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Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -

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Organisation name	Terra GeoServ Ltd. (T/A GeoServ Solutions)		
Organisation type:	☐HEI	☐Public Sector (other)	☒Private Sector
Department/section			

Project Title	Integrated interpretation and Modelling of TELLUS Aeromagnetic, Gravity, Radiometric and Multispectral Analysis of Satellite Imagery Datasets for exploration and identification of Deep Geothermal target areas in the Midland Valley Terrane. (DeepGeo)
Contract No.	2015-sc-071

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

Tellus
Understanding Underground

Marine Institute
Foras na Mara

1. Project information:

Title of project	Integrated interpretation and Modelling of TELLUS Aeromagnetic, Gravity, Radiometric and Multispectral Analysis of Satellite Imagery Datasets for exploration and identification of Deep Geothermal target areas in the Midland Valley Terrane. (DeepGeo)
Did you make any formal amendment to the project workplan / budget?	☒ yes ☐ no If yes, please specify: Budget transferred from one category to another.

Project Report (*max 1500 words, excluding figures and headings*):

(i) Objectives and scientific/engineering targets beyond the state of the art

The objectives of the Deep Geo project were to assess the potential for identifying deep geothermal targets in the Midland valley Terrane (MVT) by using the aeromagnetic, gravity and radiometric data acquired as part of the Tellus Survey and modelling and integrating these with processed satellite imagery temperature data to highlight new potential geothermal targets associated with the buried granites of the MVT.

A similar methodology to that used in the DeepGeo project, is commonly used in high enthalpy geothermal fields (Coolbaugh, 2006), has been previously applied to identify targets associated with buried intrusions (Nouraliee, 2015).

The application of spectral analysis as a way of defining temperature anomalies in low temperature fields, is dependent of the application of filtering and integration workflows to the satellite imagery that allows potential anomalous temperature signatures from the ground conditions to be applied. The Tellus radiometric dataset provides an opportunity to apply this methodology and develop a new methodology for identifying potential temperature anomalies.

(ii) Implementation (including reference to timelines, milestones, management)

The Deep Geo project was implemented through three main phases of work. The implementation of the individual phases is presented below and the results and outputs of each phase discussed.

Phase 1 of the project focussed on the selection of two target areas east of Athlone in County Weastemeath (figure 1). The initial area selection was based on the presence of a high and board magnetic amplitude anomaly identified from the Tellus airborne dataset.

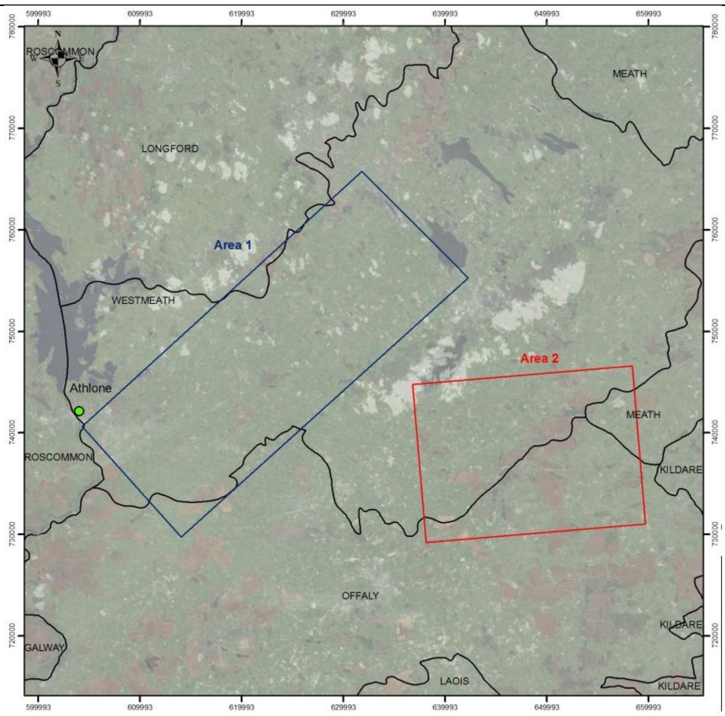

Figure 1 Location of the study area.

