Roinn Cumarsáide,
Fuinnimh & Acmhainní Nádúrtha
Department of Communications,
Energy & Natural Resources

Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

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

Name of Lead Investigator	Derek Reay
Email	Derek.reay@economy-ni.gov.uk
Phone number	02890388462

Organisation name	Geological Survey of Northern IReland	
Organisation type: Sector	☐HEI ✓Public Sector (other)	☐Private
Department/section	NI Department for the Economy	

Project Title	Geochemical anomaly detection: spatial analysis for improved use of geochemical data
Contract No.	2015-sc-069

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

Tellus
Understanding Underground

Marine Institute
Foras na Mara

Project information:

Title of project	Geochemical anomaly detection: spatial analysis for improved use of geochemical data
Did you make any formal amendment to the project workplan / budget?	☐ yes ✓ no If yes, please specify:

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

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

The objective of this project was to implement the singularity mapping procedure for anomaly detection in combination with a robust linear mixed model analysis, and to apply this to data from the Tellus surveys from the north of Ireland.

These objectives have been met.

Implementation of the methodology. The methodology was implemented on the open-source R statistical platform. The new R code takes the form of a script which allows the user to read in data, to define a window within which the singularity index will be computed and to compute singularity index values within windows of specified radius. Figure 1 below shows the values of the singularity index for As in a window spanning the Tellus and Tellus Border surveys. The code also allows us to fit and select a robust geostatistical model to the data and then to identify probable outlying values. These are superimposed on the plot. Note that the singularity index is computed within a window using some neighbouring values around the window, and that outliers among these data are also shown.

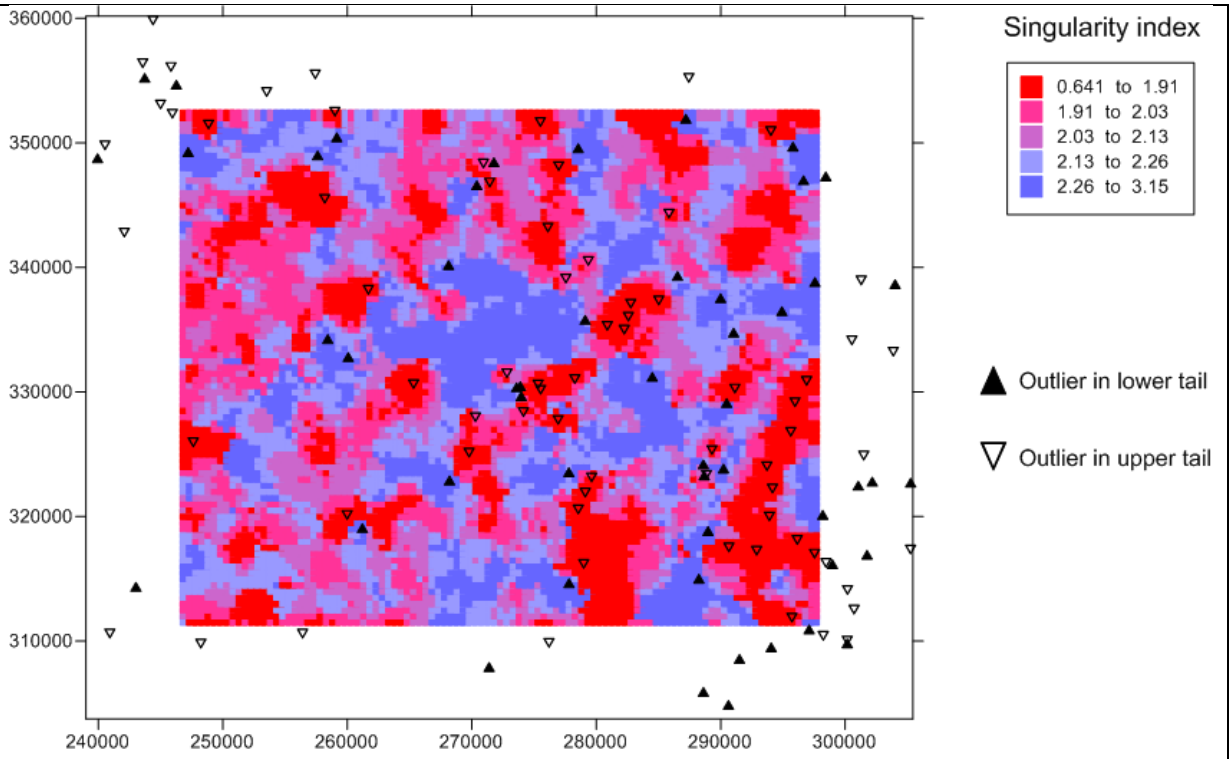

Figure 1 Values of the singularity index for As in a trial area. Outlying data identified by robust geostatistical analysis are also shown.

The script then allows the user to compute threshold values on which to distinguish background variation of the target variable from enrichment and depletion anomalies. There are two ways to do this. The first approach uses established methods based on fitting piecewise-linear models to the plot of cumulative area with singularity index values below a given threshold. This plot is shown below for the As singularity index data. When a piecewise-linear model with 3 segments is fitted the threshold values are 1.75 (all smaller values of the singularity threshold are identified as enrichment anomalies) and 2.31 (larger values are treated as depletion anomalies).

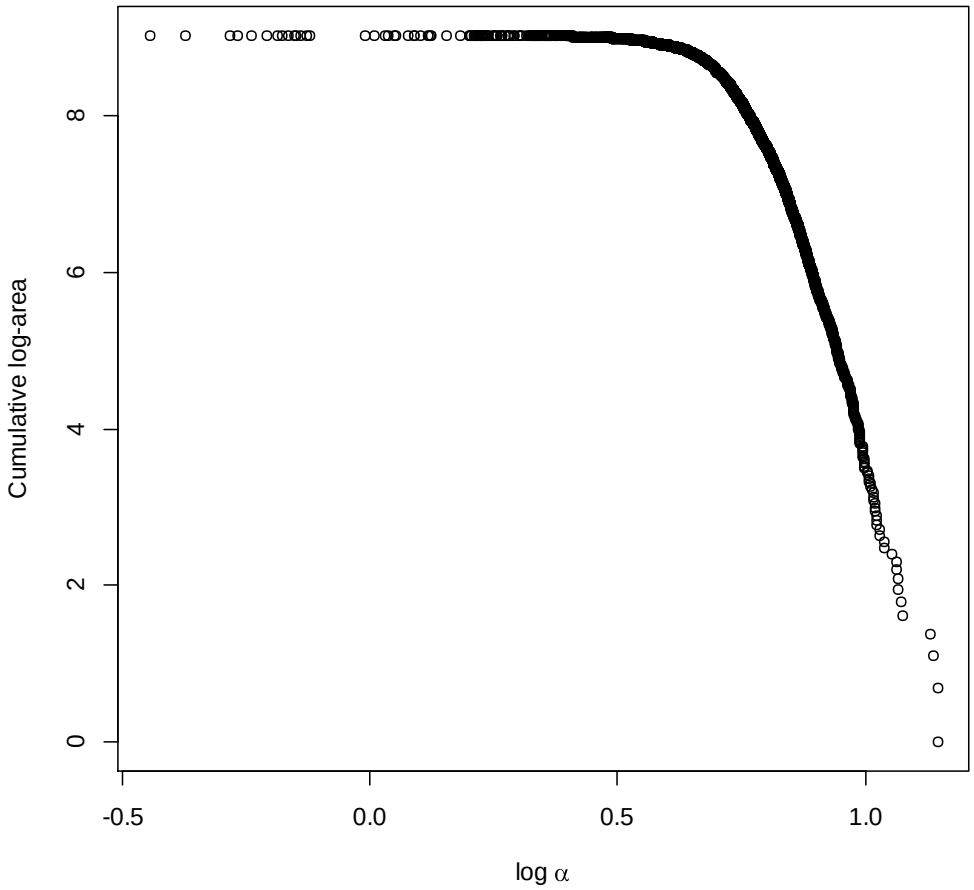

Figure 2 Plot of cumulative log area against log of the singularity index for As

The second approach is a novel development within this project, and is based on the assumption, validated by simulation, that the singularity index of the background process can be treated as a normal random variable. On this basis we model the set of values of the singularity index as a mixture of normal random variables. One of the components, the dominant one, can, in all cases examined, be identified as representing the background process. The anomalies may be represented by one or more additional distributions which introduce additional mass into the tails of the overall distribution. Threshold values are then found where the posterior probability density of the additional components of the mixture model exceeds the density of the dominant process.

The figure below shows the histogram of the singularity index values for As with a two-component model fitted. The green line shows the density of the component identified with the background process, and the red line represents a second distribution which accounts for anomalies. The threshold values by this method were 1.66 (maximum for enrichment anomalies) and 2.58 (minimum for depletion anomalies).

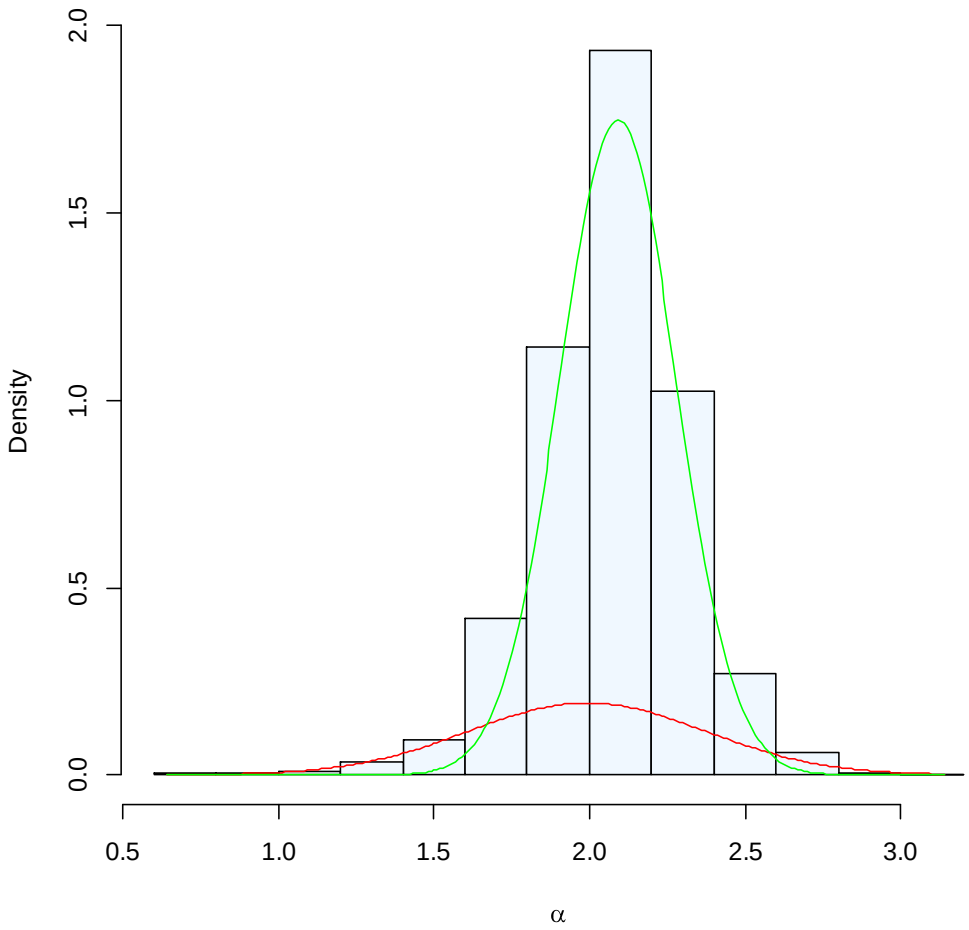

Figure 3 Histogram of singularity index values for As with probability density functions for a two-component mixture of normal distribution model.

The spatial distribution of background (grey), depletion anomalies (blue) and enrichment anomalies (red) is mapped below, along with the outliers from the robust geostatistical analysis.

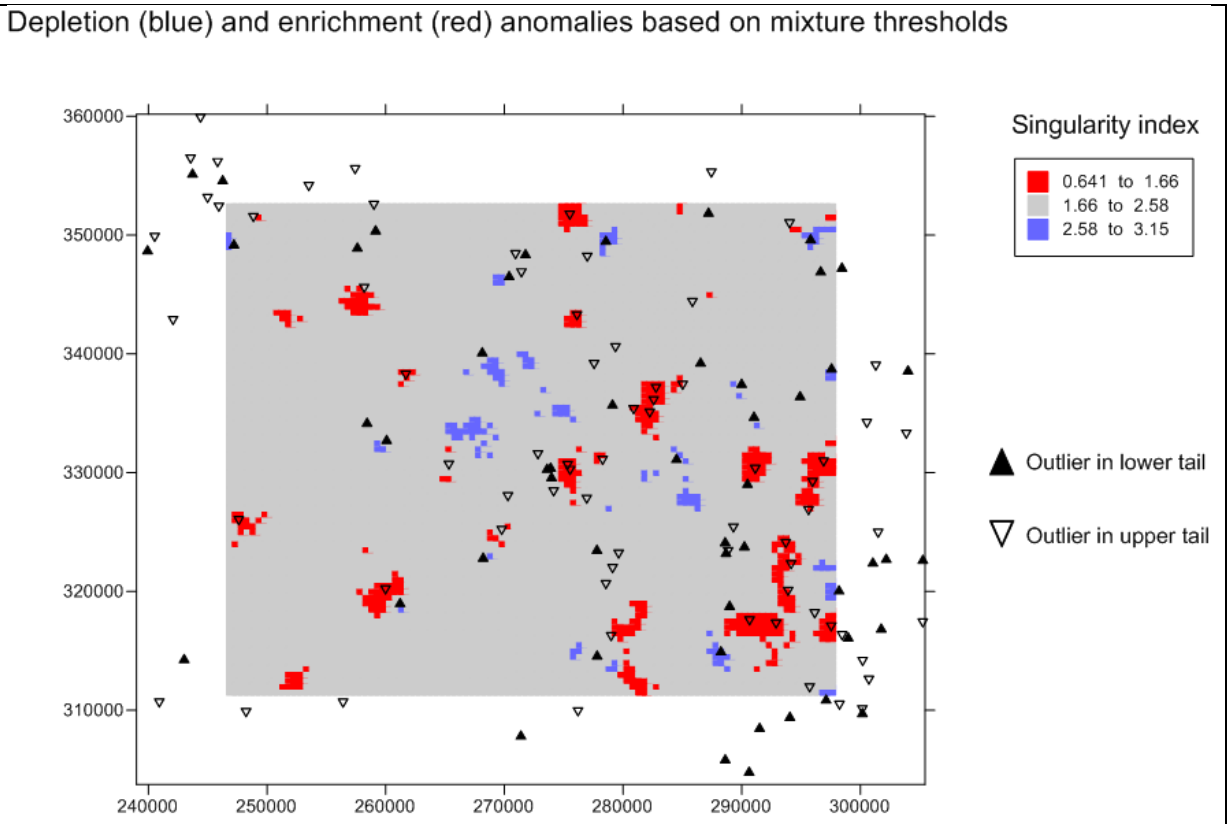

Figure 4 Mapped values of the singularity index divided by two thresholds to show anomalies

Implementation (including reference to timelines, milestones, management)
GSI Short Call - Geochemical Anomalies

Implementation

Y. Liu et al (2014) establish the method of using fractal/multifractal analysis to identify rare earth anomalies in the Nanling belt in south China. The singularity analysis method used in China was identified as a potential method for highlighting anomalous mineralisation in the Tellus and Tellus Boarder dataset for the north of Ireland.

The combined levelled dataset for stream sediments covering the Northern Ireland Tellus project area and the Tellus Border project area was used. Initially 4 subset areas were selected for study. The selection of these areas was based on known mineralisation or mineral potential. These areas were:

- The cross border Longford-Down region spanning counties Armagh in the north and Monaghan, Cavan and Louth in the south.
- The Tyrone Igneous Complex in Northern Ireland
- The cross border area centred on Killeter Forest in counties Tyrone and Donegal
- Central County Donegal

A suite of base metal and path finder elements in stream sediments were examined: arsenic, copper, lead, zinc, antimony, manganese and iron. The gold dataset was proposed but enquiries with GSI revealed levelling issues with the merged Tellus/Tellus Border data set and as a consequence the data were not available for all the research areas within the time frame of the project.

Analysis was carried out over all four areas, but results were focussed on the Longford-Down region in the first instance. This focus was largely due to the processing time required for the R programme to analyse the data, but also because the relatively homogeneous nature of the Longford-Down produced more stable results. These results could be compared with the well known mineralization located in the area.

The Longford-Down terrane of Ireland has a long history of base metal production with lead and zinc being worked at a number of small mines in Counties Monaghan and Armagh. In recent years mineral prospecting licences issued by both Exploration and Mining Division of the Department for Communications, Climate Action and Environment in Dublin and Minerals Branch of the Department for the Economy in Northern Ireland in Belfast have spanned the border, focussing on gold prospectivity. Results from this exploration are well publicised and as a consequence of this the decision was made to use this area as a 'truthing' ground for the technique.

In the absence of gold data for the region arsenic was used as a pathfinder element. Arsenopyrite is known to be associated with the gold deposits in the Longford –Down and standard inverse distance weighted (IDW) gridding of stream sediment data has indicated elevated values in the area (Figure 5). When compared with the results of the singularity analysis (Figure 6) the relatively enriched area to the west of Slieve Gullion and the Newry igneous complex is greatly reduced in intensity. Figure 7 shows the same singularity analysis with the locations of the known gold targets at Clay Lake in Co Armagh and at Clontibret and Glenish in Co Monaghan highlighted. Figure 8 shows the singularity analysis results with the threshold analysis applied. As well as the three known targets, a number of additional arsenic anomalies are highlighted within the dataset.
In terms of mineral and specifically gold prospectivity for the area these anomalies should not be taken as indicative of additional mineralisation, but should be looked at in conjunction with singularity analysis applied to other minerals and their structural and lithological context. Notably the mineralisation identified along strike at Slieve Glah in the south west of the study area is not highlighted using this method applied to the arsenic data set. However, given the accuracy with which the known mineralisation targets are identified using the technique, the additional anomalies may be worthy of consideration for follow-up ground work.

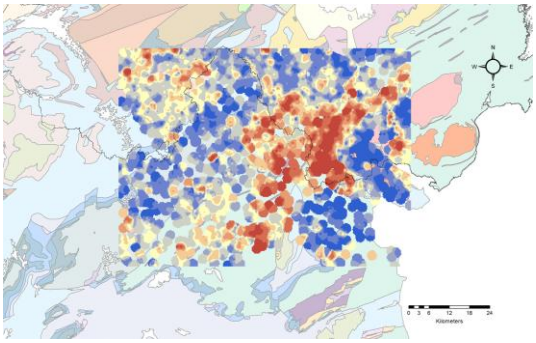

Figure 5: IDW interpolation for arsenic

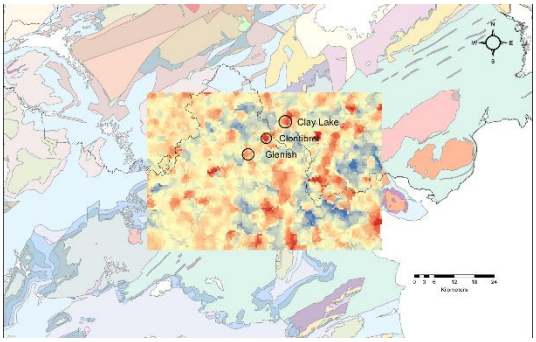

Figure 6: Singularity analysis with indicated mineralisation exploration targets

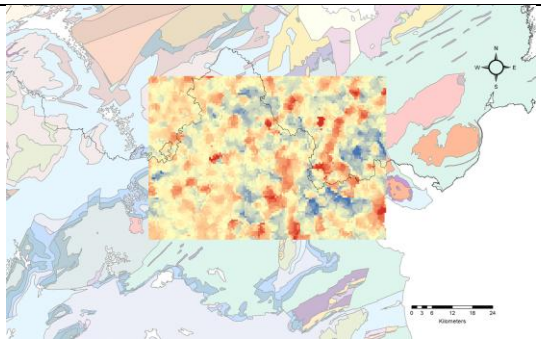

Figure 7: Singularity analysis for arsenic

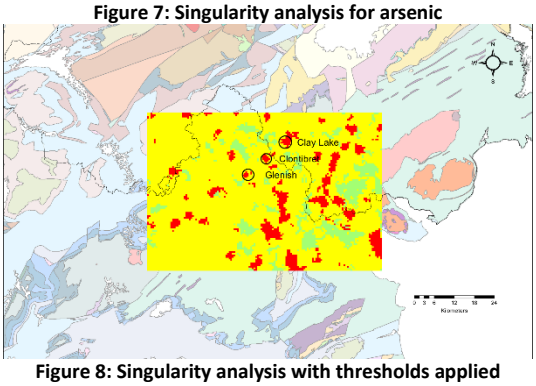

Figure 8: Singularity analysis with thresholds applied

Thresholds applied to the singularity index values for the remaining elements considered are shown in figures 9 - 14 for the Longford-Down area.

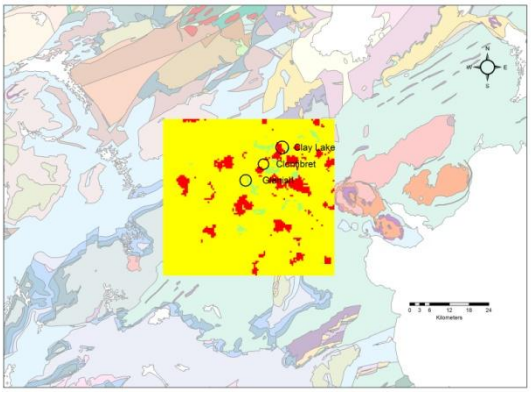

Figure 9: Copper

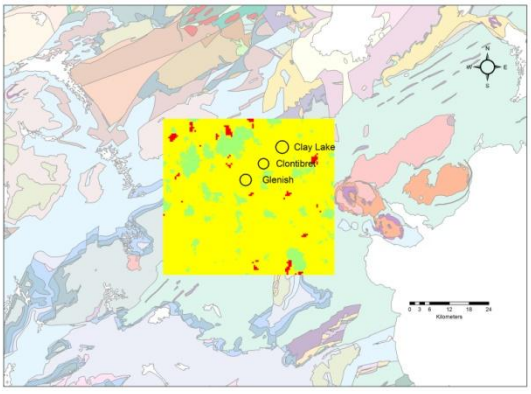

Figure 10: Iron

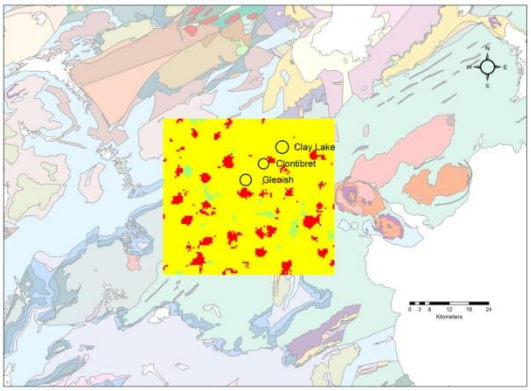

Figure 11: Manganese

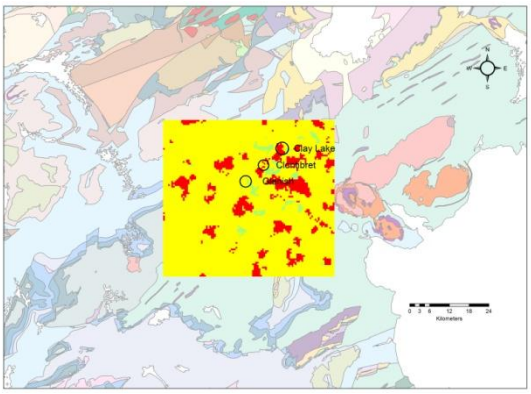

Figure 12: Lead

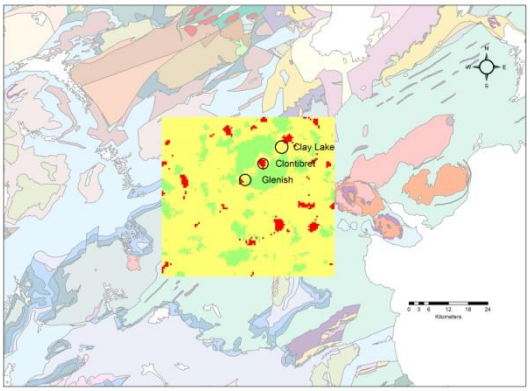

Figure 13: Antimony

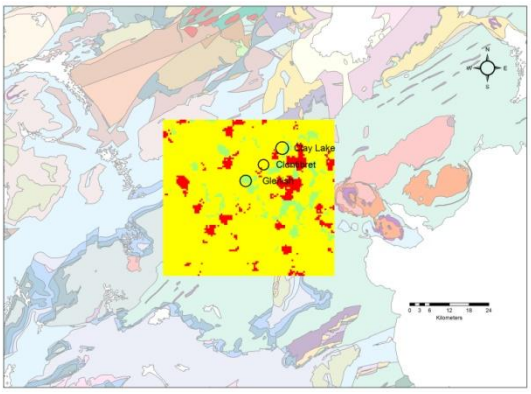

Figure 14: Zinc

Of the remaining three areas considered as part of this investigation, results for the Donegal area were produced in the same fashion as Longford-Down. Results for the Killeter Forest and Tyrone Igneous Complex are considered less reliable due to the heterogeneity of the geology for both areas. Images 15-16 below show the outline for all areas with simplified underlying geology which illustrates this.

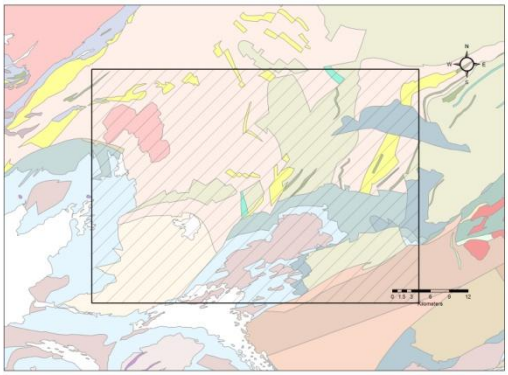

Figure 15: Killeter Forest AOI and geology

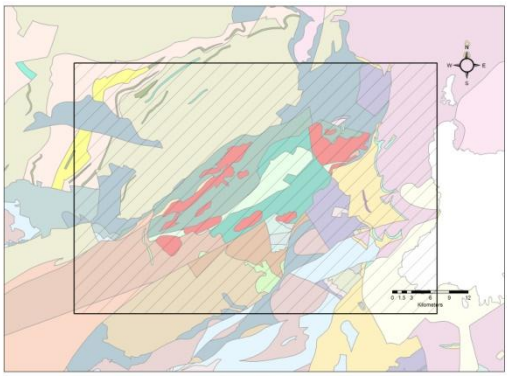

Figure 16: Tyrone Igneous Complex AOI and geology

As part of the planned continued work on this method and application, the precious metal dataset for Tellus/ Tellus Border will be sourced and analysed. A more detailed interpretation of the results for Longford-Down and Donegal will be carried out in conjunction with the structural geology of the target areas. Additional consideration will be given to the application of the technique to areas of complex geology. Comparison with the soil datasets will be carried out and incorporated into the planned publications.

Outputs (please use bullet points)

- An evaluation of singularity mapping on the Tellus and Tellus border data
- An evaluation of the robust linear mixed model for anomaly detection, and a comparison with singularity mapping
- Methodology and software (on the R platform) which can be used to apply these methods to data collected in ongoing Tellus surveys.
- A comparison of geochemical anomalies in soil and sediment data.
- Oral presentation at the launch of the Tellus Project book, held at the RIA, Dublin, October 5 2016
- Paper (in preparation) on the application of the process to the Tellus and Tellus Border data sets.
- Paper (in preparation) on the application of mixture modelling to threshold selection.

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

The project will have impacts in two key areas. Firstly the novel application of mixture modelling to determine the threshold values for the singularity index will remove the potential for subjective results emanating from the concentration area method. This in turn should result in a more reliable set of thresholds for the dataset and eliminate false anomalies produced by inaccurate thresholds.

The second impact anticipated is the application of the singularity analysis to identifying prospective mineral targets in the Tellus/Tellus Border region and the further potential for the method to be applied to the addition datasets currently being collect by GSI. The potential for the method has been demonstrated by comparing results with the known mineralisation in Longford-Down, so it is conceivable that the method can be used as an additional prospecting tool, both in Ireland and globally.

Project Expenditure (double click on table below to activate). The GSI reserves the right to request evidence of expenditure if required.

Item	*Cost €*
Personnel costs	23511.39
Student fees	0
Consumables	0
Travel (incl. Fieldwork)	668.23
Other (please specify..)	0
Total	**24179.62**
Contribution (cash & in-kind), if applicable	0
Total requested from GSI	**24179.62**

Explanation of budget deviation, if applicable *(max 500 words)*:
The drop in value of Sterling post the UK referendum on exit from the EU has resulted in budget deviations due to changes in the exchange rate between Sterling and the Euro.

GSI Funding programme

Please provide some comments on the GSI Short Call funding programme (max 500 words):

Positive: Without the short call this project would not have been carried out within the time scale which it was. Not only did it provide the impetus for the work but it has enabled the application of a novel technique to the datasets collected as part of the ongoing Tellus Project. The technique is applicable across any of the Tellus geochemical datasets and could lead to additional economic discoveries across Ireland.

Negative: The project preparation was rushed due to the timescale between announcing and project submission. More time to consider what might be possible within the time frame of the proposed project would be better.

Appendix 1 – Publications & Presentations:
See cover page for formatting.

Appendix 2 – Any additional information not included above: