, a large range of additional products can also be generated, which may be helpful in specific geological settings or for particular applications:

   (i) **Concentration ratio maps** of Thorium:Potassium (Th/K), Uranium:Potassium (U/K) and Uranium:Thorium (U/Th).

(ii) **Ternary maps of concentration ratios** – Th/K–U/K–U/Th, which may emphasize different geological units when compared with the standard ternary image.

(iii) **Sum normalized relative abundance maps**, computed as the ratio of the concentration of one radioelement to the sum of all three concentrations, for example, for potassium, %K/(%K+eU+eTh).

(iv) **Ternary maps of normalized relative abundances.** These maps are helpful in mapping radon sources.

(v) **Radiogenic heat production maps**. Computed using the three radionuclide concentrations and an assumed, constant rock density.