The Tellus Aeromagnetic geophysical data exhibits, two broad anomalies in the areas selected, with high amplitude with an overall total magnetic intensity anomaly that ranges from -30 nT to 100 nT (figure 2). The anomalies are aligned with the main trend Irish Iapetus Suture Zone (O'Reilly, 1996) . In addition, Tellus EM data shows high values of apparent conductivity that ranges from 400 (mS) and 1200 (mS) at 50 m depth map, in the studied area. Both anomalies are observed to be oriented in the same direction. (figure 3).

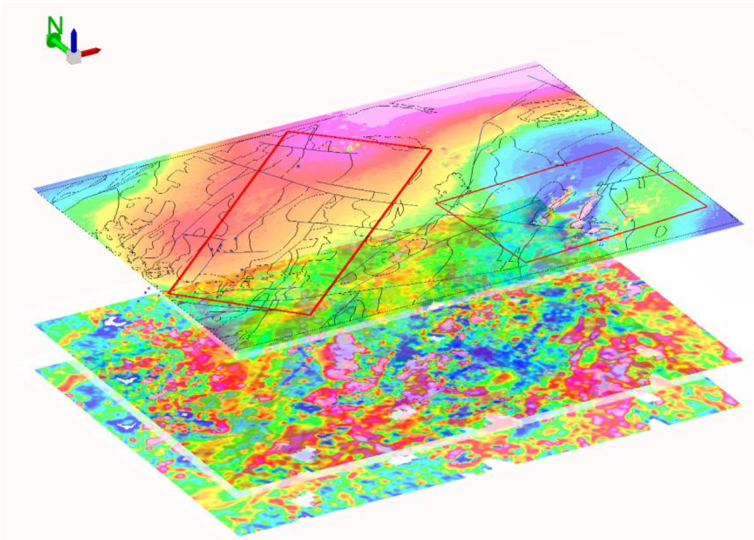

Figure 1 Location of magnetic anomaly and EM 10 m and 50 m depth data from Tellus dataset historical well data location.

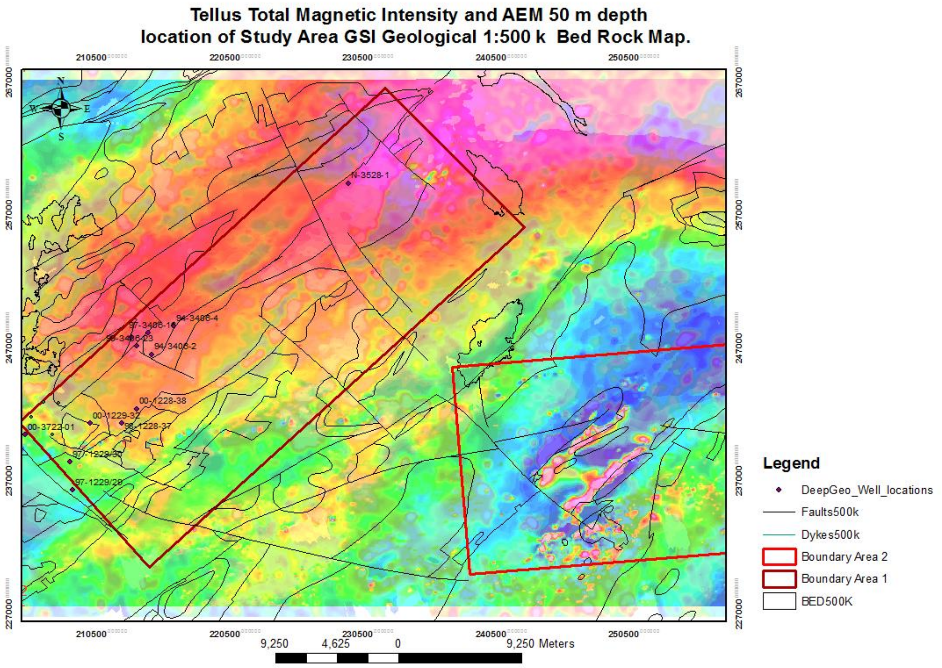

Figure 2 Total Magnetic intensity and Tellus EM 50 (m) depth data in the study areas 1 and 2

The Tellus EM dataset (figure 4) for both study areas was considered. Similarly to the aeromagnetic anomalies, this was found to be constrained by regional North East- South West trending fault structures. Mineral exploration boreholes N-3528-1, 94-3406-4, 97-3406-16, 94-3406-2, 99-3406-23, 97-3406-18, 00-1228-38, 98-1228-37 are located along the anomaly see figure 4.

The areas selected are coincident with low gravity anomalies identified in the midlands of Ireland and postulated as potential deep buried granites occurring in a NEto SW direction and at intersections with N NE trending lineaments resulting in crustal dilation and potentially controlling the emplacement of these granites (Readman *et al*, 1997).

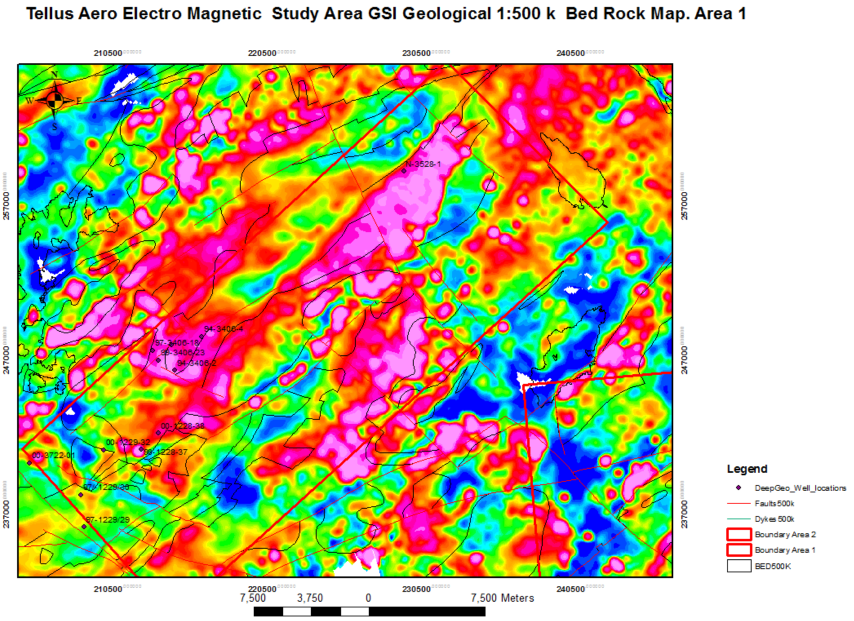

Figure 3 Tellus Mineral Exploration Borehole locations and AEM dataset in Area 1

A series of detailed temperature measurements were taken from a number of mineral exploration boreholes as part of a geothermal assessment study carried out in 2004 (Goodman, 2004). The location of the temperature measurements are shown in figure 5. Profiles where extracted across Area 1 where borehole log data was available to correlate Total magnetic intensity anomaly, the radiometric data and the EM high responses for both areas. An example of these is shown in as Profile 1, oriented in the North-East South West trend, and Profiles 2 and 3 oriented to the North West -South West respectively (figure 5).

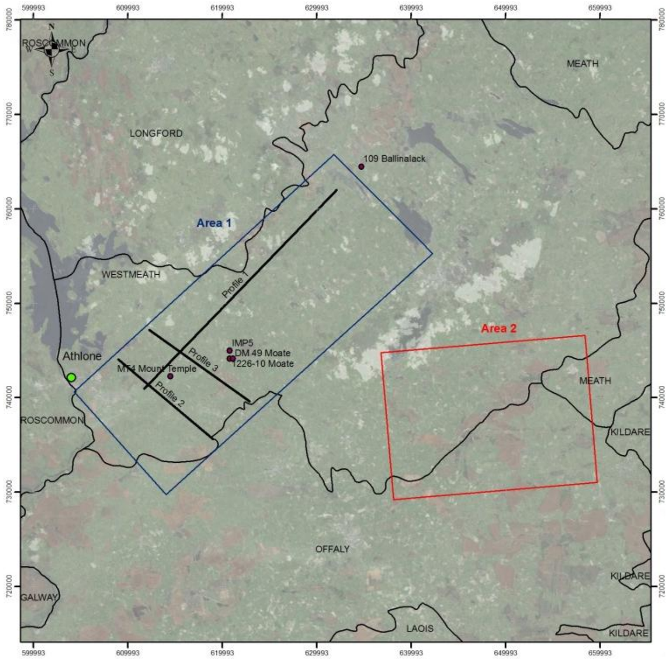

Figure 5 DeepGeo Project study areas and locations of detailed subsurface temperature logs and Profile locations.

Phase 2 of the project focussed on using ASTER and Landsat satellite imagery data (ASTER Global EmissivityDataset, 100 meters - Lansat 8 Oli/TIR LC82070232013192LGN00 (8 Bands) 11/07/2013 path 207 and row 23 – ASTER ASTL1T00302092007114646 (14 Bands) 2016-03-09Tat 17:33:35) and processing these to obtain a corrected temperature response and to carry out an inversion to correlate these data with the bedrock geology of the area.

Images where corrected and calibrated in order to build RGB composites in the visible and near and far infrared range. These composite bands highlight the influence of vegetation in the area of study which is critical when assessing observed reflectance variations during the image processing and in the SWIR and thermal bands. Maximum and minimum reflectance variations were in the range 0.1 to 0.7 was observed and consistent with the expected reflectance from a black body. The character of the SWIR (5, 6 & 7) bands were analysed so that these could be related to the USGS spectral firms database based on the observed signatures from the inversion process. Lansat 8 Oli near infrared and short infrared wavelength range variations was also analysed (figure 6). This parameters are relevant in terms of image quality therefore, the wider the bandwidth, the resolution of the image increased due its frequency content would resolved better each pixel component. Spatial pixel resolution for these images are 30 (m) for each band, 15 (m) for the Panchromatic image, and 90 (m) in the thermal bands.

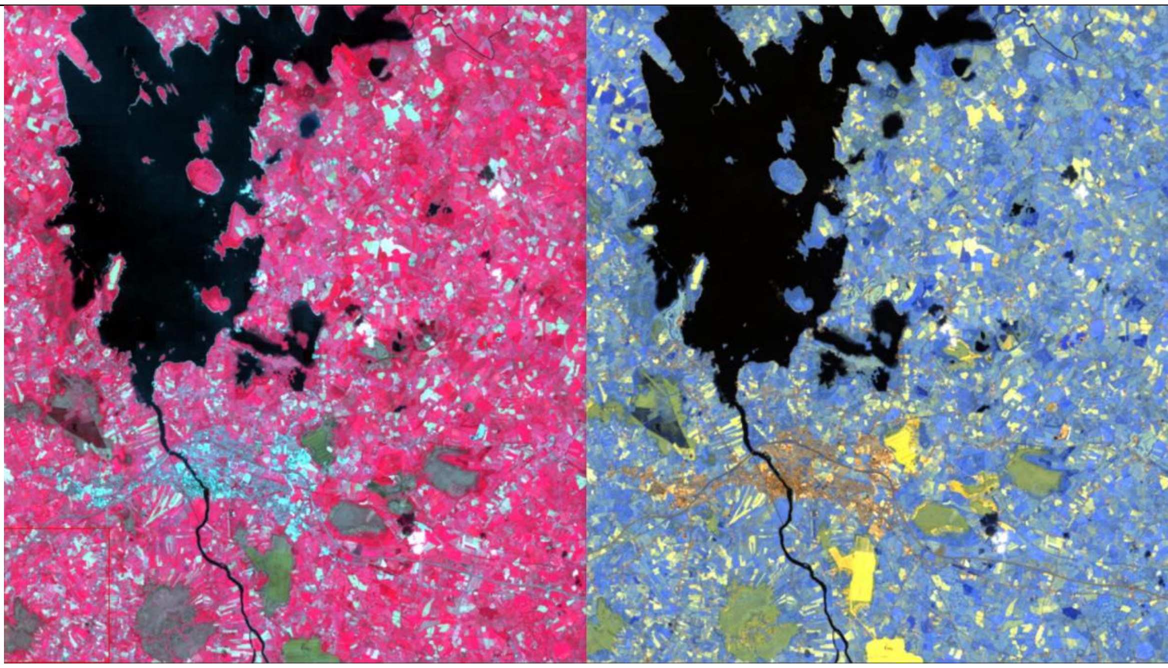

Figure 6 shows near infrared band composite (5 ,4, 3) and short infrared composite bands (7 6 5) Image Lansat Oli8

Therefore, the ASTER image (figures 7 & 8) was compared with Lansat 8 Oli/ TIR (figure6) and considered more suitable based on the constrat observed and the increase number of bands giving better spectral resolution. Figures 7 and 8 show the evaluation of satellite images.

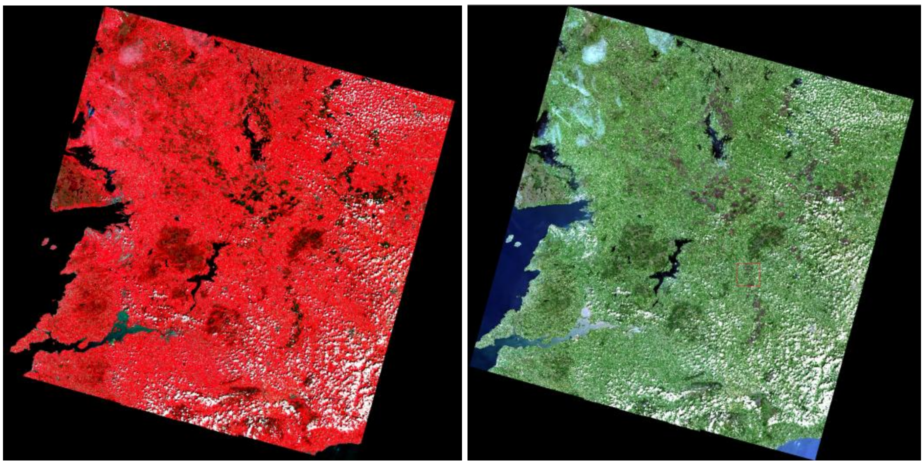

Figure 7 RGB Composite bands 5 4 3 & composite 4 3 2 & cloud coverage in area of interest lower than image at LC82070232013192LGN00.

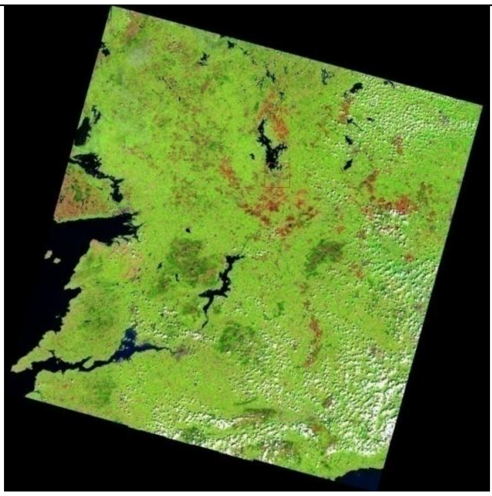

Figure 8 False colour composite of image bare soils are highlighted in red due their emittance in the infrared range image LC82070232013192LGN00

Cross plots from image LC82070232013192LGN00 and for the LandSat/Oli8 images along with cluster diagrams were built to extend the analysis onto bands 7 vs 5, 7 vs 6 and 5 vs 4 as bands 7 vs 5 were found to be highly correlated and unlikely to discriminate pixels effectively. Therefore, characterisation of bands 7 vs 6 and 6 vs 5 was deemed to be essential to allow a temperature signature and mineralogical correlation to be performed.

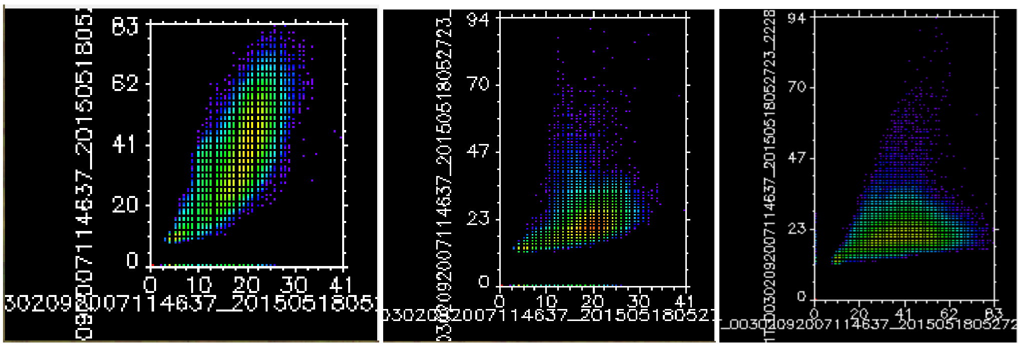

Figure 9 Sample Cluster analysis results for bands 4, 3 & 2. Band 4 vs 3 (left). Band 4 vs 2 (centre).Band 3 vs 2 (right).

Figure 9 shows the results of the cluster analysis performed on the ASTER image and the broad correlation between bands. Water pixels are distributed from 0 to 10 % of spectral reflectance range. Soils and healthy vegetation varies from 15 to 20 % in the short infrared and from 20 to 62 % in the far infrared spectral reflectance. While, urban areas spectral reflectance varies from 15 to 20 %. Cluster, diagram shows bands 4 vs 2. Water pixels are limited in the VIR from 0 to 6 %. Urban pixels are limited in the range of 8 to 16% in the infrared bands. 18 to 36 % are limited the healthy vegetation and soils. This cluster diagrams shows a broad distribution of the spectral reflectance.

These cluster analysis results were used to perform a pixel classification and relate this to surface mineralogy alterations by calculating the spectral firms in the imagery and correlating these based on the USGS spectral firms database.

A principal component analysis (PCA) was performed (figure 11) on the ASTER pixel dataset to enhance the dominant component of the image and remove the effects of vegetation, soils and urban and cultural effects. The PCA data was used in conjunction with the EPA Teagasc soil and sub soils datasets to assess the impact of soils on the pixels and on surface temperature. The results of the PCA were used to calibrate the surface temperature dataset obtained

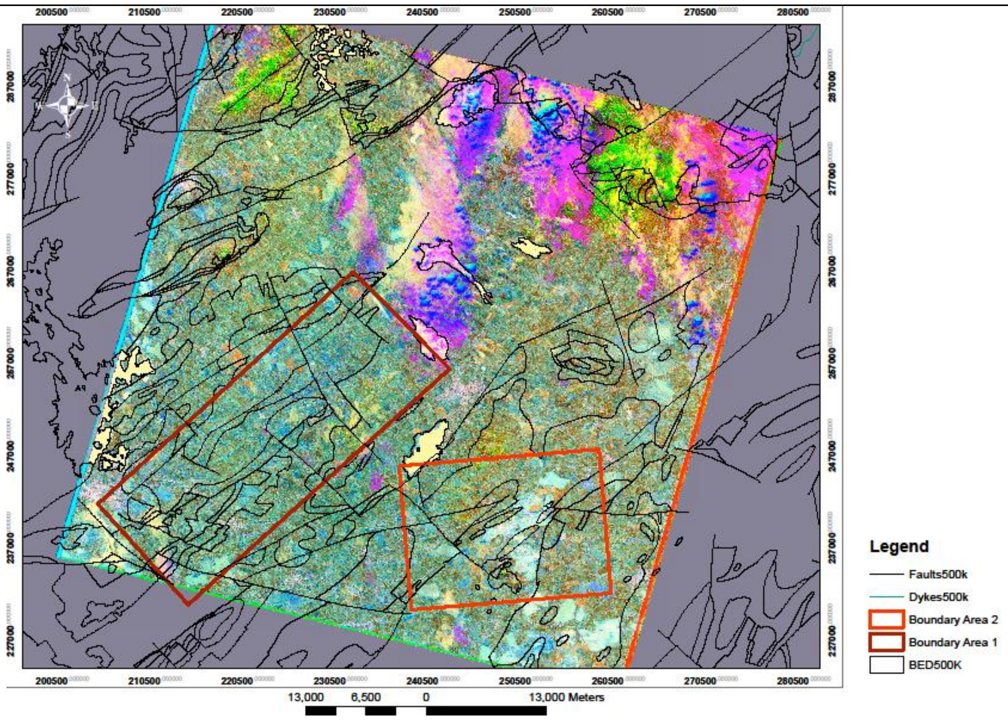

Figure 10 Tellus Mineral Exploration Borehole Surface Temperature derived from the Deep Geo Inversion and profiles

Phase 3 focussed on completing the final data inversion and deriving a corrected temperature signature from the corrected satellite image pixels. Thermal bands where converted from spectral radiance to brightness and temperature applying the thermal constant from the metadata file which are related based on the followed relationship.

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)}$$

where:

$\mathrm{T} = \text{At satellite brightness temperature}$

$\mathrm{L}_\lambda = \text{TOA spectral radiance } (\frac{\text{Watt}}{\text{m}^2} * \text{Srad} * \mu\text{m})$

$\mathrm{K}_1 = \text{Band specific thermal convertion constant from metadata file}$

$\mathrm{K}_2 = \text{Band specific thermal convertion constant from metadata file}$

The data set used i to derive surface temperature maps included the ASTER Global Emissivity Dataset 100 meters HDF5 v003 (AG100). The Emissivity Science Data set in Aster GED is multidimensional, giving emissivity as stacked of layers including mean and standard deviation for each of the five spectral bands. Figure 11 shows, a map with the corrected bedrock temperature distribution overlaid by the 1:100,000 series bedrock geology data for the study area. A correlation of the resulting temperatures was found to be in closed correlation with the temperature data shown in the boreholes measurements for the area 1 (figure 5).

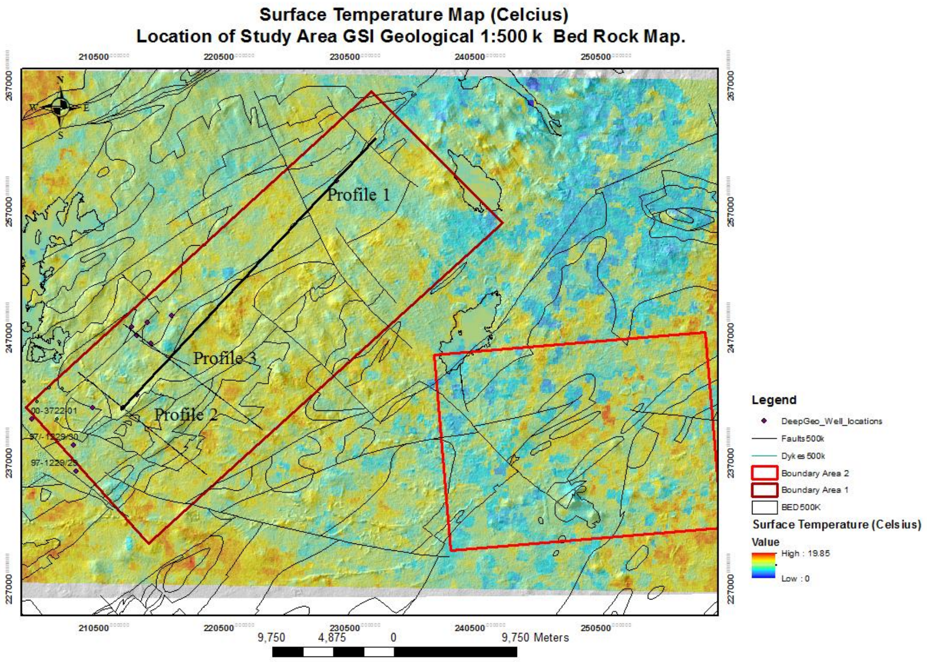

Figure 11 Tellus Mineral Exploration Borehole Surface Temperature derived from the Deep Geo Inversion and profiles assessed in Area 1

The project then focussed on assessing the radiometrics data from the Tellus survey and attempted to correlate the emissivity (and resulting temperatures) derived from the satellite imagery data with the emissivity associated with the decay process of the U, Th and K values as seen on the Tellus radiometrics. The correlation of these data along profile 2 (figure 5) are presented in figure 12. The plots show a potential correlation between the U/Th ratios observed from the radiometrics data and the derived surface temperature from the ASTER satellite image processing.

Whilst the relationship is also highlighted along other profiles considered in the project, further work using the geochemical data from the Tellus midland survey is required to allow for the U and Th concentrations in soils to be accounted for and for the relationship between the magnetic anomalies observed, the radiometrics dataset and the derived temperature to be potentially correlated with geological and structural features in the study area.

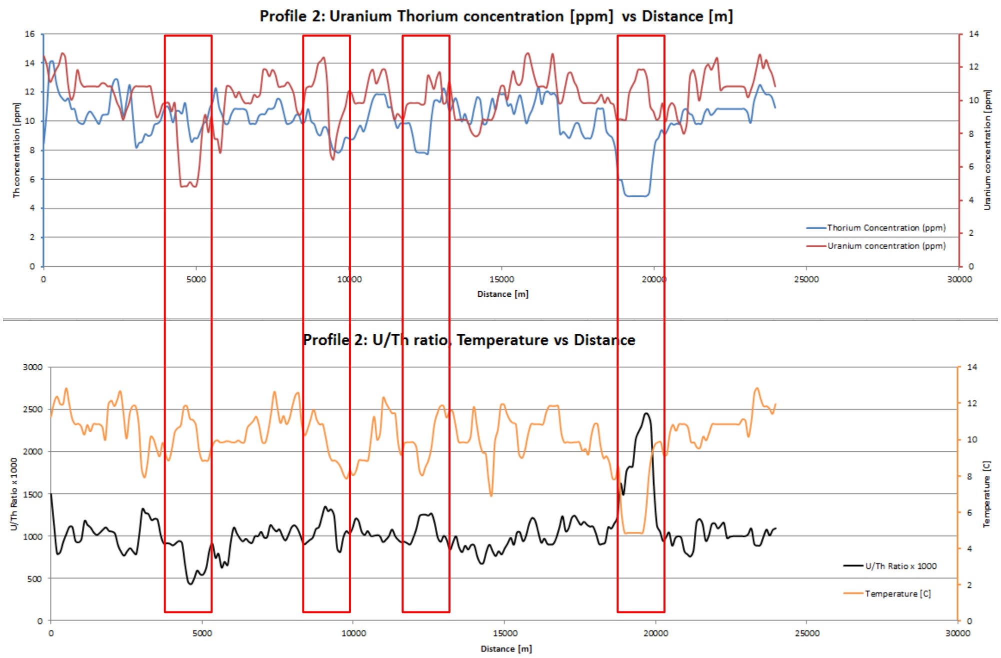

Figure 12 Tellus Radiometrics Data and Derived Surface Temperature along Profile No. 2 showing potential interrelationship between U/Th ratios and measured surface temperature.

The DeepGeo project has used the Tellus Magnetics data to select areas coincident with identified gravity low anomalies where potential deep geothermal targets associated with buried granites might be present. Satellite imagery from the same areas was used to derive the emissivity and corresponding potential temperature from the ground conditions. The newly acquired Tellus radiometrics data has been used to analyse the relationship between radiogenic heat production, the measured levels of Uranium and Thorium and the derived surface temperatures from the satellite imagery by completing a Principal Component Analysis. A relationship The DeeGeo project has allowed for a new methodology to be developed and tested as an approach to exploring for potential deep geothermal targets in a low-enthalpy setting. The method provides a new approach to integrating the Tellus radiometrics datasets and using these as to derive bedrock surface temperature data to identify anomalous ground temperatures. Further work using the sampling and testing results from the soils in the areas selected is required to attribute the U/Th ratios observed to soils and subsoils or to bedrock conditions, helping to derive a temperature signature from the bedrock. The technique tested by the project should be further investigated in areas where soil geochemistry data is already available. Areas where warm springs are present of detailed subsurface temperature logs should also be considered.

(iii) Outputs (please use bullet points)

- Aeromagnetic Maps of target areas 1 and 2
- Multi spectral analysis and Radiometric maps for areas 1 and 2 and specific profile analysis
- Multispectral analysis of orthorectified satellite imagery
- Surface derived temperature anomaly map
- Outline integration of Tellus dataset as with produced data as an indication of possible target areas

Impact/value of the project (M*ax 500 words*):

The DeepGeo project has allowed for a new methodology to be developed and tested as an approach to exploring for potential deep geothermal targets in a low-enthalpy setting. The method provides a new approach to integrating the Tellus radiometrics datasets and using these as a final proxy to derive bedrock surface temperature data to identify anomalous ground temperatures.

The methodology has potential to be transferred to other part of the Ireland where existing Tellus surface geochemistry data is available and to be used as standard method for identifying bedrock surface temperature anomalies. The use of subsurface temperature measurements or data from areas where warm springs have been identified and documented could be ideally suited to using this method.

The potential for identifying new geothermal prospects developed by the method, allows for cost effective screening tool for deep geothermal resource identification to be developed.

Appendix 1 – Publications & Presentations:

[Conference Publication] Ramirez Loaiza, K., Yépez, S., Pasquali, R., Rath, V., Muller, M. (2016) Integrated interpretation and modelling of Tellus Aeromagnetic, Gravity, Radiometric and Multispectral Analysis of the Satellite Imagery datasets for the exploration identification

of deep geothermal target areas in the Midlands Valley Terrane. *European Geothermal Congress 2016 – S-GP-265.* EGC2016 Strasbourg, France, 19-23 SEPT 2016.

[Conference Poester] Ramirez Loaiza, K., Yépez, S., Pasquali, R., Rath, V., Muller, M. (2016) Integrated interpretation and modelling of Tellus Aeromagnetic, Gravity, Radiometric and Multispectral Analysis of the Satellite Imagery datasets for the exploration identification of deep geothermal target areas in the Midlands Valley Terrane. *Presentation to the Tellus stakeholder's meeting.* RIA, Dublin, Ireland, 5 OCT 2016.

Appendix 2 – Any additional information not included above: