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

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Organisation name	Aurum Exploration Services		
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Contract No.	2015-sc-051



2. Project information:

Title of project	Characterisation of Mining Waste
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

In recent years, resource efficiency has moved to the forefront of strategic thinking with respect to securing the future supply of raw materials. Secondary Raw Materials form a significant pillar in the sustainability of Europe's access to both critical and non-critical raw materials. From an economic standpoint, two main strategic challenges exist within a raw materials framework. A high dependence on imports and an insecure supply are risks to a strong and stable industrial base. The European Commission has created a list of Critical Raw Materials (Table 1) which combine a high economic importance with a high risk associated with their supply (Figure 1). Many of these materials have only recently increased in economic value, e.g. those involved in the manufacture of electronics, energy critical elements (ECEs) etc., and may have been ignored where present in historic mining operations. As

such, mine waste has been earmarked as a valuable potential source of raw materials.

On a national level, previous work by the Geological Survey (GSI), the Environmental Protection Agency (EPA) and the Exploration and Mining Division has emphasised the pollution potential and risk characterisation of sites (Environmental Protection Agency Ireland 2009), with no regard given to the potential asset value of these facilities.

Antimony	Beryllium	Borates	Chromium	Cobalt	Cooking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural Graphite	Niobium
PGMs	Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten	

Table 1 Critical Raw Materials 2014 (Reference)

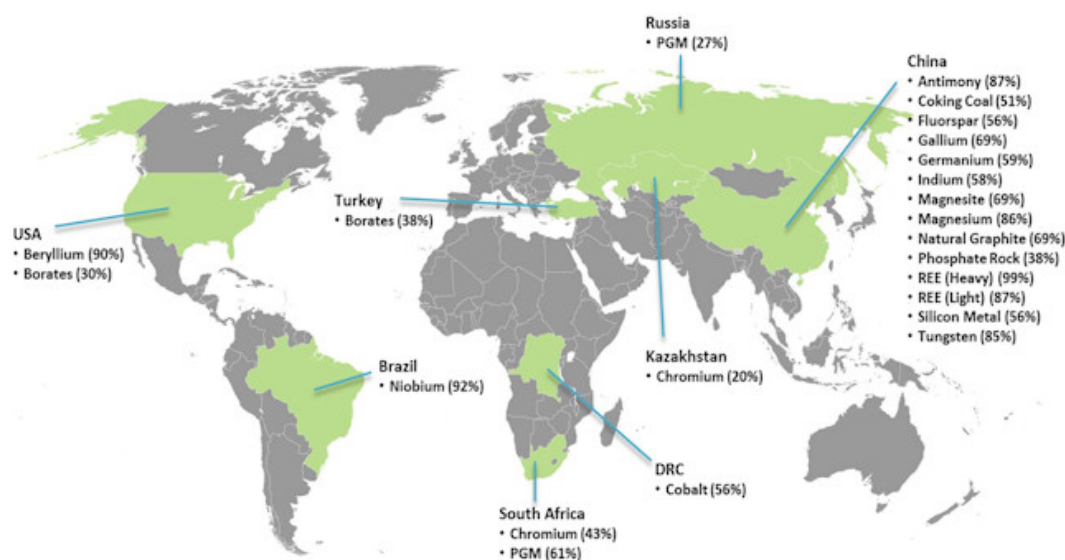


Figure 1 Sources of CRMs

The primary objective of this project was to analyse samples of mine waste from sites across Ireland, with an emphasis on their economic potential. The project has expanded the current knowledge of mine waste and its potential as a raw material source.

Given the large costs associated with historic mine remediation processes, there is the potential for some of this cost to be offset by the economic exploitation of the hazardous material. Similarly, the necessary costs of remediation may also reduce the concentrations at which specific raw materials may be economically extractable. A preliminary economic assessment of mine waste has not been undertaken previously in Ireland.

Within the waste material examined as part of this study, it is clear that Avoca has the most interesting assemblage from an economic point of view. While Glendalough has high lead and relatively high silver values, none of the other mine sites have enough samples with the grades that may be of economic interest. With high gold, silver, copper and Rare Earth contents, the waste dumps at Avoca however are deserving of further analysis (Table 2)

While hard rock open pit mines with low grades are relatively common around the world, mine waste mineral extraction projects frequently operate at much lower grades. The Kounrad facility in Kazakhstan processes ore at 0.1% copper (Central Asia Metals PLC 2015) compared to 0.2% for some copper mines. Similarly while some gold mines can produce at grades under or around 0.5g/t, DRDGOLD are currently

processing material from the large Witwatersrand tailings stockpile at 0.24g/t Au (DRDGOLD 2016).

Average and maximum values from Avoca			
	Tailings	Spoil	Maximum
Au (g/t)	0.054	1.575	9.980
Ag (g/t)	0.654	23.515	91.900
Cu (%)	0.042	0.226	1.125
TREO (%)	0.046	0.141	0.258

Table 2 Average and maximum values for selected elements in Avoca waste dumps.

Conclusions

- The majority of historic Irish Mine Waste stockpiles included in this study can be dismissed as of no economic value.
- Avoca is the mine site which this study found to have the greatest economic potential.
- The spoil material at Avoca has significantly more potential than the tailings material.
- Further work is needed to fully assess the quantity and value of the Avoca material.
- Combining resource extraction with a remediation or rehabilitation project may allow sub-economic resources to be reclaimed, thus mitigating the cost of environmental protection.

Recommendations

- This project was limited by the sample suite available from the HMS study. It is recommended that the Avoca historic mine waste is studied further to fully assess the value and quantity of material present.
- There are significant mine waste stockpiles not included in this project. These include Lisheen, Galmoy and Navan lead zinc mines and the waste material from Aughinish Alumina in Foynes, Co. Limerick. It is recommended that they should be similarly examined and their economic potential assessed.
- State and semi-state bodies in Ireland make a vast quantity of data available to users at no charge. It is recommended that these available datasets (e.g. soil, rock and water geochemistry) from the Geological Survey, the EPA, EMD, Teagasc, Tellus Project etc., are compared to the results from this project to ascertain if they can provide any additional pertinent information.
- It is recommended that the data generated from this project regarding the rare earth distribution in the study areas is further examined to improve knowledge of the mineralisation present in the specific districts.

References

Central Asia Metals PLC. 2015. *Annual Report*.

Crowe, Schaffalitzky & Associates Limited. 1992. *A Review of the Gold Resources in Mine Dumps at Avoca, Co. Wicklow*.

DRDGOLD. 2016. *Annual Integrated Report*.

Environmental Protection Agency Ireland. 2009. *Historic Mine Sites- Inventory and Risk Classification: Volume I*.

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

The research project largely followed the planned programme. The timeframe had to be extended as the lead researcher was unavailable for a 3-month period (June-August) due to other work commitments. The cooperation and assistance from staff within the GSI who assembled the original HMS dataset was invaluable.

(iii) Outputs (please use bullet points)

- A full comprehensive report on the project delivered to the GSI including a set of recommendations arising from the work undertaken.
- An INSPIRE compatible dataset including all new analyses undertaken in the course of the project.
- A Poster presented at Geoscience 2016.
- This project has increased the value of the Geological Survey's HMS study by using the samples and original results in a new economic framework
- It is proposed that a peer-reviewed paper is published from results.

Impact/value of the project (Max 500 words):

With an extremely small number of samples from each area, this study did not permit any quantitative analysis of the contents of the Irish mine waste stockpile. However a qualitative examination of the results and comparison to other worldwide deposits concludes that only Avoca may warrant further assessment. This conclusion will allow for any remediation projects at examined sites, other than Avoca, to proceed without the possibility that economically valuable material could be ignored or wasted.

At Avoca, the cumulative values of gold, silver and copper content compare favourably to economic deposits worldwide. In particular, the gold values compare favourably to the average grade at DRDGOLD's South African stockpiles with only 6 of the Avoca samples containing less gold than the 0.24g/t average grade in Witwatersrand (DRDGOLD 2016).

The gold content reported from the current study for Avoca is within the ranges reported by the CSA study (1992), which estimated approximately 18,000oz of gold in a specific selection of heaps. This suggests that further work should be undertaken at Avoca to quantitatively assess the contents of the waste material. Initial work should focus on the Cronebane/Mount Platt dump area, where it is estimated that almost 50% of the waste material is located.

The primary conclusion of this study is that there is enough evidence to encourage further investigations at Avoca particularly with respect to combining resource extraction with a remediation or rehabilitation project, thus mitigating the cost of environmental protection.

The project has also demonstrated the additional value which can be generated from existing datasets and sample archives.

Appendix 1 – Publications & Presentations:

[Conference Poster] Mc Grath, E. (2016) An Economic Assessment of Irish Mine Waste *Geological Survey of Ireland Geoscience 2016 Conference*, Dublin Castle, Dublin, Ireland, 02-NOV-16

Appendix 2 – Any additional information not included above:

Comprehensive report and dataset arising from the research included.

An Economic Assessment of Irish Mining Waste

An Economic Assessment of Irish Mining Waste

Prepared For:

The Geological Survey of Ireland

8th December, 2016

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Contents

1. INTRODUCTION.....	4
1.1 Background.....	4
1.2 Project Objectives and Deliverables	5
1.3 Definition of a historic mine site	6
1.4 Overview of geology of Ireland	7
1.5 Mining History of Ireland	8
2. PREVIOUS STUDIES	9
2.1 Historic Mine Sites – Inventory and Risk Classification.....	9
2.2 Analogous Research Studies	9
EnviREE project	9
ProSUM	10
USGS.....	10
3. SAMPLING AND ANALYTICAL METHODOLOGY	11
3.1 Spoils	13
3.2 Tailings.....	13
4. STUDY AREAS	14
4.1 Abbeytown	15
4.2 Avoca	16
4.3 Clare Pb	17
4.4 Caim.....	17
4.5 Donegal Pb	18
4.6 Silvermines	18
4.7 Glendalough	20
4.8 Gortdrum.....	21
4.9 Tynagh	22
5. LABORATORY RESULTS AND INTERPRETATION	23
Introduction	23
5.1 Base Metals	24
5.2 CRM	27
5.3 Precious Metals.....	31

5.4	Results by district	32
	Abbeytown.....	32
	Avoca.....	32
	Caim	36
	Clare Pb	36
	Donegal Pb	36
	Glendalough.....	36
	Gortdrum	37
	Silvermines.....	38
	Tynagh.....	38
6.	PRELIMINARY ECONOMIC ASSESSMENT OF MINE WASTE.....	39
6.1	A review of recent mining and mine waste projects	39
	DRDGOLD	39
	Cínovec.....	40
	Central Asia Metals	40
	Quest Rare Minerals	41
	Other	42
6.2	Comparison to current study	42
6.3	Economic assessment	43
7.	COMPARISON OF CURRENT RESULTS TO HMS STUDY	45
8.	CONCLUSIONS.....	47
9.	RECOMMENDATIONS	47
10.	References	48

Figures

Figure 1 Sources of CRMs (European Commission 2014).....	5
Figure 2 Outline map of Ireland showing location of Mine Waste in this project	14
Figure 3 Log/Log plot of elemental values from duplicates of sample GOR-07-AGR01.3.....	23
Figure 4 Cu content in Mine Waste samples by area	25
Figure 5 Pb content in Mine Waste samples by area	25
Figure 6 Zn content in Mine Waste samples by area	26
Figure 7 Ni content in Mine Waste samples by Area	26
Figure 8 Sb content in Mine Waste samples by area	28
Figure 9 Cr content in Mine Waste samples by area	28
Figure 10 Co content in Mine Waste samples by area	29
Figure 11 Ga content in Mine Waste samples by area	29
Figure 12 Nb content in Mine Waste samples by area.....	30
Figure 13 Total Rare Earth Oxide content in Mine Waste samples by area.....	30
Figure 14 Ag content in Mine Waste samples by area	31
Figure 15 Cu in Avoca waste material.....	33
Figure 16 Cr in Avoca waste material	33
Figure 17 Ag vs Au in Avoca waste material (log/log plot)	34
Figure 18 Au in Avoca waste material	34
Figure 19 Total Rare Earth Oxides in Avoca waste material.....	35
Figure 20 Rare Earth Element distribution in the Avoca tailings.	35
Figure 21 Copper and Silver at Gortdrum.....	37
Figure 22 Silver and Arsenic at Tynagh	38
Figure 23 Sn lab values from this study compared to lab results from HMS study	45
Figure 24 As lab values from this study compared to XRF values from HMS study.....	46

Tables

Table 1 Critical Raw Materials 2014 (European Commission 2014).....	4
Table 2 Location of samples selected for this project	11
Table 3 Preparation and Analyses conducted by ALS Minerals Loughrea.....	12
Table 4 Estimated volumes of waste, Abbeytown Mine	15
Table 5 Estimated volumes and tonnage of spoil material, Avoca.....	16
Table 6 Estimated volumes of waste, Clare lead district	17
Table 7 Estimated volumes of waste, Glendalough district	20
Table 8 Estimated volumes of waste, Gortdrum.	21
Table 9 Estimated volumes of waste, Tynagh	22
Table 10 Au data for standards including result from ALS analysis.....	24
Table 11 2016 JORC compliant mineral resource estimate for Witwatersrand mining waste.	40
Table 12 2014 JORC compliant mineral resource estimate for Kounrad waste dumps.	41
Table 13 2012 JORC compliant mineral resource estimate for Chañaral Beach Tailings	41
Table 14 Reserve grades from producing copper mines (*2015 production grades)	42
Table 15 Average and Maximum values for selected elements in Avoca waste dumps.....	43

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1. INTRODUCTION

1.1 Background

In recent years, resource efficiency has moved to the forefront of strategic thinking with respect to securing the future supply of raw materials. Secondary Raw Materials form a significant pillar in the sustainability of Europe's access to both critical and non-critical raw materials. From an economic standpoint, two main strategic challenges exist within a raw materials framework. A high dependence on imports and an insecure supply are risks to a strong and stable industrial base. The European Commission (European Commission 2014) has created a list of Critical Raw Materials (Table 1) which combine a high economic importance with a high risk associated with their supply (Figure 1). Many of these materials have only recently increased in economic value, e.g. those involved in the manufacture of electronics, energy critical elements (ECEs) etc., and may have been ignored where present in historic mining operations. Additionally, within the Europe 2020 strategy, Resource Efficiency is one of the seven flagship initiatives that are currently the focus of much work across the continent. As such, mine waste has been earmarked as a valuable potential source of raw materials.

On a national level, the National Sustainable Development Strategy for Ireland (Dept. of Environment 2012) has identified Resource Efficiency as a key measure in improving sustainability. Within the implementation plan arising from this report, Resource Efficiency has been assessed as an immediate priority requiring the "Whole of Government" to contribute. The current national focus on Ireland's historic mine sites and current mine waste facilities is overwhelmingly from an environmental perspective. Previous work by the Geological Survey (GSI), the Environmental Protection Agency (EPA) and the Exploration and Mining Division (EMD) has emphasised the pollution potential and risk characterisation of sites, with no regard given to the potential asset value of these facilities. Assessing the resource potential of a significant component of the country's mine waste stockpile would contribute to Ireland's implementation of this strategy.

Antimony	Beryllium	Borates	Chromium	Cobalt	Cooking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural Graphite	Niobium
PGMs	Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten	

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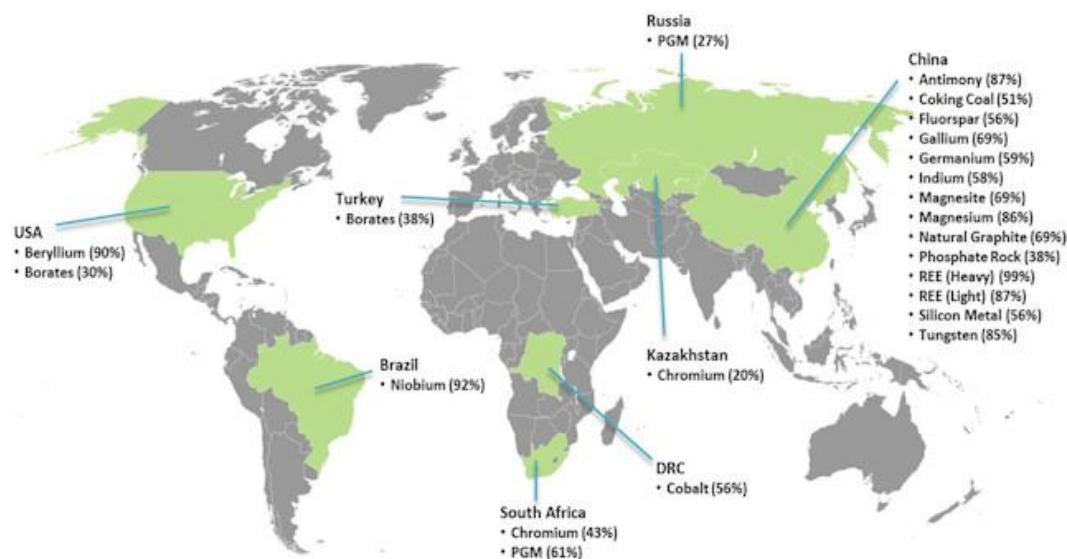


Figure 1 Sources of CRMs (European Commission 2014)

1.2 Project Objectives and Deliverables

The primary objective of this project is to analyse samples of mine waste from sites across Ireland, with an emphasis on their economic potential. The samples selected are those collected as part of the EPA's Historic Mines Site Inventory and Risk Classification project (HMS) (Environmental Protection Agency Ireland 2009) and the study will focus on Europe's Critical Raw Materials (CRMs). The project will also provide an INSPIRE compatible dataset that can be directly contributed to the ProSUM project by Geological Survey. It will also assist in helping Aurum Exploration Services, an Irish SME, develop their research capabilities in the field of mining waste and tailings, improving the capacity of the private sector to attract business in new sustainable areas.

This project will expand the current knowledge of mine waste and assess its potential as a raw material source.

Given the large costs associated with historic mine remediation processes, there is the potential for some of this cost to be offset by the economic exploitation of the hazardous material. Similarly, the necessary costs of remediation may also reduce the concentrations at which specific raw materials may be economically extractable. A preliminary economic assessment has not been undertaken previously in Ireland and this project will perform this role as a secondary outcome.

The project will also improve the current state of knowledge of tailings composition in Ireland

1.3 Definition of a historic mine site

Mining is one of the most ancient industrial activities in the world. Early hematite mining in southern Africa has been dated to approximately 43,000 years ago, with mining in Ireland dating back into the Bronze Age. However, exploration of mineral resources has often been carried out without due recognition of the effects on the environment, especially prior to the 20th century. In the latter part of the 20th century, the environmental impacts of mining became more apparent and regulators responded to this by enhancing legislation and permitting requirements.

Not all mining is created equal however, and there are significant differences in the waste and the hazards generated dependent on the mining activities involved. Early mining from prehistoric times through to pre-industrial revolution involved very little waste generation as the simple technologies available ensured that only extremely high grade deposits were worked. Additionally, early mining for copper, gold etc. created little in the way of hazardous waste. In contrast, the nineteenth and early twentieth century saw significant demand for metals in Britain leading to the establishment of many lead and copper mines across Ireland. The larger of these generated large piles of waste with high contaminant values, including lead and arsenic. These waste piles were largely left untreated and simply abandoned following closure of the mine.

The HMS study in 2009, from which the sample suite for this project was generated, was driven by the requirement of Article 20 of the extractive industries waste directive issued in 2006. This states the following:

‘Member States shall ensure that an inventory of closed waste facilities, including abandoned waste facilities, located on their territory which cause serious negative environmental impacts or have the potential of becoming in the medium or short term a serious threat to human health or the environment is drawn up and periodically updated.’

The study consequently focused only on historic mine sites which had associated waste material, discounting numerous sites at which waste is not present.

1.4 Overview of geology of Ireland

Ireland contains a wide variety of Geology in a small area. A small belt of Precambrian rocks outcrops in the northwest of the country with Lewisian and Grenvillian gneisses present. These are overlain by late Precambrian and Lower Palaeozoic rocks which record the development and closure of the Iapetus Ocean across a NE-SW suture zone through central Ireland.

Lower and Middle Devonian rocks related to fault controlled continental basins are preserved predominately in the south and southwest of the country, where significant thicknesses of sediment are present. They are covered by the largely flat lying Carboniferous limestones that dominate the areal extent of the country. Post Carboniferous deposits within the country are limited to small grabens such as at Kingscourt, although larger outcrops occur in Northern Ireland.

Mineralisation in Ireland is found in several different settings. The Dalradian and Precambrian hosted mineralisation is related to sedimentation in fault controlled basins or volcanic arc development while there is also mineralisation related to granite plutons of Ordovician and Devonian age. Wicklow in particular hosts a number of mineral deposits associated with the Caledonian granite, including the historic mine sites at Avoca and Glendalough. The West Cork copper deposits are hosted in thick Devonian continental basins and likely derived from the clastic fill of the basins.

The majority of Ireland's mines sit within the Carboniferous stratigraphy, including Navan, Lisheen, Galmoy, Gortdrum, Silvermines and Tynagh. Navan and Silvermines are also located in close proximity to the Iapetus Suture Zone; a significant north-east to southwest mineralised trend within in the Irish Midlands.

Within the post Carboniferous, the Kingscourt Inlier hosts a gypsum mine focused on production for the construction industry.

1.5 Mining History of Ireland

The earliest evidence of metal mining in Ireland is provided by Bronze Age copper workings at Ross Island, Co. Kerry in southwest Ireland. These workings, dated at between 2,400 and 2,000 BC (O'Brien 1996) constitute the oldest recognised in northwest Europe. Few records remain of mining activity prior to the major period of mining in the 19th century. Sparse texts attest to iron working at Avoca (Co. Wicklow) in the 2nd century, to iron and copper mines in the 9th century, alum mining in the 12th century and lead-silver workings and copper mining around 1500. Better information exists for the 16th and 17th centuries, when small-scale iron workings are known to have flourished across the eastern half of Ireland. The iron ores exploited included gossans from Avoca, carbonate ore (ironstones) from the coalfields and the widespread bog iron ore. By the early 1700s, the iron industry was much reduced in Ireland, primarily due to the exhaustion of timber supplies that were used in the production of charcoal for smelting.

The Irish mining industry expanded in the late 18th and 19th centuries, triggered by the needs of the Industrial Revolution in Britain. Copper mining boomed in southwest Ireland, especially at Allihies, and there was significant exploitation of lead, copper (e.g. Avoca) silver, coal, barite, manganese and slate elsewhere (see Cole, 1922 for a detailed inventory of all sites from which extraction took place). Much of the metal mining was sporadic and small-scale and there was a tendency to mine only the coarse-grained, metallurgically clean ores that could be manually cobbled.

The late 18th century also witnessed a local gold rush in Co. Wicklow. For six weeks in 1795, some 80kg of alluvial gold is estimated to have been recovered from what subsequently became known as the Gold Mines River. Following State intervention and dispersal of the gold diggers, mining was subsequently carried out by the Government (1796-1803), by the local populace (1804-39), and by a private company (1860). The total amount of gold recovered is calculated at some 300kg, although the true figure may be much higher.

The fall in metal prices ca 1880, caused the Irish mining industry to enter a period of prolonged depression. Up to the 1950s, the only mining of note was a period of bauxite production in Northern Ireland, pyrite for sulphur from Avoca, phosphate from the west of Ireland, barite from Benbulbin (1942-1960), and gypsum mining from the Kingscourt area (1936 onwards). Mining of thin coal seams also continued from the Arigna, Rossmore and Ballingarry areas.

Today, Ireland is internationally known as a major zinc-lead mining province. Over the last 40 years a string of significant base metal discoveries have been made and exploited, including the giant ore deposit at Navan (>70Mt). Zinc-lead ores were also mined until recently from two other underground operations in south-central Ireland: Lisheen and Galmoy.

2. PREVIOUS STUDIES

2.1 *Historic Mine Sites – Inventory and Risk Classification*

The Historic Mine Sites – Inventory and Risk Classification (HMS-IRC) project was a joint project of the Environmental Protection Agency, the Department of Communications, Energy and Natural Resources (DCENR), the Geological Survey of Ireland and the Exploration and Mining Division. The project, which commenced in February 2006, was managed by the GSI and the work was completed in 2009.

This project identified waste piles and other features associated with closed/abandoned mines in Ireland. It also identified broader issues of health and safety and the environment linked to closed mine sites. It provided a comprehensive understanding of each mine site/district and scored 27 mine sites/districts (encompassing 82 individual sites) relative to each other.

2.2 *Analogous Research Studies*

EnviREE project

Despite recent numerous exploratory and research efforts in the EU aiming at strengthening REE supply chains using European sources of rare earth elements (e.g. FP7 EURARE project), important REE-containing materials have not been properly addressed. Since many of the promising materials are chemically very different, a general method of REE recovery cannot be found. The ENVIREE project is aimed at completing the picture of effective REE supply within Europe by addressing exploitation of specific secondary sources.

The project's goal is to generate a complete extraction process proposal for these secondary sources of REE. Currently it is investigating innovative leaching followed by selective and effective separation of the metals.

The ENVIREE objectives include:

- to develop novel and environmentally friendly leaching processes for different waste materials
- to develop environmentally friendly and economical separation processes for the different materials depending on which metals are to be recovered
- to ensure that the above processes comply with normal process optimization, e.g. grain size, solid to liquid ratio etc. and all possible chemicals like extraction and leaching agents will be recirculated
- to assure environmental and economic feasibility of the processes including their energy efficiency, mine closure and rehabilitation when relevant.

ProSUM

ProSUM, Latin for 'I am useful', is a European project focused on **P**rospecting **S**econdary Raw Materials in the **U**rban Mine and **M**ining Wastes. Its objectives are related to the European Union's push towards a circular economy, and it is planned to deliver an Urban Mine Knowledge Data Platform. From a Mine Waste perspective, this will provide a centralised database of all available data and information stocks, flows and treatment of mining wastes. It will also integrate primary and secondary raw materials data, easily accessible all-in-one platform which provides the foundation for improving Europe's position on raw material supply, with the ability to accommodate more wastes and resources in future.

USGS

The USGS Crustal Geophysics and Geochemistry Science Center completed a major project 'Metal and Mineral Commodities in the Built and Waste Stream Environments' which included a focus on recovery and reuse of metals from waste streams within the USA. Examples of waste streams studied include slag, sludge, drainage and waste from mining, compost facilities, landfills, and various industrial and municipal waste streams.

The objectives of this task were to determine the elemental composition of various waste-stream materials, and to investigate the metal-recovery potential of valuable and critical commodities present in diverse waste streams including mine waters and historical mining wastes. The task provided a reconnaissance study of the existence and characteristics of mineral and metal commodities present in various types of waste streams.

3. SAMPLING AND ANALYTICAL METHODOLOGY

A sampling programme is a significant expense incurred in any geochemical project, and it is important that all samples are fully leveraged to generate as much useful data as possible. One key aspect of this project was to significantly increase the value of the Geological Survey Historic Mine Waste Inventory samples (HMS study) by using them in a new economic framework. As such, the sample selection was constrained by the available sample suite archived within the Geological Survey. The HMS study selected 27 districts within Ireland from 32 initially assessed. Several districts contained numerous sites (e.g. Avoca). Only those districts and sites where waste material is present were included.

For this study, it was decided to exclude the samples generated from the various coal mining areas. This was due to a combination of budgetary constraints and an initial evaluation of potentially economically viable sites. Of the 27 districts included in the HMS, 9 districts which had physical samples available within the Geological Survey were selected for this project. This totalled 176 samples (Table 2).

Location	Number
Abbeytown	5
Avoca	31
Caim	4
Clare Pb	4
Donegal Pb	2
Glendalough	60
Gortdrum	49
Silvermines	5
Tynagh	16
Total	176

Table 2 Location of samples selected for this project

The sampling methodology is described in detail within the HMS report (Environmental Protection Agency Ireland 2009). It focused on field analysis using an FP-XRF analyser allowing semi-quantitative in-situ analysis of mine waste and quantitative laboratory-based analysis of prepared samples. Approximately 10% of sites analysed in the field were sampled for follow-up analysis. The samples were passed through a 2mm nylon sieve before being quartered and ground to 85% < 75 µm in a contaminant free mill. The samples were then analysed by the Geological Survey by portable XRF using a bench-top docking station. Most of these samples were also sent to a certified commercial laboratory where they were analysed by inductively coupled plasma – atomic emission spectrometry (ICP-AES) after multi-acid digestion. As the HMS investigation focused on contaminants, no analysis was conducted for gold, PGMs or REEs.

The material for the current project consisted of the remaining ground material and the coarser sieved material from each location. Remaining ground material from the HMS study

samples were preferentially selected in order to reduce processing costs at the laboratory. Samples were submitted to ALS Minerals, Loughrea, Co. Galway on March 8th 2016. An analysis for four acid digestion with multi-element ICP-MS including Rare Earth Elements was requested. Four acid digestion quantitatively dissolves nearly all minerals in the majority of geological materials, however it must be noted that this data will represent the acid leachable portion of the rare earth elements only. In addition to the standard analyses, numerous samples with high values of Pb, As, Cu, Zn, and Ag were analysed for ore-grade values to ensure a complete dataset. Results of the analyses were available on March 23rd 2016.

Following the initial analysis of the results it was decided to submit the remaining portions of samples from the Avoca district to ascertain gold, palladium and platinum content via fire assay and ICP-AES finish. A second aliquot of the ground material from the Geological Survey sample suite was submitted for each of the Avoca samples. In 6 cases, insufficient ground material (<30g) was available to support a secondary analysis. For these samples, aliquots from the coarser sieved material were submitted and prepared by ALS prior to fire assay. Samples were submitted on 25th October 2016 and results of the analyses were available on 9th November 2016. A summary of the preparation and analytical techniques is presented in Table 3.

No. of samples	Lab Code	Description
185	ME-MS61r	4A multi-element ICP-MS + REE
7	Ag-OG62	Ore Grade Ag - Four Acid
85	ME-OG62	Ore Grade Elements - Four Acid
6	Cu-OG62	Ore Grade Cu - Four Acid
77	Pb-OG62	Ore Grade Pb - Four Acid
36	Zn-OG62	Ore Grade Zn - Four Acid
1	Ag-GRA21	Ag 30g FA-GRAV finish
2	Pb-OG62h	High Grade Pb – 4Acid
2	Me-OG62h	Extended Ore Grade 4-Acid
3	As-OG62	Ore Grade As - Four Acid
Preparation and Gold/PGM analysis on Avoca Samples		
6	PUL-31	Pulverize split to 85% <75 µm
35	PGM-ICP23	Pt, Pd, Au 30g FA ICP

Table 3 Preparation and Analyses conducted by ALS Minerals Loughrea

A summary of the field collection methodology adopted by the HMS study samples is presented in sections 3.1 and 3.2 for mine spoils and tailings respectively.

3.1 Spoils

For single spoil heaps of relatively homogeneous appearance, the aim was to obtain an estimate of the range and median element concentrations in the heap. For every 5 to 10 field XRF sample spots a 0.5 – 1kg sample of material from the spot analysed was collected and returned to GSI lab for processing.

3.2 Tailings

A similar approach to that for spoil heaps was applied to tailings. Additionally, multiple samples from differing depths were gathered by either digging a pit or using a handheld auger.

4. STUDY AREAS

Samples from total of nine areas were selected from the HMS inventory for use in the current study. The locations of these sites are shown in Figure 2 and each is described in the following sections. Estimates of the volume of mine waste material at each site are taken from the HMS study.

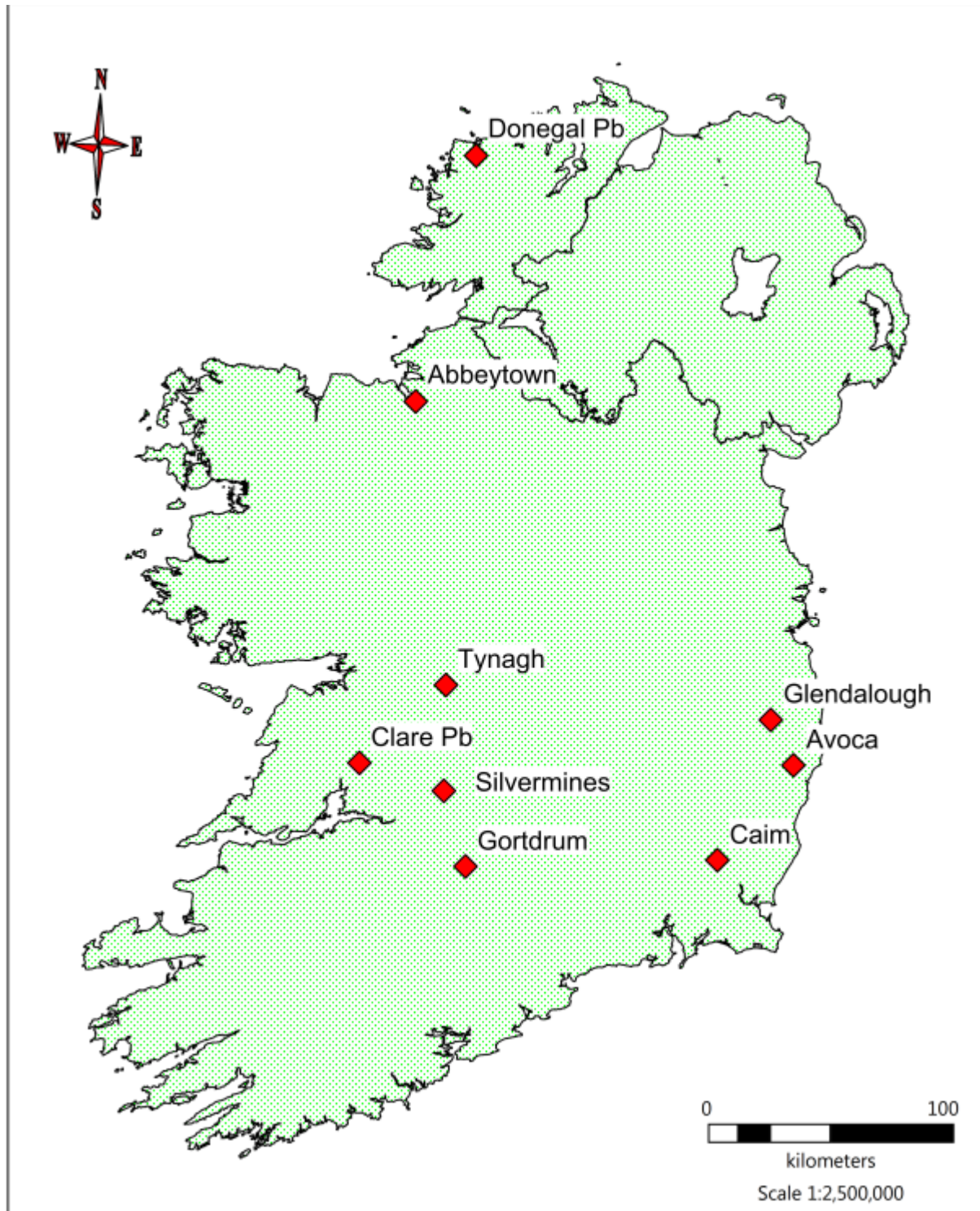


Figure 2 Outline map of Ireland showing location of Mine Waste in this project

4.1 Abbeytown

Abbeytown mine is located immediately west of Ballysadare village in Co. Sligo, 6 km south of Sligo town (Figure 2). The site covers approximately 30 ha. The mine was last worked in 1961 and since then has been largely subsumed by a large limestone quarry that now extends beyond the original boundaries of the mine site.

The mineralization is hosted by the Lower Carboniferous Abbeytown Limestone Formation, a transgressive carbonate sequence of calcarenites, shale and sandstones, and the overlying Ballyshannon Limestone Formation, comprising thick-bedded calcarenites. The Abbeytown Limestone Formation unconformably overlies the metasedimentary basement of the Ox Mountains Inlier. Three main mineralizing events were recognized by Hitzman, (1986). The mineralization has been related to extensional movement on two faults that terminated in the Abbeytown area. The textures and timing of the mineralization relative to the host-rock suggests that Abbeytown can be classified as an MVT deposit.

Abbeytown was originally mined for silver as well as lead and zinc. The earliest documented workings were in the 18th century, though it is likely that the deposit was mined at an earlier date. Production was intermittent until the 1870s when a group of local merchants reopened the mines. Hundreds of tons of ore were produced in this period and again between 1917 and 1921. In the aftermath of the Second World War, metal prices were controlled and, as a consequence of demand, very high. At its peak, Abbeytown produced 280-300 tons of ore per day. It closed in 1961 after exhaustion of the main ore zone. Total production is estimated to have been 1.1 Mt of c. 1.5% Pb, 3.8% Zn and 40-45g/t Ag.

The site today has three main components remaining from the mining period; the Tailings Management Facility, now partly revegetated and partly used as a host for quarry settling ponds; the tailings spill on the foreshore and the extant underground mine workings, accessible through the modern quarry. The open pit has now been subsumed by the modern quarry.

The major extant surface feature at Abbeytown is the tailings pond, its surface now covered by soil and hardcore and in use for various quarry-related works. During the last period of mining a major tailings spill created a large fan of contaminated material on the foreshore. Since this is an active quarry site and subject to monitoring by Sligo County Council, the samples taken during the HMS project were largely confined to the tailings pond and the contaminated material on the foreshore. Estimates of the volumes for each area are presented in Table 4.

Location	Volume (m ³)	Area (m ²)
Foreshore	68,958	34,479
Tailings	136,141	19,611

Table 4 Estimated volumes of waste, Abbeytown Mine

4.2 Avoca

The Avoca mining area is located in the eastern foothills of the Wicklow Mountains some 55 km south of Dublin. The Vale of Avoca divides the mine sites into East and West Avoca. These mine sites cover approximately 0.34 km² and 0.29 km² respectively, extending from the river onto the higher ground on either side of the valley to the north east and south west. The main ore bodies, from which pyrite and copper were extracted, occur as generally stratiform lenses up to a few tens of metres thick at top of the Ordovician Avoca Formation, a sequence of silicified and altered chloritic tuffs overlain by sericitic tuffs and felsites.

The main ore types are banded sulphides with more than 95% pyrite accompanied by chalcopyrite, sphalerite and galena, vein or disseminated ore invariably associated with silicification and containing pyrite and chalcopyrite and lead zinc ore with banded pyrite, galena and sphalerite. All three have minor quantities of arsenic and bismuth minerals.

There is evidence to suggest that Avoca was worked for copper as long ago as the Bronze Age (c.2500-600 BC) and possibly through medieval times. From the 12th century, the site was mainly producing iron but this had been exhausted by the end of the 17th century. The earliest documented activity at East Avoca was in 1752 when 500 miners were reported to be at work at “Crone Bawn” (Cronebane), most likely producing lead. Up to the 1850s copper was the most important mineral produced. After this date, iron pyrites was the dominant mineral being mined. Sulphur, from the pyrites, was produced from 1840-1865 and intermittently until 1949, especially during the two World Wars. Minor amounts of gold, silver and zinc have also been extracted over the life of the deposit but these were never significant.

There are numerous occurrences of mine waste at Avoca, with the most prominent of these being the waste rock from the Cronebane pit. A former tailings facility is located at Shelton Abbey, to the south of the mine location. The content of the East Avoca waste dumps was assessed by Crowe Schaffalitzky and Associates (CSA) in 1992 with a calculation of approximately 850,000t of waste material present (CSA, 1992). This assessment did not include the West Avoca dumps at Ballygahan or Ballymurtagh which the HMS study estimated to contain a total volume of 420,000m³. Table 5 summarises the findings from the two reports. The West Avoca volumetric assessment has been converted to a mass estimate by applying the density used in the CSA report.

Location	Volume (m ³)	Tonnage (t)	Density (t/m ³)
East Avoca	1035805	849350	0.82
West Avoca	422278	346260	0.82
Total	1458087	1295610	

Table 5 Estimated volumes and tonnage of spoil material, Avoca

4.3 Clare Pb

The Clare lead mines district consists of several mine sites within 10km of Ennis, Co. Clare at Ballyhickey, Ballyvergin and Kilbricken. Table 6 shows the estimated volume of waste material at each site.

Kilbricken is approximately 5km east of Ennis. Limited production records are available but the main source of revenue appears to have been silver. The first ore shipped contained 70% Pb and 120 oz/ton Ag (Cole 1922). Mining was conducted between 1834 and approximately 1855. The old dressing floor at Kilbricken is grassed over, however solid waste is visible in places.

Ballyhickey was discovered by Taylor in 1834 (Cowman 1992) while seeking an extension of the lode at Kilbricken, 2 km to the southeast. Approximately 2500 tons of ore were extracted from an opencast pit in the first four years. Mining appears to have died out rapidly after 1838 and by 1840 production had declined to around 40 tons per month with the ore considered to have been nearly “worn out” (Cole 1922). However, there are records of minor production up to 1846. Some coarse-grained mine waste lies around the base of the chimney and the remains of the engine house but most of the solid waste on the site is covered by soil and grass.

Ballyvergin was worked for a total of eight years between 1853 and 1861 (Cowman 1992). In addition to copper, lead and silver, sulphur was exported to England. Production ended as the mineralization became less economic with depth. Irish Base Metals carried out a modern exploration programme at Ballyvergin in the 1960s. Estimates of the size of the existing deposit vary from around 150,000 to 230,000t grading 1-1.2% Cu and 15g/t Ag (Andrew 1986a).

Location	Area (m ²)	Volume (m ³)
Ballyhickey	8,425	4,212
Ballyvergin	2,323	7,928
Kilbricken	6,414	6,414

Table 6 Estimated volumes of waste, Clare lead district

4.4 Caim

Caim, or Ballyhighland mine, is located several km to the west of Enniscorthy, Co. Wexford. The mine was opened around 1815 but then abandoned in the 1820's due to a lack of appropriate machinery. It was reopened between 1836 and 1846 when some 3,000 tons of galena were extracted. Minor extraction continued until 1855.

The mine site now comprises two distinct sections: the northern part, where most of the mining activity occurred, is largely overgrown with trees and shrubs, notably gorse, while the southern part is the site of a large heap of processing waste. It is estimated that there is approximately 24,000m³ of waste material at Caim.

4.5 Donegal Pb

The Donegal lead district is comprised of the Glentogher and Keeldrum historic mine sites. Of these, Keeldrum is the only site for which samples were available from the HMS study.

Keeldrum is located approximately 8.5km north of Gweedore in Co. Donegal. It was the site of a nineteenth century lead mine. The extraction took place between 1825 and 1832 producing an estimated 1689 tons of ore (Cole 1922). Mineralisation at Keeldrum is hosted by the Dalradian Falcarragh Pelite Formation but lithologies in the mine area include pelites, quartzites and metamorphosed basic intrusions. Galena occurs in quartz veins, in brecciated quartzite and most commonly in the amphibolites which also contain some pyrite.

A large waste heap at the site comprises a considerable proportion of mine waste and appears to have been created in the course of field clearance. Smaller waste heaps are present in the northern part of the site around the ruins of the engine house and processing building. An estimated 1,361m³ of spoil is present on site.

4.6 Silvermines

The Silvermines District is in County Tipperary, on the northern flank of the Silvermines Mountains. It extends west for 5 km from the village of Silvermines, approximately 8km from Nenagh. Mining took place intermittently at Silvermines for over 1000 years, from the 9th century until 1993. Zinc, lead, silver, copper and barite were produced, with the bulk of production taking place in the second half of the 20th century during a period of large-scale modern mining.

The mineralization at Silvermines is hosted by basement rocks of the Silurian and Devonian Old Red Sandstone and by the overlying Lower Carboniferous succession (Andrew 1986b). The geology of the area is dominated by a complex of faults known as the Silvermines Fault that was active during sedimentation and mineralization. Mineralization occurs in fracture zones and as replacements within the Silurian greywackes, Devonian clastics and Lower Dolomite of the ABL and as stratabound zones within brecciated and dolomitized Waulsortian Reef Limestone. All the replacement mineralization occurs within or close to the Silvermines Fault zone.

The fracture-fill and replacement ores lie closest to the Silvermines Fault and were mined at Ballygown, Garryard, Gorteenadiha and Shallee. Together they contained an estimated 4.75 million tons grading 2.44% Pb and 5.49% Zn. The stratabound mineralization is estimated to have contained around 13 million tons grading 2.55% Pb, 6.78% Zn and 5.5 million tons of 85% BaSO₄ (Andrew 1986b).

Earliest mining records date back to the 9th century when the Danes extracted silver from argentiferous galena (Andrew 1986b). Sporadic operations between the 17th and 19th

centuries raised Cu, Pb, Ag, Zn and sulphur from small-scale mines along the Silvermines Fault. The period of large-scale modern mining began in 1963 when Magcobar began working the stratabound barite deposit from an opencast pit. In 1968 Mogul commenced underground mining of Pb and Zn at Garryard, exploiting the stratabound mineralization in the Waulsortian as well as the fracture-fill and replacement mineralization along the Silvermines Fault. Mogul produced some 10.7 million tons of ore grading 2.7% Pb and 7.36% Zn. Magcobar continued mining barite until 1992, producing more than 5.5 million tons.

Waste material from the Silvermines District can be subdivided, on the surface, into six individual sites, incorporating both modern and pre-20th-century sites. These individual sites do not incorporate all mine features in the district. However, they do include all the significant known waste sources. The six sites are Ballygown, Magcobar, Garryard, Gorteenadiha, Shallee and Gortmore tailings management facility (TMF). The Silvermines District has been investigated in detail since 1999 by various Government departments and agencies as part of a detailed risk assessment. As a consequence, no major investigation was carried out as part of the HMS project. Only 5 samples were collected, two from Gortmore and three from Garryard.

The Gortmore TMF was built by Mogul to store the tailings produced by its large-scale underground mining at Garryard, 2 km to the east. The total TMF footprint, including the outer embankment, is 76 ha with the tailings covering approximately 58 ha. The total volume of tailings in the TMF is estimated to be just over 5,000,000 m³.

The Garryard area is the location of the former Mogul surface plant and mine access shaft. Substantial processing waste is present in this area, particularly where the ore was stockpiled prior to processing. The volume of waste material at Garryard is estimated to be in the region of 70,000m³.

4.7 Glendalough

The Glendalough mining area is located in the eastern foothills of the Wicklow Mountains some 50 km south of Dublin. It consists of several individual mine sites located over three adjacent valleys. The twin valleys of Glendasan and Glendalough are the northernmost of the sites, with Glendasan further south.

The first reference to lead mining in Wicklow is in the early 19th Century. Lead was first discovered in Glendasan and later these veins were followed through the mountainside to the adjacent valley of Glendalough. The Camaderry Mountain separates the two valleys and the two mine areas. The Glendasan area includes the Foxrock mine on the northern flank of the valley, the Hero processing site (adjacent to the obvious car park on the southern flank of the valley), the Ruplagh area at the western end of the valley and St. Kevin's mine at the foot of the valley where the most recent workings were centred. The workings in the Glendasan Valley were connected by a tunnel through Camaderry Mountain into Glendalough. This allowed for natural drainage of the shafts and tunnels and made transportation of the ore for processing in Glendalough Valley easier. The Glendalough Miners' Village was located at the western end of this tunnel.

There were three distinct phases to the mining at Glendasan/Glendalough. The first phase was associated with the development of the mines by the Mining Company of Ireland from 1825 until 1890. The second phase was a re-working of the mines and tips by the local Wynne family from 1890-1925. A modern operation between 1948 and 1957, the final phase, concentrated on the development of new workings at depths below old workings in the Glendasan Valley.

Further south, the historic mines of Glenmalure were all worked for argentiferous lead although none were substantial enterprises. Various sources note a total of six principal lead mines, with or without zinc and copper in the Glen. These mines included Ballinafunshoge, which is one of the sample sites in this study.

Remains of mining activities are visible at various points in the district. The most conspicuous are off - white coloured spoil heaps composed principally of fine quartz and rock debris. Additional material is located at the various processing sites. Estimates of volumes within the Glendalough district are presented in Table 7.

Location	Volume (m ³)	Area (m ²)
Spoil	150,556	271,422
Tailings	13,257	4,713

Table 7 Estimated volumes of waste, Glendalough district

4.8 Gortdrum

The Gortdrum Cu-Ag-Hg orebody is situated in southwest Tipperary, c. 2.5 miles due east of Limerick Junction. It lies on the northern side of an ENE-trending normal fault (the Gortdrum Fault, dipping at 70°N), adjacent to a pre-Carboniferous inlier, in basal Carboniferous Courceyan limestones.

The strata-bound (Snelgrove 1966) base metal deposit exhibits predominantly structural control (Thompson 1966). Folding and faulting, produced pre-mineralisation high porosity by recrystallisation, shearing and brecciation. The orebody is divided into two parts. The western end lies between the main fault and an easterly trending vertical dyke complex, which intersects the fault at about the centre of the mine area. At the eastern end the ores are relatively high grade and occur for the main part in a narrow fault-bounded wedge of crushed and partially dolomitized limestones and breccias, which extends into the Devonian sandstones for about 100m below the limestone base.

Total production over the lifetime of the mine is estimated (Tyler 1979) to be 34,737 tonnes Cu, 82,704 kg Ag and 271,029 kg Hg. At the original grade of 1.19% Cu, this implies over 3.5 million tonnes of ore were mined.

The waste material in Gortdrum can be divided into four distinct areas. The tailings management facility (TMF) is now revegetated and in use by the land-owner as a cattle pasture and the open pit is now flooded and is a 90m deep lake used for fish farming. Several large waste heaps and stockpiles on the northern side of the open pit lake now serve as source material for aggregate production and the old mine processing area in the southeast corner of the site contains the remains of processing buildings and the mercury plant siltation pond.

Samples available from Gortdrum include 9 from the tailings facility, 3 from the spoil heaps, 5 from the aggregate material, 2 from the processing area and 30 from the siltation pond. Estimates of waste volumes at Gortdrum are presented in Table 8.

Location	Area (m ²)	Volume (m ³)
Tailings	348,439	3,348,077
Spoil Heaps	1,922	845
Aggregate Material	309,340	2,334,465
Processing Area	848	424
Siltation Pond	12,120	12,120

Table 8 Estimated volumes of waste, Gortdrum.

4.9 Tynagh

The Tynagh mine site is located 1.5 km north of the village of Tynagh, Co. Galway. The former mine site covers an area of approximately 115 hectares which is broken up into different sections with the tailings management facility (TMF) covering an area of approximately 48.5 ha.

The host geology of the mine site is Waulsortian Reef Limestone. The mine is located along a fault line and as a result the bedrock geology varies over short distances. The principal ore minerals present on the site were galena, sphalerite, chalcopryrite, pyrite, arsenopyrite, tetrahedrite and bornite. The main gangue or host minerals were barite and calcite. Minor quantities of silver occurred in association with galena and copper sulphides and some mercury was also associated with copper sulphosalts. The major minerals which were extracted were lead, zinc, copper, silver and barium sulphide.

Diamond drilling began in 1961 and eventually defined three ore bodies, a secondary ore body overlying a primary orebody with the third lying along the fault to the east. Production of the secondary orebody commenced in 1965 from the open pit and continued from this source until 1974. The underground production of ore from the primary orebody then commenced from the bottom of the open pit. The mine ceased operation in 1982 and the mining lease expired in November 1983.

Primary crushing of the ore was done underground. After grinding in the mill at the processing area on the surface, the fine material underwent thickening and froth floatation. From 1965 to 1980 approximately 8 million tonnes of ore were produced. Initial reserves for the primary ore were estimated to be 5.8 million tonnes of approximately 4% Pb, 4% Zn, 0.6% Cu and 56 g/t Ag (Hutchings 1979). The richer secondary ore had initial reserves of 4 million tonnes of up to 9.9% Pb, 7.4% Zn, 1.3% Cu and 100 g/t Ag. Barite was a major component of the gangue and Ba was recovered from the tailings in a separate processing plant operated by Milchem.

Extraction of Pb and Zn from the secondary ore was less efficient than extraction from the primary ore. As a consequence, the tailings produced during processing of the secondary ore are relatively rich in metals. This is reflected in the high Pb and Zn concentrations measured during the HMS project.

The samples taken for the HMS project include 3 samples of spoil and 13 samples from the tailings facility. Estimated volumes for mine waste at Tynagh are listed in Table 9.

Location	Area (m ²)	Volume (m ³)
Spoil	160,054	1,409,291
Tailings	515,377	10,284,078

Table 9 Estimated volumes of waste, Tynagh

5. LABORATORY RESULTS AND INTERPRETATION

Introduction

Samples were submitted to ALS Minerals, Loughrea, Co. Galway on March 8th 2016. An analysis for four acid digestion with multi-element ICP-MS including Rare Earth Elements was requested. In addition to the standard analyses, numerous samples with high values of Pb, As, Cu, Zn, and Ag were analysed for ore-grade values to ensure a complete dataset. Results of the analyses were available on March 23rd 2016.

On 25th October 2016, samples pertaining to the Avoca area were submitted to ALS Minerals to determine Au, Pd and Pt content by fire assay and ICP-AES finish.

QA/QC

The initial samples submitted included 4 blank samples and 5 duplicated samples. No certified reference materials (standards) were submitted with the first batch. All of the duplicated samples returned consistent results within the expected margin of error. Figure 3 shows excellent duplication of analytical results.

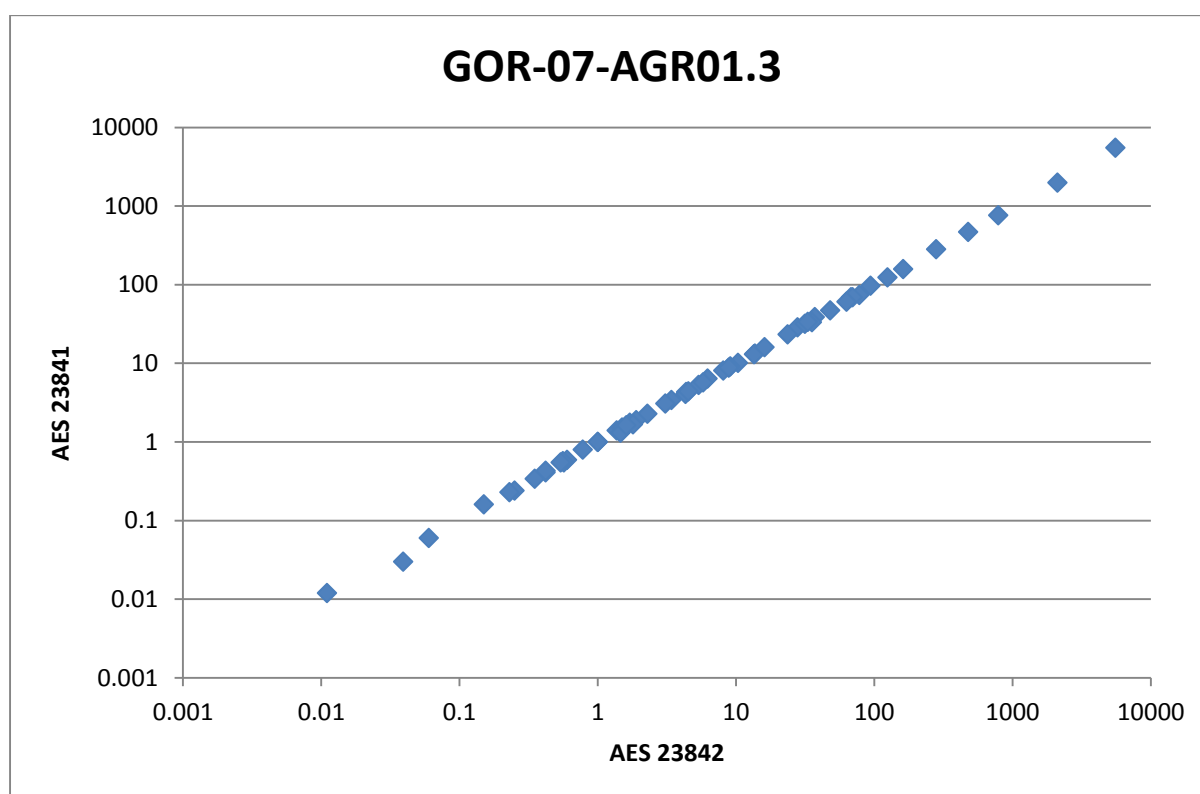


Figure 3 Log/Log plot of elemental values from duplicates of sample GOR-07-AGR01.3

2 gold standards (OREAS 66a and OREAS 68a) and 2 blank samples were submitted with the second batch of Avoca samples for PGM analysis. No duplicates were submitted due to insufficient material available. The inserted blanks were within acceptable thresholds and

show no evidence of contamination Results for the standards (Table 10) were within the expected ranges.

Standard	Certified Value Au (ppm)	1SD	Lower Threshold (-2 SD)	Upper Threshold (+2 SD)	ALS value
OREAS 66a	1.237	0.054	1.129	1.345	1.245
OREAS 68a	3.89	0.15	3.59	4.19	3.96

Table 10 Au data for standards including result from ALS analysis.

General Observations

The results show a high level of variability, both between different mining districts and between differing locations within each district. The results are limited by the samples available in the HMS archive, however it is possible to identify where potentially significant occurrences may exist within the mine waste stockpile.

The analytical data is included in an appendix to this report.

5.1 Base Metals

The base metals show a large variation between mine districts. The highest values of copper are found at Gortdrum with some high values present at Avoca (Figure 4). This is to be expected from the former copper mining sites. The extremely high values at Gortdrum are all from the processing area, with all 5 samples from this region returning >5% copper. These samples also have extremely high arsenic content as noted in the HMS report.

As expected, lead values are highest in the historic lead mining areas (Figure 5). The Clare, Donegal and Caim samples show the highest lead values, with all samples returning values of greater than 5% Pb. These values reflect the mining history of the regions and the high lead values in the spoil may be indicative of historically inefficient processing. The Glendalough district also shows elevated lead content in comparison to other sites.

Zinc values partially match the distribution of lead, with Glendalough and the Clare districts showing elevated Zn content (Figure 6). Silvermines and Tynagh also show high Zn content, reflecting their primary history as zinc producers in the twentieth century compared to the more historic mines where zinc may have been associated with the lead ore.

Nickel values are elevated at Gortdrum, Silvermines and Tynagh, with slightly higher than expected content at Abbeytown (Figure 7). The absolute values for Ni are several orders of magnitude less than the other base metals however, with a maximum value of 320 ppm Ni.

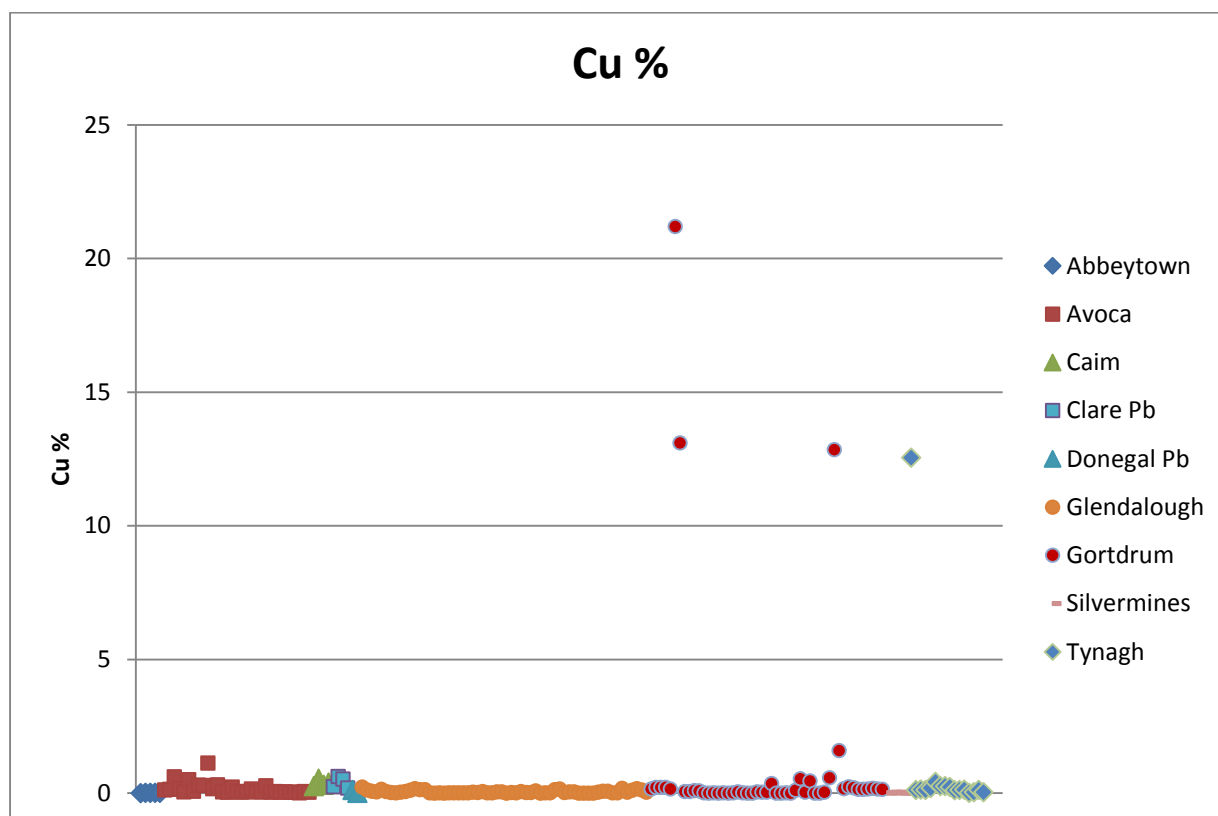


Figure 4 Cu content in Mine Waste samples by area

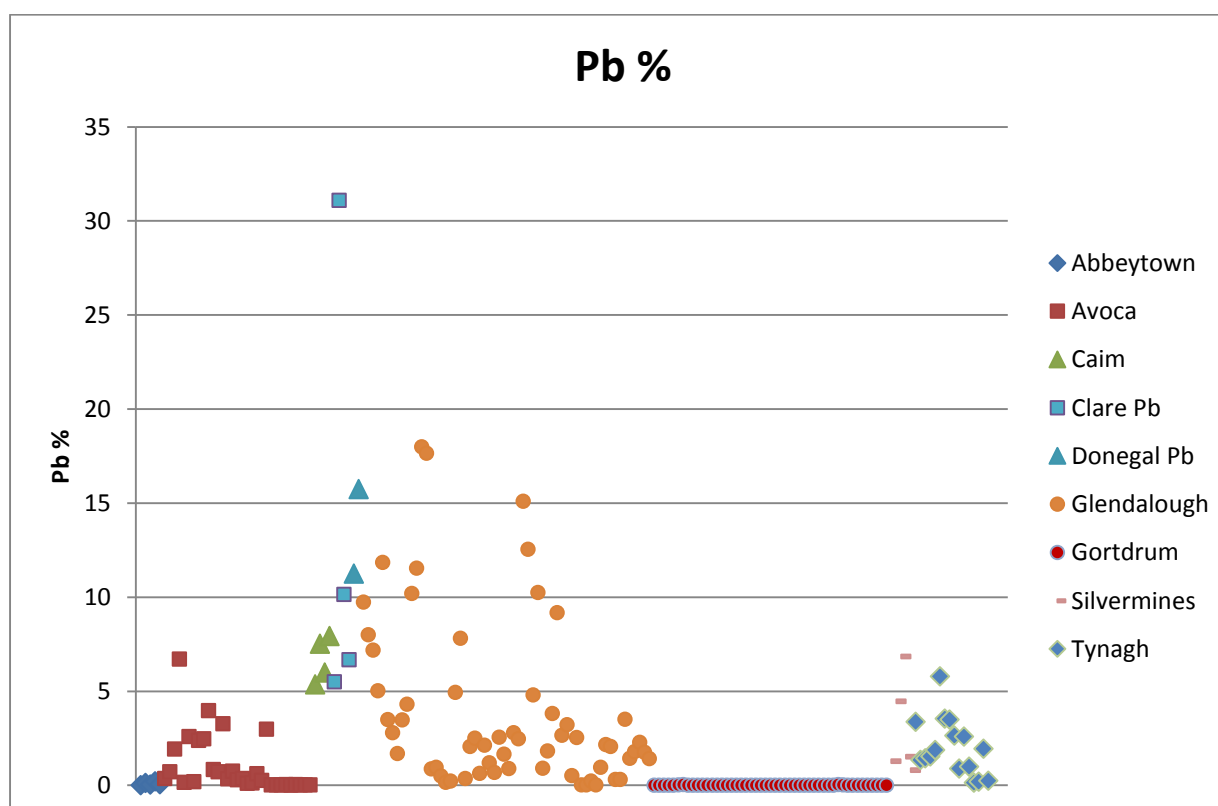


Figure 5 -Pb content in Mine Waste samples by area

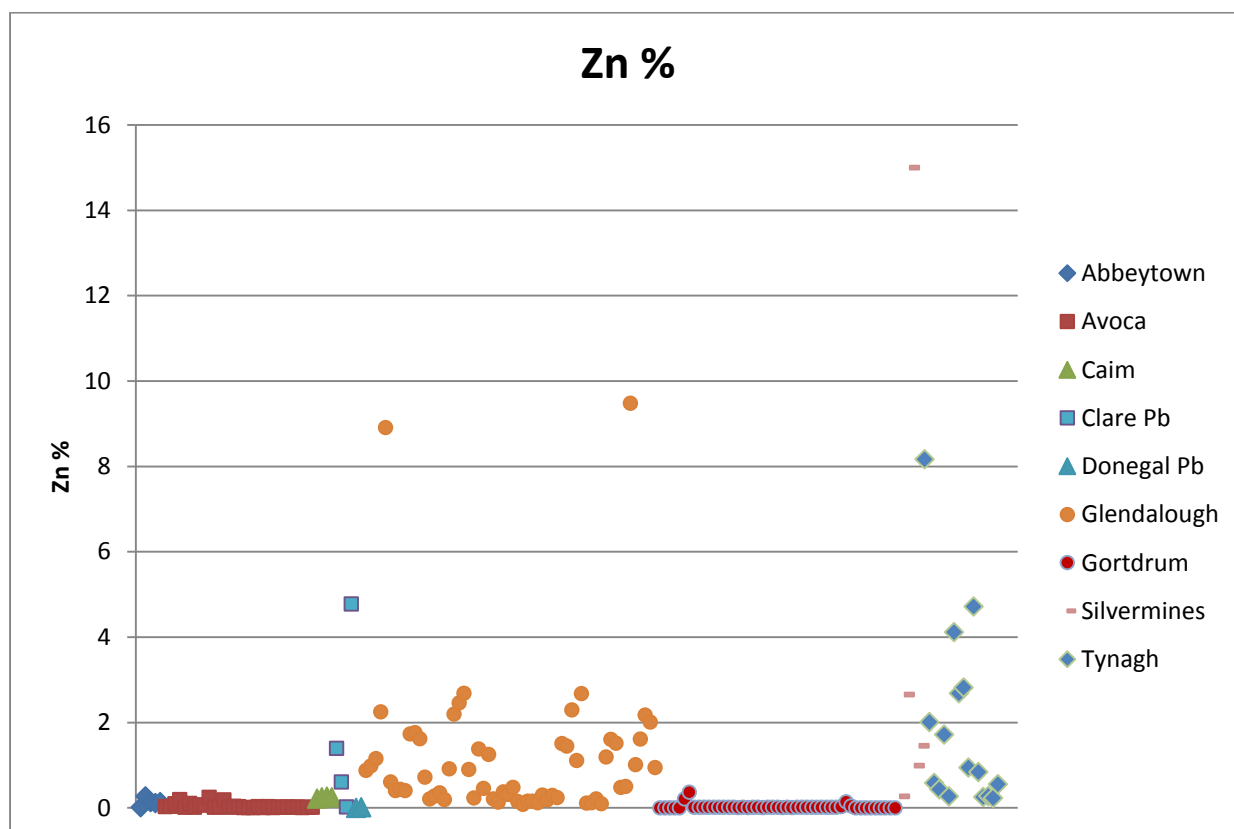


Figure 6 Zn content in Mine Waste samples by area

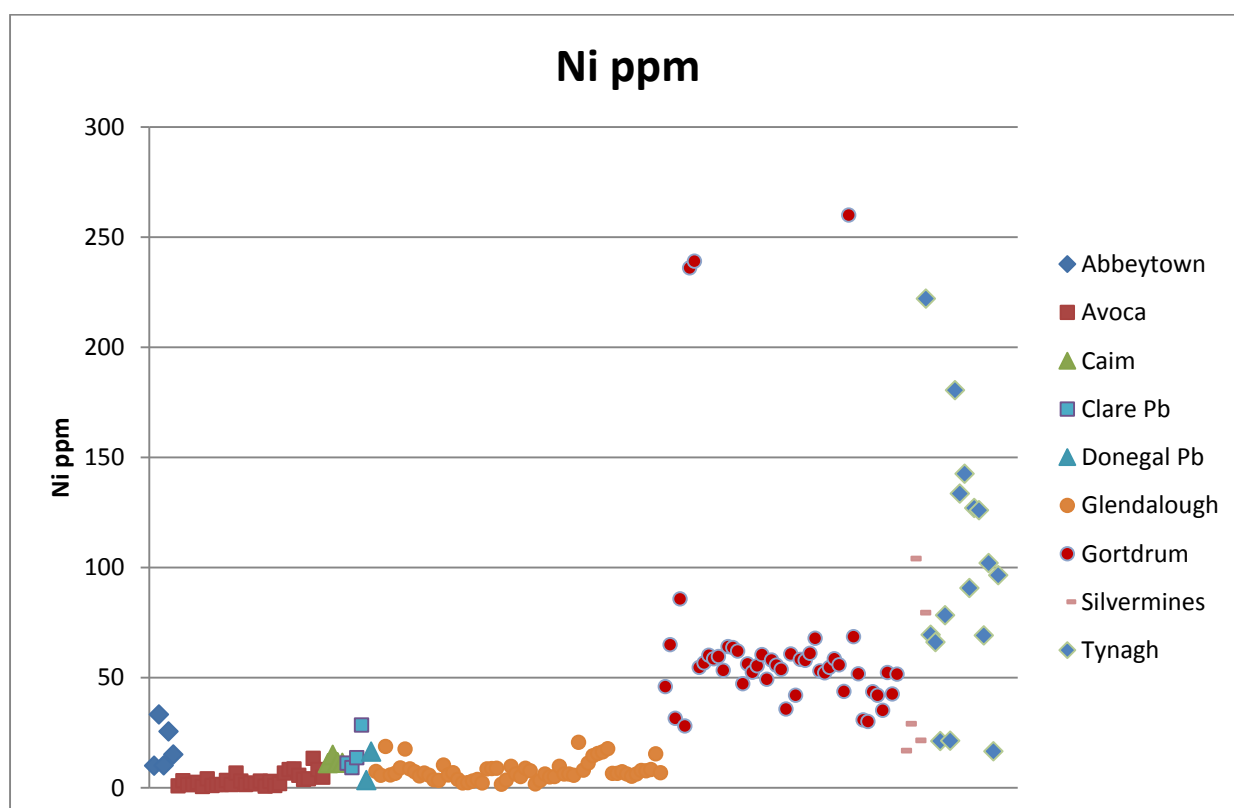


Figure 7 Ni content in Mine Waste samples by Area

5.2 CRM

The critical raw materials as defined by the European Commission (Table 1) have varying distributions across all the mine sites examined in this study. PGMs are categorised as CRMs however they are addressed separately in the Precious Metals section below (Section 5.3).

Antimony values are elevated at Gortdrum, Kilbricken (in the Clare Pb field) and at Tynagh (Figure 8). The high Gortdrum values are also the samples from the processing area of the mine site where high copper was observed.

Beryllium values are extremely low, with a maximum of 12.7ppm recorded. Glendalough has slightly elevated Be content in comparison to other sites however the absolute values are very low.

Chromium values are also low across the entire sample suite, with only one value from Tynagh higher than 100ppm (Figure 9).

Cobalt values are most elevated in Gortdrum and Tynagh mine waste compared to other areas, specifically the processing area samples at Gortdrum (Figure 10). There are however only 6 samples with Co results >100ppm.

Gallium, Germanium and Indium are frequently associated with sphalerite and zinc ore, therefore it is to be expected that former zinc mines would show higher concentrations of these elements. The highest values in this study are found in Glendalough and Avoca, with several Ge outliers from Gortdrum and Tynagh (Figure 11). The absolute values for Ge are extremely low as seen in the charts below.

Niobium is enriched in Avoca, with all samples containing >45ppm (Figure 12) and two samples >200ppm. Gortdrum has higher Nb content than the remaining sites, however there is only one sample from this district with >50ppm.

For the REEs, the accepted industry unit for reporting grades is total Rare Earth oxides (TREO). It is calculated by converting the elemental values to REE₂O₃ content and summing for all the rare earth elements. To ensure that any grades from this study can be compared to published reports under the CRIRSCO code (Committee for Mineral Reserves International Reporting Standards n.d.), the TREOs include La₂O₃, Ce₂O₃, Pr₂O₃, Nd₂O₃, Sm₂O₃, Eu₂O₃, Gd₂O₃, Tb₂O₃, Dy₂O₃, Ho₂O₃, Er₂O₃, Tm₂O₃, Yb₂O₃, Lu₂O₃ & Y₂O₃. Note that yttrium is included as a REE although it is not part of the lanthanoids. Scandium is also frequently considered a Rare Earth, however it is not included as such in this study. For investigating the distribution of the REES, the concentration values of Anders & Grevesse, (1989) have been used. Rare Earth elements are significantly enriched in the Avoca samples compared to all other areas, with up to an order of magnitude difference (Figure 13). 30 of 31 Avoca samples have higher REE content than any other samples in the project.

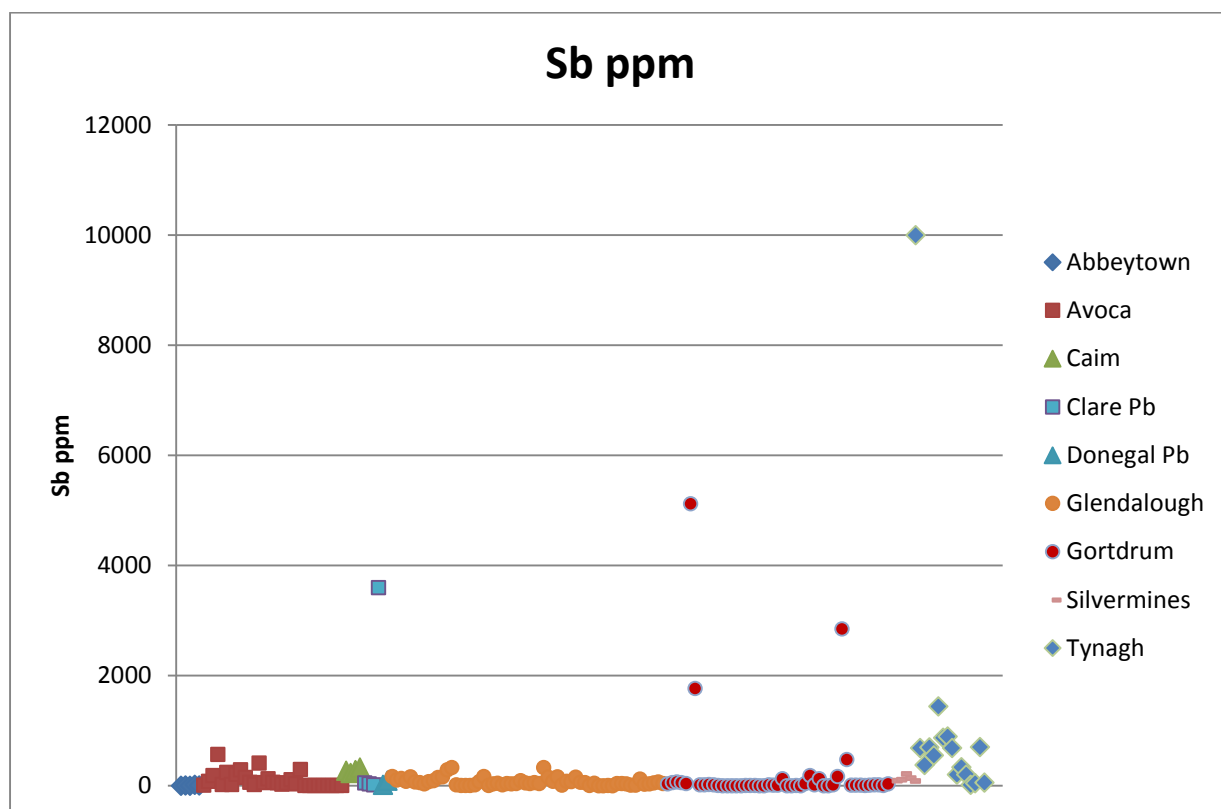


Figure 8 Sb content in Mine Waste samples by area

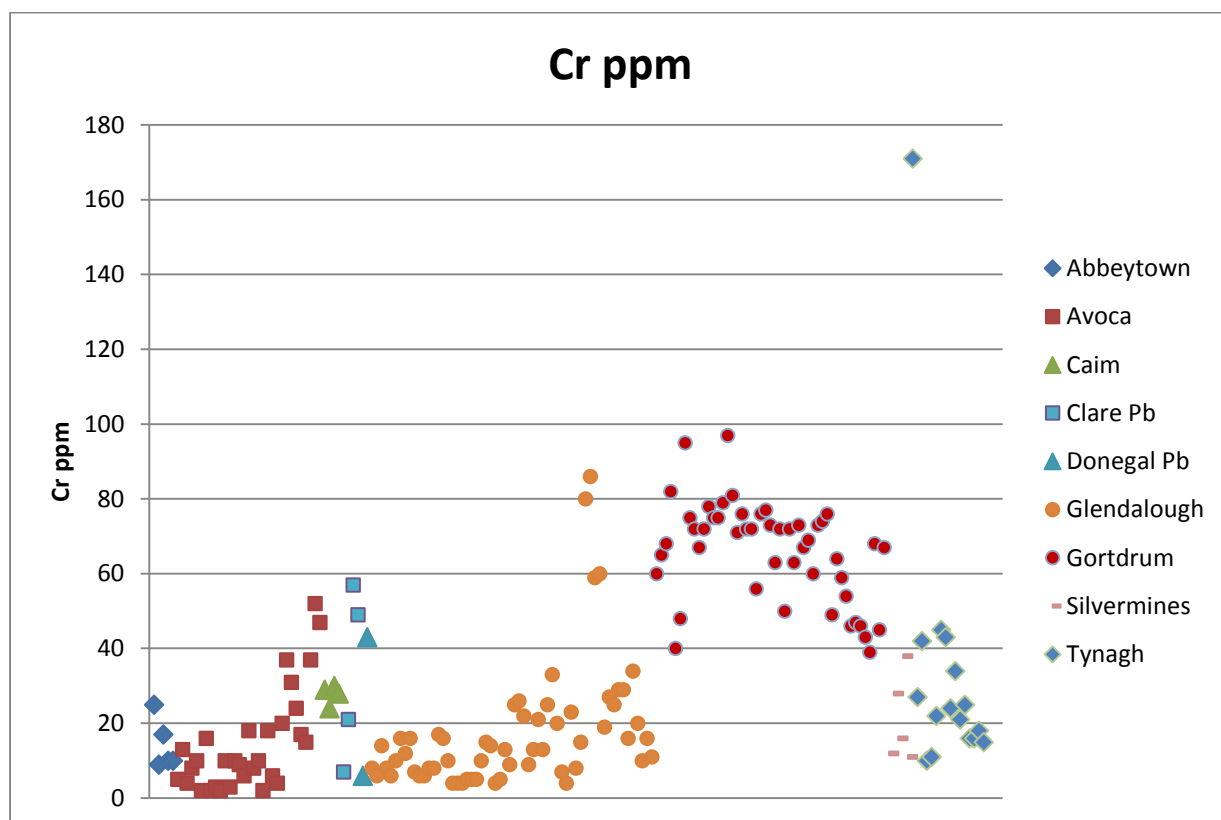


Figure 9 Cr content in Mine Waste samples by area

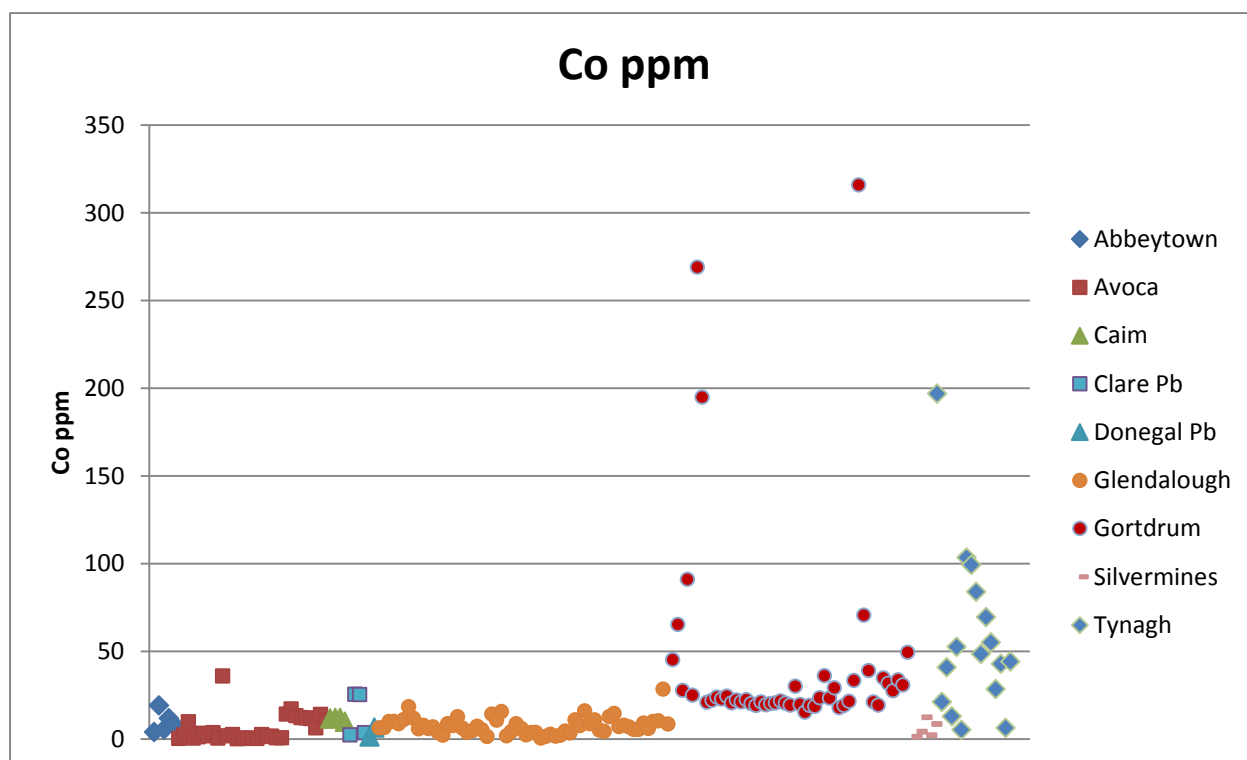


Figure 10 Co content in Mine Waste samples by area

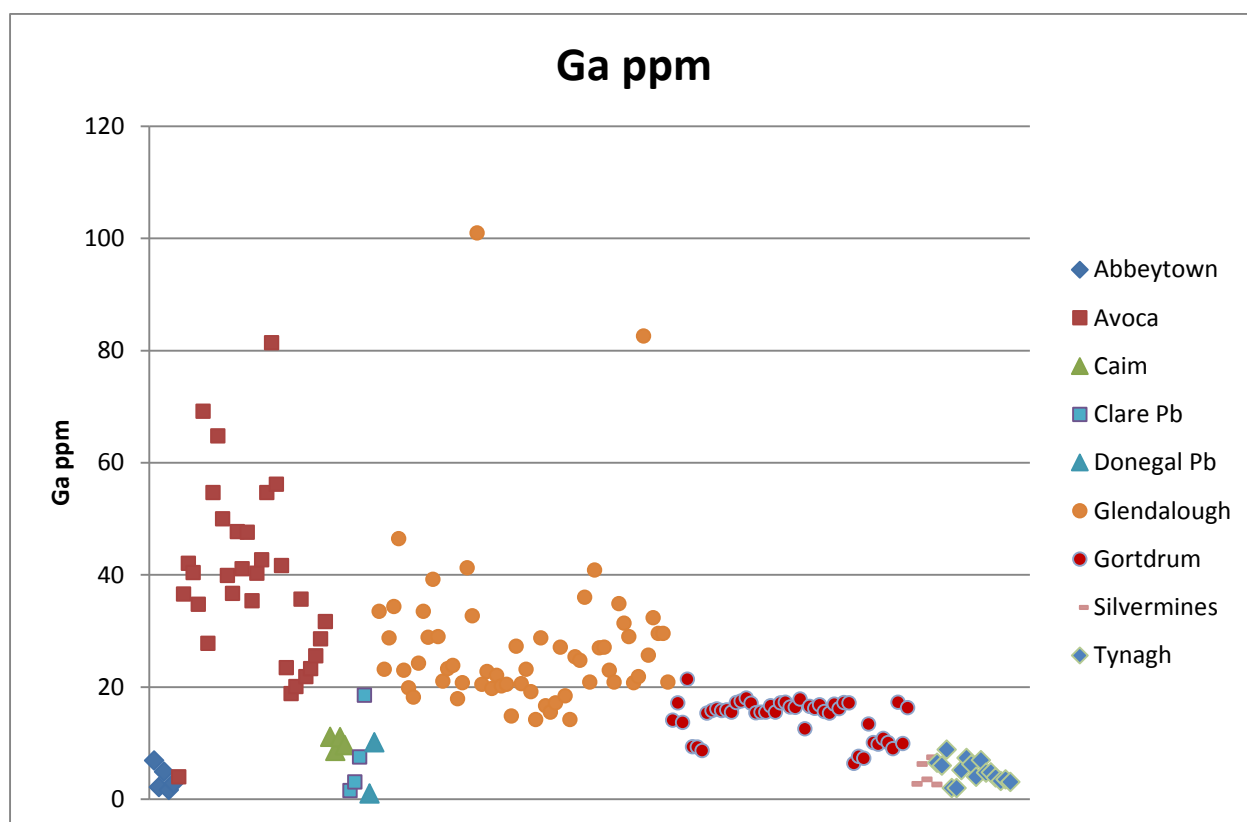


Figure 11 Ga content in Mine Waste samples by area

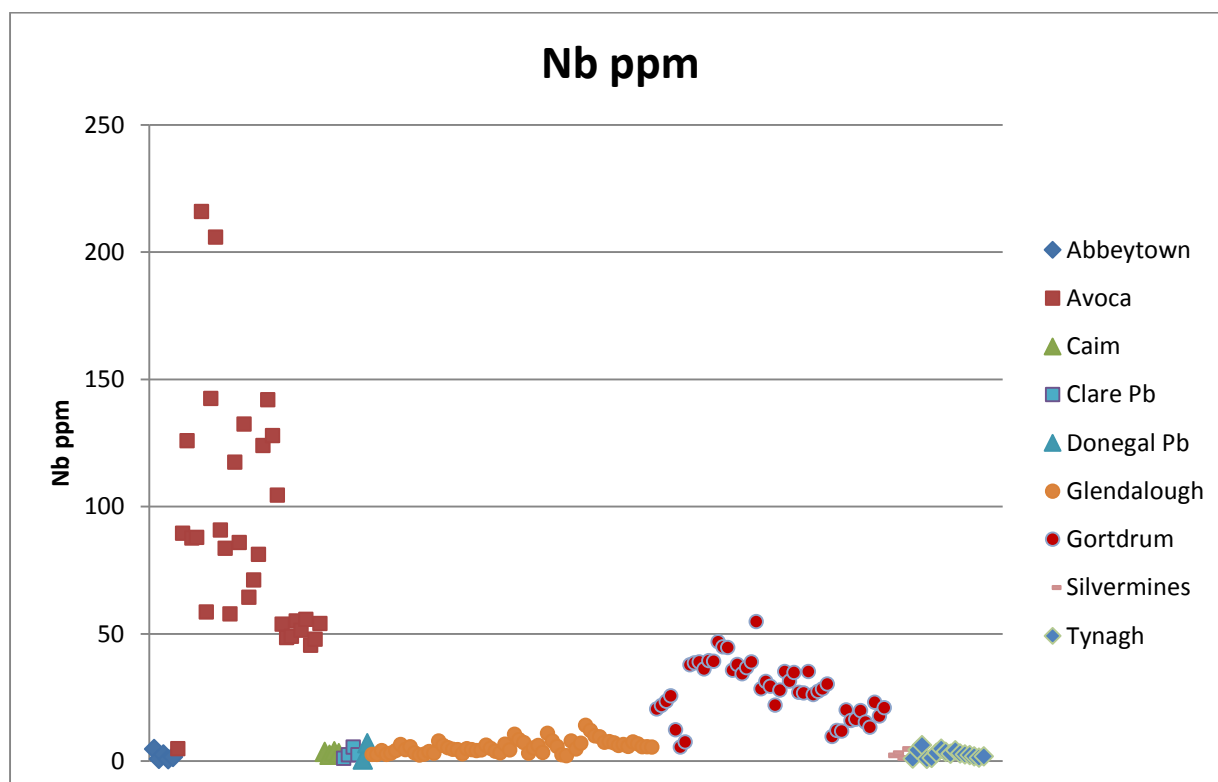


Figure 12 Nb content in Mine Waste samples by area

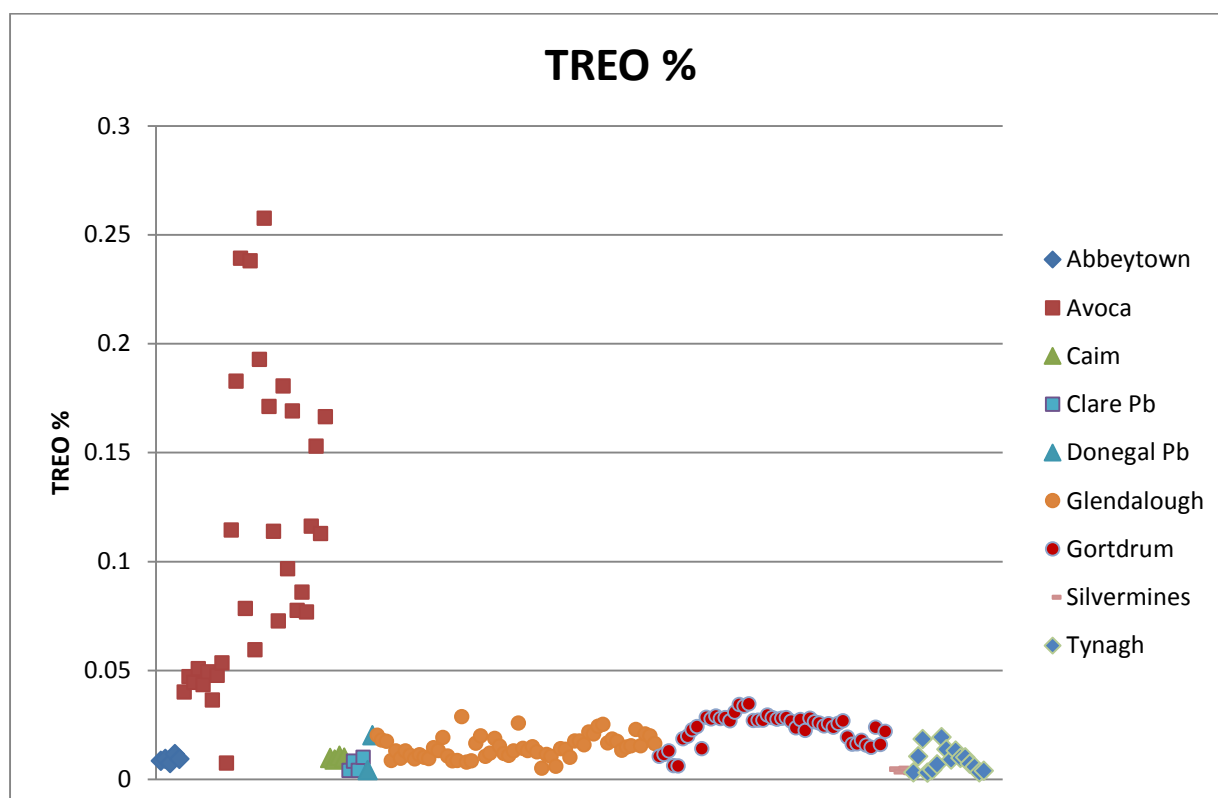


Figure 13 Total Rare Earth Oxide content in Mine Waste samples by area

5.3 Precious Metals

Silver is the primary precious metal that was analysed for all samples. Extremely high values were recorded for samples in the Clare lead district, at Gortdrum and at Tynagh, where one sample contained 1720ppm Ag (Figure 14). Relatively high silver compared to other sites was recorded across the entire suite of Clare and Tynagh samples, with some elevated values from Glendalough and Avoca. The processing area samples are the only ones from Gortdrum that show Ag > 20ppm.

Subsequent analysis for gold, platinum and palladium was conducted on the samples from Avoca. While Pt and Pd values were at or below detection limit for all samples, there were some high gold values recorded, up to 9.8ppm, with 8 samples returning values over 1ppm. These results are discussed further in the Avoca section below. Other PGM elements (Ru, Rh, Os & Ir) were not included in the analytical suite.

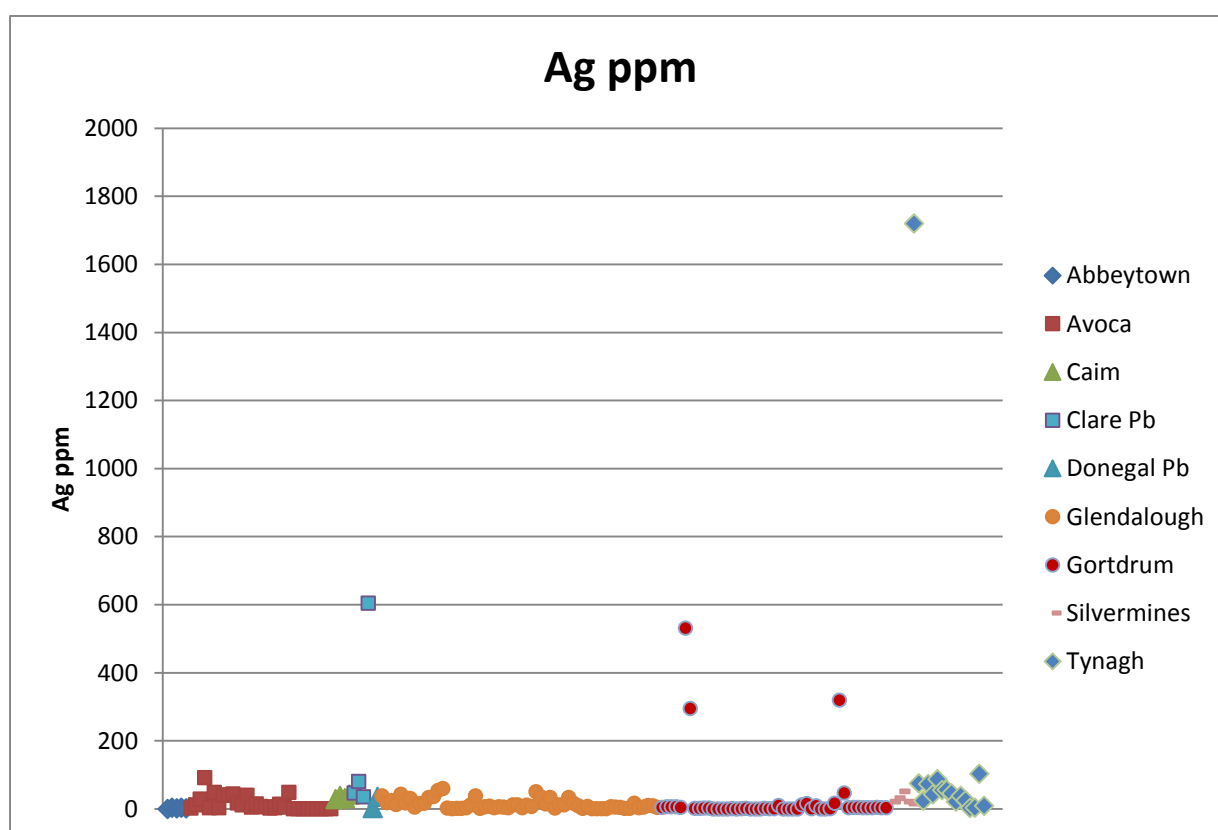


Figure 14 Ag content in Mine Waste samples by area

5.4 Results by district

Abbeytown

Analysis of the Abbeytown waste material shows low levels of most elements of interest. Magnesium is the only element which is relatively enriched in Abbeytown in comparison to other sites across Ireland with the three of the most Mg rich samples in the study all coming from this site. This may reflect dolomitisation of the carbonate host-rock as noted by Hitzman (1986). The samples from Abbeytown are also depleted in cadmium in comparison to the more southerly lead and zinc mines.

Avoca

Avoca presents some of the highest levels of numerous elements. Of greatest economic importance are the high levels of REEs and gold. Within the district there is a very clear difference between the mine waste in the former tailings facilities and the spoil heaps. For most elements, the spoil heaps have much higher values, frequently an order of magnitude greater. For example copper values in the spoil heaps over 0.5% have been noted, with the most elevated tailings Cu content 0.06% (Figure 15). Exceptions to this include cobalt and chromium where the values are elevated in the tailings relative to the spoil (Figure 16).

There are several groups of significantly correlated elements ($R^2 > 0.9$) within the Avoca waste material. Of these, silver, lead and antimony are closely linked, with high values of each element associated with the other two. Similarly linked groups include K, Cs & Rb; Ta, Hf, Nb, Th & Y; Zn & Cd. There is also a broad correlation between gold and silver (Figure 17).

Gold values at Avoca are significantly elevated within the spoil heaps in comparison to the tailings (Figure 18). Values of up to 9.8 ppm are recorded with a mean spoil value of 1.57ppm Au. These values compare favourably to economic gold grades.

The Rare Earth Elements (REEs) are also highly elevated within the spoil heaps, with values of up to 0.238% TREO recorded. The mean value for the spoil is 0.116% TREO. Grades for economic deposits of REEs currently under development are around 0.5% (Nora Karr, Strange Lake) although lower grade deposits are known in the Murmansk region (Kalashnikov et al. 2016). The Avoca REEs show a clear negative europium anomaly in both tailings (Figure 20) and spoil. Although beyond the scope of this study, the data gathered may be of use to conduct more detailed analyses of the Avoca mineralising system.

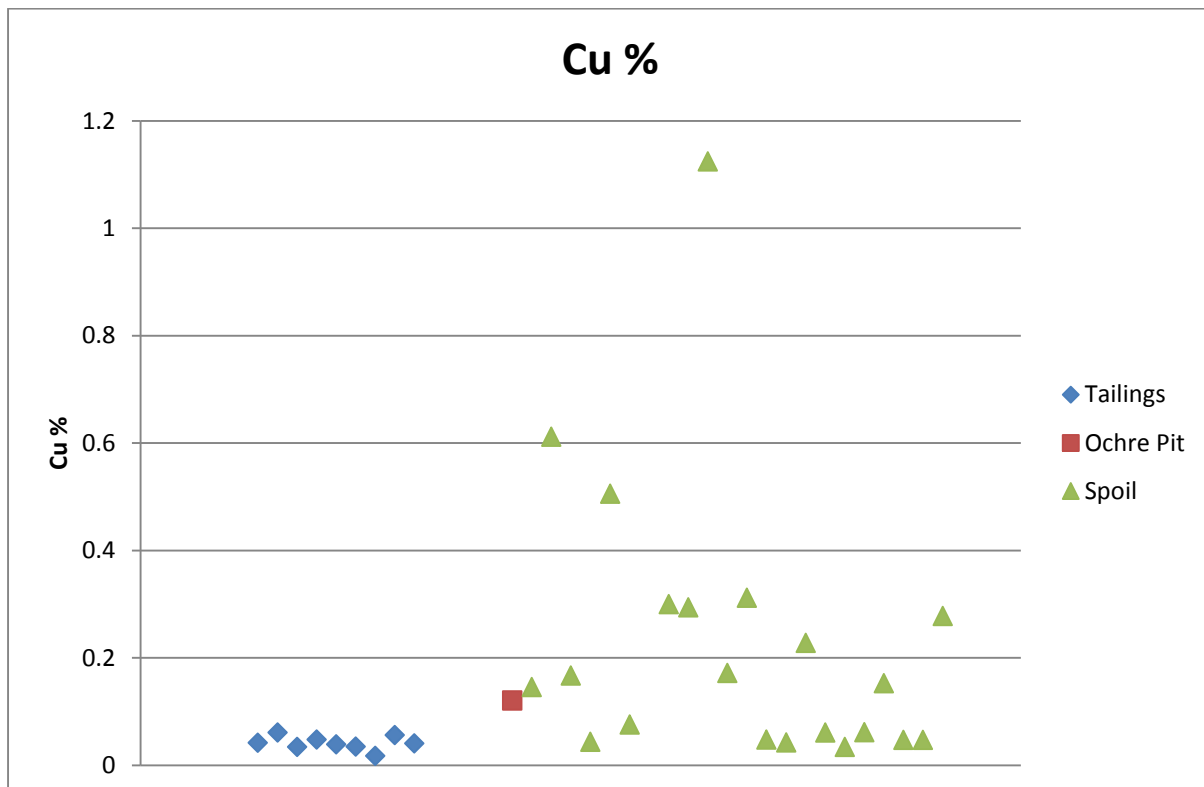


Figure 15 Cu in Avoca waste material

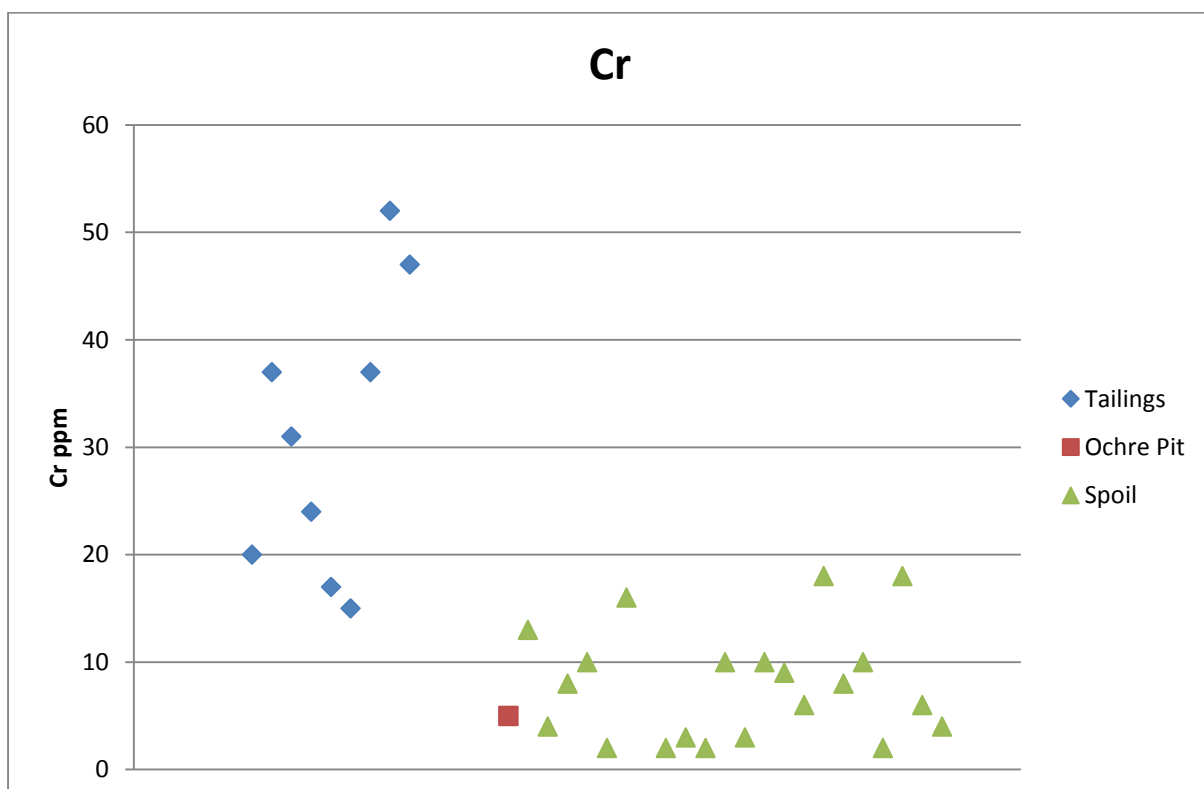


Figure 16 Cr in Avoca waste material

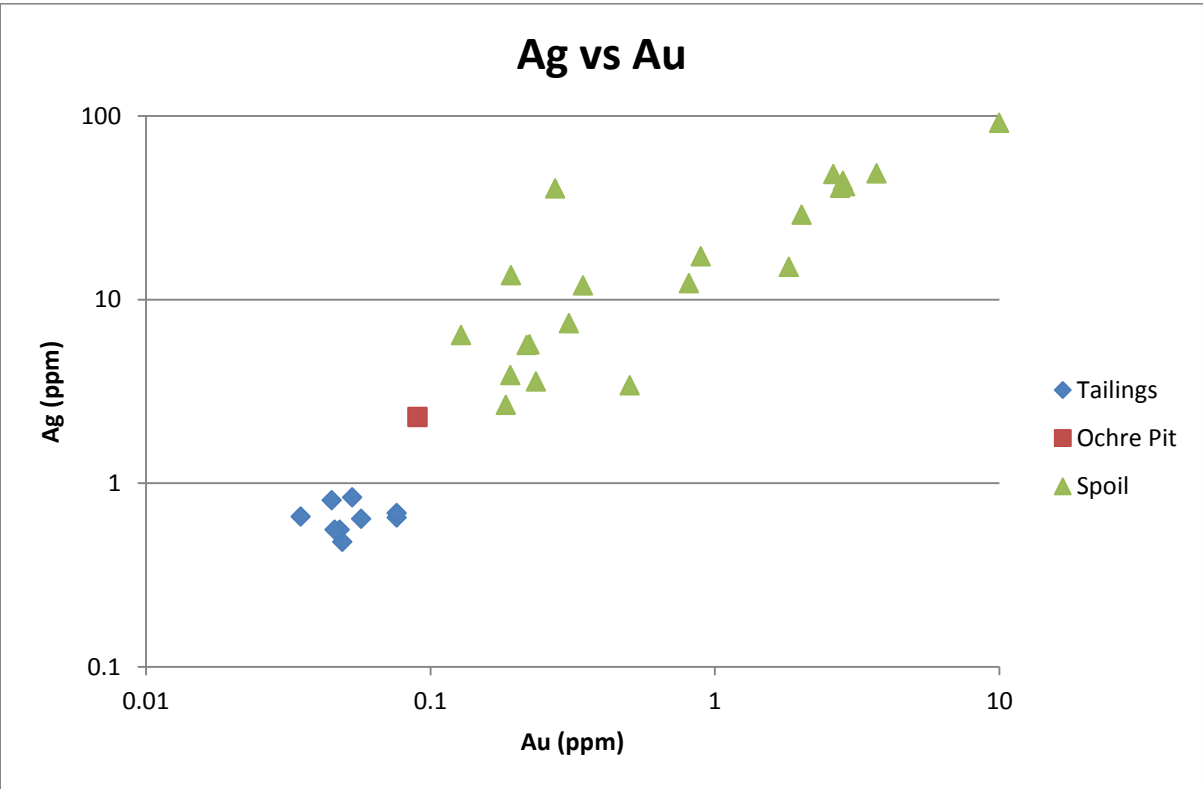


Figure 17 Ag vs Au in Avoca waste material (log/log plot)

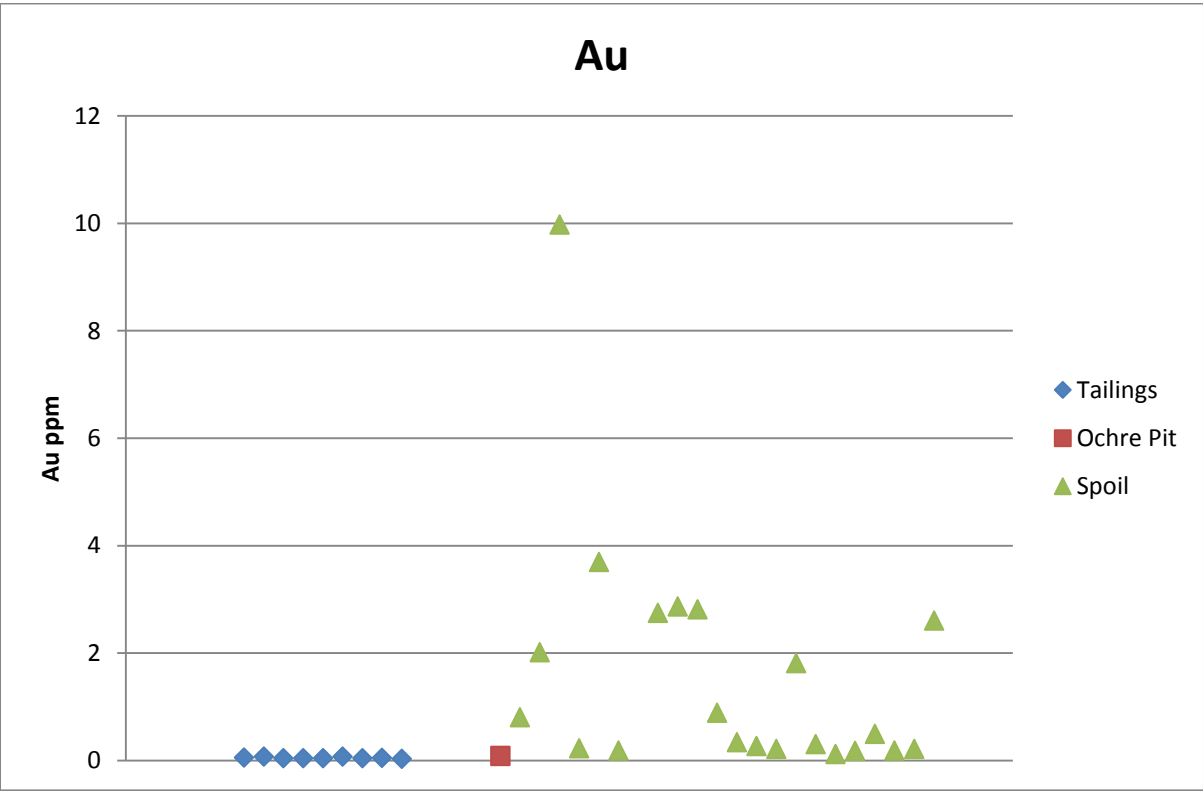


Figure 18 Au in Avoca waste material

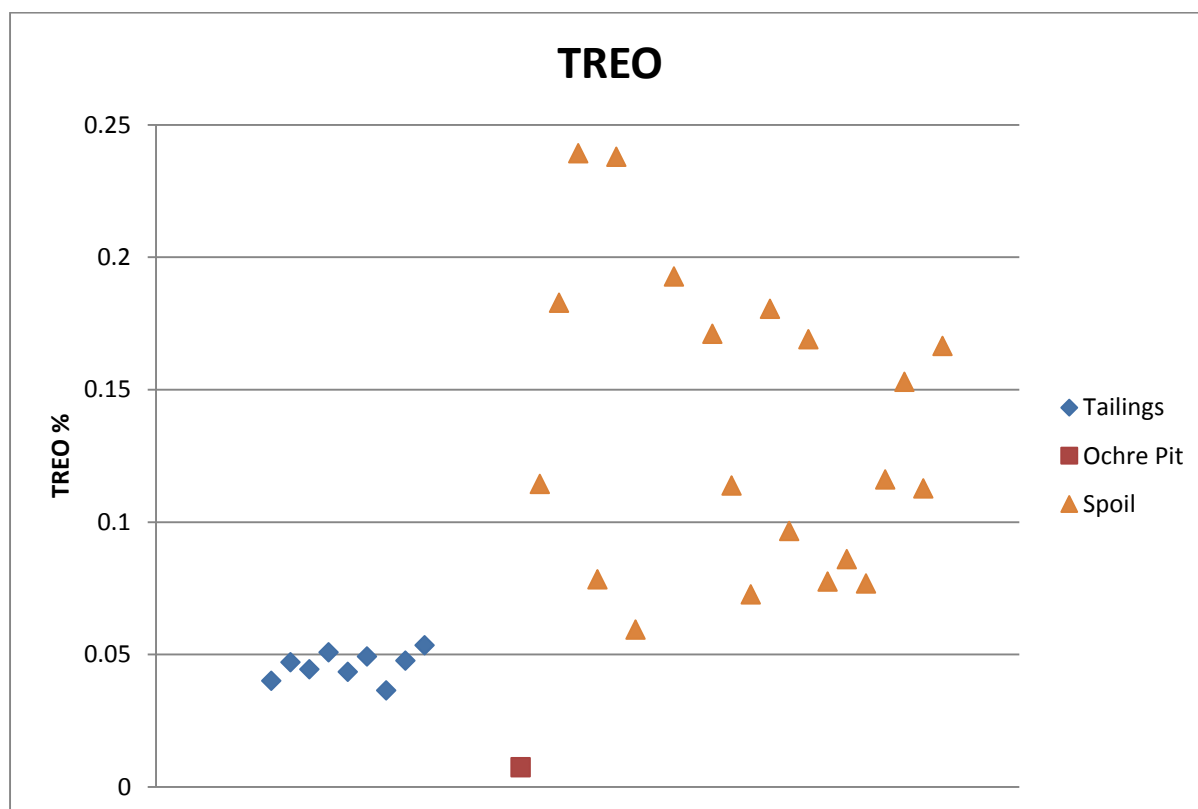


Figure 19 Total Rare Earth Oxides in Avoca waste material

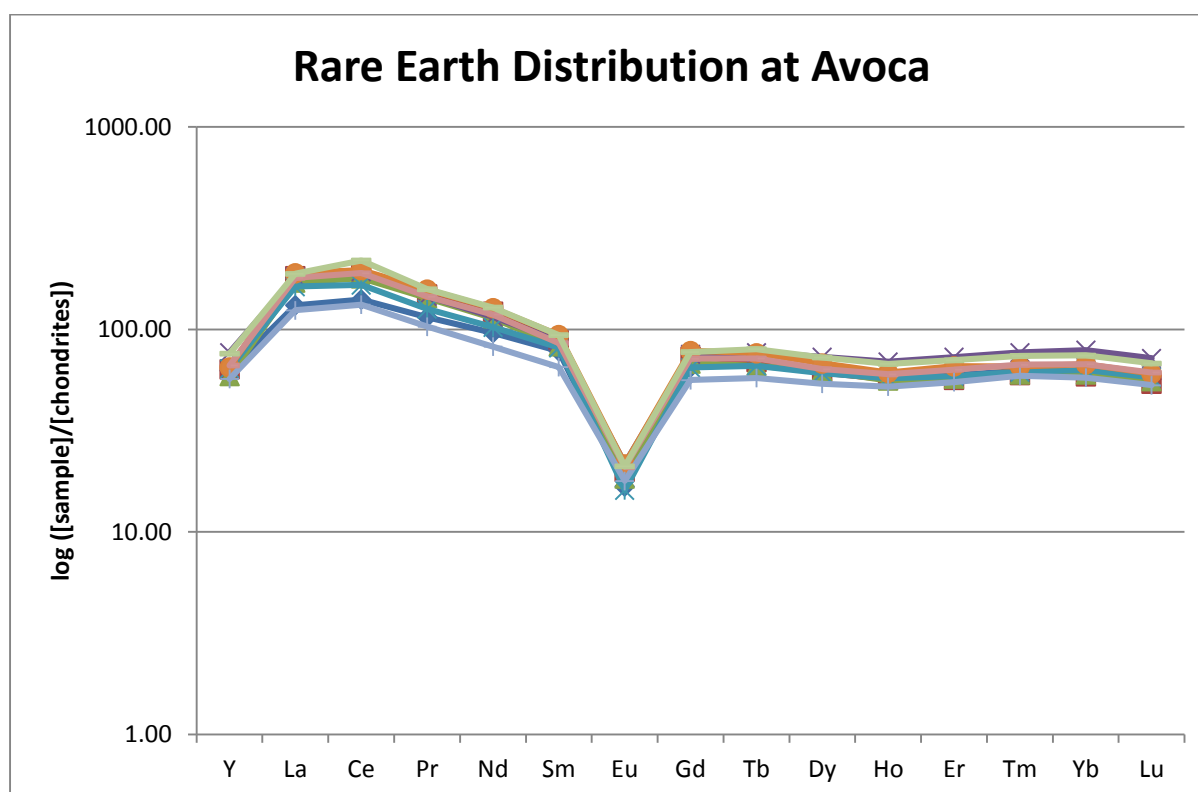


Figure 20 Rare Earth Element distribution in the Avoca tailings.

Caim

Analysis of the Caim waste material shows low levels of most elements in comparison to other mine sites within the study. Copper is slightly elevated, with values up to 0.5% recorded. Lead values are also quite high, with all Caim samples measuring greater than 5% Pb. These values reflect the mining history of the region, specifically the extraction of lead and chalcopyrite. The high lead values in the spoil may be indicative of historically inefficient processing.

Clare Pb

The Clare samples show several elements which are somewhat enriched although few are at a level which would encourage further analysis of the waste material. Silver is present in 3 of the 4 samples, those from Ballyhickey and Ballyvergin, up to 600ppm, with no silver in the Kilbricken waste material. There is also elevated copper present, up to 0.62% with a similar distribution to the silver. The Clare samples also show some of the highest lead values, with all returning values of greater than 5% Pb. These values reflect the mining history of the region, specifically the extraction of argentiferous lead and chalcopyrite. The high lead values in the spoil may be indicative of historically inefficient processing. The Clare lead district also contains high arsenic values which were previously noted in the HMS study.

Donegal Pb

Both of the samples from the Donegal lead district show elevated lead, but all other elements are within the ranges for most of the deposits. The two samples analysed were both in excess of 10% lead content. Cadmium is depleted in the Donegal and Abbeystown mine waste when compared to other lead-zinc mine sites.

Glendalough

The Glendalough samples show relatively high levels of lead and zinc with numerous results of greater than 10% Pb. Beryllium and caesium are also enriched in the Glendalough samples relative to other mine waste sites with higher levels of gallium and indium in comparison to other lead and zinc mine sites. The rare earth distribution at Glendalough shows a minor positive Europium anomaly.

Gortdrum

Gortdrum shows some individual samples with high silver content (three samples over 250 ppm) and it also has the highest arsenic value noted at 8720ppm. The elements elevated at Gortdrum differ from those typically associated with the lead & zinc mine sites and include cobalt, chromium and scandium. High copper and antimony values were also noted, with three samples over 10% Cu, including one at 21.2%.

The copper is associated with arsenic and antimony with a clear correlation between each of these elements. The silver values are also closely related to the copper values (Figure 21), suggesting that the high values in the mine waste are due to the presence of original ore material from the Cu-Ag-Hg deposit. The highest values are all associated with 5 samples from the processing area, where significant quantities of ore would have passed through. As noted in the HMS report, the extraction of metals from the secondary ore was less efficient than extraction from the primary ore. This has resulted in the presence of samples with extremely high metal content remaining in the waste material.

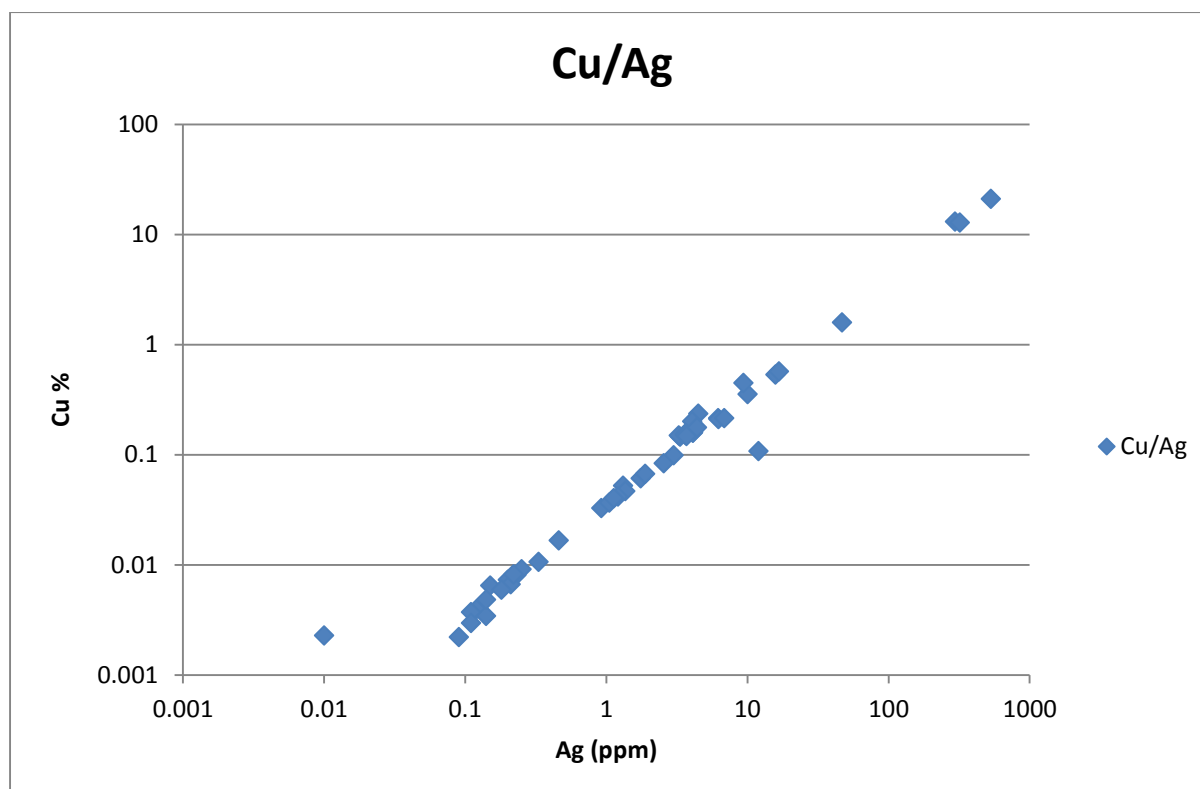


Figure 21 Copper and Silver at Gortdrum

The rare earth distribution at Gortdrum shows a very weak negative Eu anomaly. While not in the scope of this project, future work may use the REE data generated by the analyses for more detailed mineralogical investigation.

Silvermines

Analysis of the Silvermines waste material shows low levels of most elements in comparison to other mine sites within the study although one sample was measured to have 15% zinc content. Only 5 samples were available from Silvermines as part of this study, however much more extensive work has been done in this region as part of the rehabilitation of the mining site. It may be useful to refer to this work to more fully ascertain the content of the waste material in this district.

Tynagh

Samples from Tynagh show high silver, with a maximum value of 1720 ppm. Additionally there are 6 samples with Ag > 50ppm. The silver is related to arsenic, lead and antimony, with all four elements showing clear associations when plotted together, e.g. Figure 22. Arsenic (3.3 %) and zinc (max of 8.17%) are also elevated at Tynagh while in comparison to the other sites within the study, the mine waste shows elevated cadmium and cobalt.

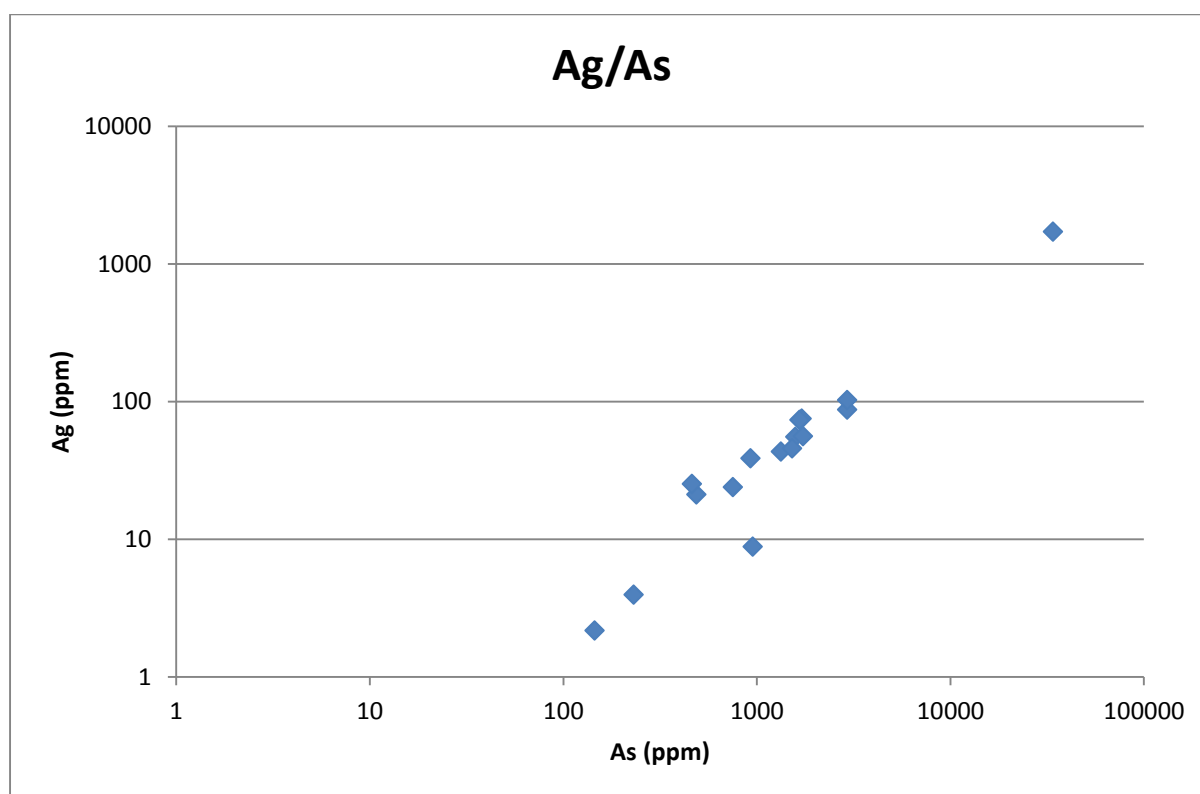


Figure 22 Silver and Arsenic at Tynagh

6. PRELIMINARY ECONOMIC ASSESSMENT OF MINE WASTE

While a significant amount of data is required to establish the economic viability of any mineral deposit, three main criteria can be used to make an initial assessment of a deposit. Grade, tonnage and mining methods are the first things that must be analysed to determine whether further work is warranted. The three are inextricably linked in each deposit, for example a lower grade may be economically viable if the deposit contains a greater amount of ore, while deposits that may be economic to mine at surface might not have sufficient ore to exploit from underground developments. The recovery of metals from mine waste represents a different approach to more traditional mining methods. A brief review of some projects that may have similarities to some of the Irish mine waste stockpile is presented below.

6.1A review of recent mining and mine waste projects

The large number of mining operations worldwide has led to the establishment of a significant knowledge base concerning tonnage, grade and mining method, with a good knowledge in the industry of what combination of these allows deposits to be economically extracted. However the dearth of mining waste recovery projects worldwide means that there are only limited examples upon which to draw.

DRDGOLD

DRDGOLD Limited is a South African gold producer focusing on the recovery of the metal from the retreatment of surface tailings. Its assets are located in the Witwatersrand Basin, South Africa. This area has been a world renowned location for gold mining since the mid 1880's and in over a century of production, extensive dumps of waste material have been created. The older of these dumps can contain significant gold which is recoverable by modern methods (DRDGOLD 2016).

Sand dumps are the result of the less efficient 'stamp-milling' process employed in the early gold mining years. They consist of coarse-grained particles which generally contain higher quantities of gold. Sand dumps are reclaimed mechanically using front end loaders that load sand onto conveyor belts. The sand is fed onto a screen where water is added to wash the sand into a sump, from where it is pumped to the plant. Most sand dumps have already been retreated using more efficient milling methods.

Slimes dams are also the result of older treatment methods, although they are more recent than sand dumps, and contain lower grades of gold. However, this material has become economically more viable to process owing to improved treatment methods and a higher gold price. The material from the slimes dams is broken down using monitor guns that spray jets of high pressure water at the target area. The resulting slurry is then pumped to a treatment plant for processing. DRDGOLD produces over 140,000oz of gold per annum with a total cash cost of \$1072/oz (2015). The process also allows for the environmental

rehabilitation of the waste dumps, freeing up significant land in the area for other uses. A summary of the DRDGOLD mineral resources is presented in Table 11 (DRDGOLD 2016).

DRDGOLD Mineral Resource Estimate								
	Inferred				Total			
	Tonnes Mt	Grade g/t	Contents Au tons	Contents Moz	Tonnes Mt	Grade g/t	Contents Au tons	Contents Moz
Surface	822.121	0.20	164.424	5.286	1 550.960	0.24	368.561	11.849

Table 11 2016 JORC compliant mineral resource estimate for Witwatersrand mining waste.

Cínovec

Cínovec is a former Sn-W mine in the Bohemia region of the Czech Republic. Extensive Tungsten mining commenced in the late 19th century although the earliest references to the site as a tin mine date to the 14th century. Mining activities ceased in 1990 with a large waste stockpile remaining. At that time, the waste material was declared uneconomic, however recent demand for Li prompted a re-examination of the facility.

Approximately 670kT of material waste is located at the site with over 2000 tonnes of lithium metal present (Rambousek & Jandová 2015). A licence has been granted to commence mining of the waste stockpile as a lithium deposit over a 5 to 6 year mine life. A large Sn-W-Li hard rock deposit is also present in the Cínovec area which is currently under exploration.

Central Asia Metals

Central Asia Metals is the owner and operator of a solvent extraction–copper recovery plant at the Kounrad mine site, near the city of Balkhash in central Kazakhstan. The company is also a partner in the proposed mining of the Copper Bay (Chañaral Beach) tailings in Chile.

The Kazakhstan operation recovers copper from waste dumps that originated from the Kounrad open-pit copper mine. Sitting on the surface, these dumps accumulated from open-pit mining operations carried out between 1936 and 2005. Over time, oxides and low-grade sulphides of copper formed a significant tonnage deposited at the mine site. Approximately 650Mt of waste material was generated by mining activity between 1936 and 2005. This waste averages 0.1% grade for a resource of 614kt contained copper (Central Asia Metals PLC 2015).

Recovery of this copper is achieved by leaching followed by SX-EW process. This process is far less cost intensive than traditional mining, as there is no need to drill, blast or transport ore – the waste dump rocks can be leached in-situ. This allows the production of copper cheaply and efficiently. Although an extremely low grade operation, the easily accessible waste piles allow for economically efficient extraction.

SX-EW is a two-stage hydrometallurgical process that first extracts and upgrades acid-soluble copper from low-grade waste dumps, using dilute sulphuric acid, followed by

extraction and upgrading of the leached copper solutions into an organic solvent mix containing a chemical that selectively reacts with and removes the copper. The copper is then extracted from the organic solvent using a strong solution of acid which is then plated as very high purity copper onto stainless steel cathode blanks using an electrolytic procedure (electrowinning).

The Kounrad facility produces approximately 12Kt of copper per annum with a total cash cost of \$0.97/lb (2016) (Central Asia Metals PLC 2016). The process also allows for the environmental rehabilitation of the waste dumps. Estimated resources within the waste dumps at Kounrad are presented in Table 12.

Kounrad Waste Dumps Mineral Resource Estimate				
Resource Type	Category	Quantity (Mt)	Grade (%)	Cu Content (Kt)
Oxide	Indicated	89.7	0.10	85.8
	Inferred	79.6	0.10	81.7
Sulphide	Indicated	275.4	0.10	276.2
	Inferred	169.4	0.09	160.3
Mixed	Indicated	20.9	0.03	6.2
	Inferred	12.1	0.03	4.0
Total		647.1		614.2

Table 12 2014 JORC compliant mineral resource estimate for Kounrad waste dumps.

From 1938 to 1975, the Potrerillos and El Salvador copper mines disposed of the tailings residues from their respective mineral processing operations into the Rio Salado which outflows into Chañaral Bay. Over that period, it is believed that some 250 million tonnes of tailings were discharged into the bay. These tailings now sit in the bay and on the beach at Chañaral and cover an area of 13 square kilometres. Estimated resources within the waste dumps at Chañaral Bay are listed in Table 13 (Central Asia Metals PLC 2016).

Chañaral Beach Tailings Mineral Resource Estimate			
Classification	Volume (m ³)	Tonnage Cu (kt)	Cu Grade (%)
Indicated	28,475,763	42,714	0.244
Inferred	5,645,741	8,469	0.234

Table 13 2012 JORC compliant mineral resource estimate for Chañaral Beach Tailings

Quest Rare Minerals

The Strange Lake project in Canada is a large rare earth (REE) deposit. The mineral resources occur near to surface and are amenable to conventional open pit mining methods. For their resource calculation and economic cut-off base case grade of 0.5% TREO was considered appropriate.

Indicated Mineral Resources are estimated at 278.13 Mt at 0.93% TREO. Inferred Mineral Resources are estimated at 214.35 Mt at 0.85% TREO (Quest Rare Minerals Ltd. 2016).

Other

Table 14 shows a selection of low grade copper mines currently operating (The Angry Geologist 2016).

Selected copper mines with reserve grades			
Mine	Cu (%)	Au (g/t)	Ag (g/t)
Mt. Milligan	0.196	0.349	-
Aitik*	0.230	0.150	0.130
Sierrita	0.240	-	1.420
Mt. Polley	0.295	0.302	0.615
Constancia	0.300	0.054	2.970

Table 14 Reserve grades from producing copper mines (*2015 production grades)

6.2 Comparison to current study

Within the waste material examined as part of this study, it is clear that Avoca has the most interesting assemblage from an economic point of view. While Glendalough has high lead and relatively high silver values, none of the other mine sites have enough samples within the grades that may be of economic interest. With high gold, silver, copper and Rare Earth contents, the waste dumps at Avoca however are deserving of further analysis.

The mineral grades mentioned in the mine examples above can be broadly divided into two separate categories; reprocessing of mine waste and REE deposits. The mine waste projects show grades which are significantly lower than might be expected from mines. This is possibly due to the lower cost of extraction, typically waste material does not require drilling, blasting or significant transport, thus eliminating large expenditures from the processing cost.

While hard rock open pit mines can operate with copper grades as low as 0.2% (Table 14), it is significant that the Kounrad facility is processing ore at 0.1% copper (Central Asia Metals PLC 2015). Similarly while some gold mines can produce at grades under or around 0.5g/t (Cadia Valley etc.), DRDGOLD's Witwatersrand tailings operation is processing ore at 0.24g/t. It is noteworthy however that each of the copper mines listed above also produces either or both silver and gold, and it is common for mines to produce more than one single commodity. With this in mind, there are several elements that could be considered together when considering the economic potential of Avoca. A summary of the average and maximum values for selected elements from analyses conducted as part of this project is shown in Table 15.

Average and maximum values from Avoca			
	Tailings	Spoil	Maximum
Au (g/t)	0.054	1.575	9.980
Ag (g/t)	0.654	23.515	91.900
Cu (%)	0.042	0.226	1.125
TREO (%)	0.046	0.141	0.258

Table 15 Average and Maximum values for selected elements in Avoca waste dumps.

6.3 Economic assessment

With an extremely small number of samples from each area, this study does not permit any quantitative analysis of the contents of the Irish mine waste stockpile. However a qualitative examination of the results and comparison to other worldwide deposits concludes that of the districts within the project, only Avoca may warrant further assessment. This conclusion will allow for any remediation projects at examined sites, other than Avoca, to proceed without the possibility that economically valuable material could be ignored or wasted.

At Avoca, the cumulative values of gold, silver and copper content compare favourably to economic deposits worldwide. However there is a major discrepancy in the amount of material available at Avoca compared to other deposits. At an estimated 1.3Mt of spoil, this is an order of magnitude less than the annual throughput of the Kounrad facility in Kazakhstan (Central Asia Metals PLC 2016).

Similarly, the gold values compare favourably to the average grade at DRDGOLD's South African stockpiles with only 6 of the Avoca samples containing less gold than the 0.24g/t average grade in Witwatersrand. In a similar comparison to Kounrad however, the total waste material available at the DRDGOLD project is equivalent to over 1,000 Avoca stockpiles (DRDGOLD 2016).

The gold content reported from the current study for Avoca is within the ranges reported by the CSA study (1992), which estimated approximately 18,000oz of gold in a specific selection of heaps. This suggests that further work should be undertaken at Avoca to quantitatively assess the contents of the waste material. Initial work should focus on the Cronebane/Mount Platt dump area, where it is estimated that almost 50% of the waste material is located.

Although increased resource efficiency is a goal of the European Union, most mine waste stockpiles are still considered to be hazardous waste rather than resources. Consequently, it may be economically viable to extract commodities as part of a remediation process. In particular, if a requirement is that waste material is moved as part of a remediation programme, it may be possible to reduce the overall cost of the project by processing the waste for any valuable content. Although the material may be sub-economic grade, if significant amounts are to be spent on moving material within a rehabilitation project, then it may be that some of the large fixed costs of resource extraction would already be absorbed.

Additionally, while one single commodity may not be present in economic quantities, there may be a combination of several commodities which could be extracted either simultaneously or sequentially. This may require some more detailed investigation,

particularly regarding the metallurgical properties of the waste and potential extraction techniques.

In spite of the low tonnages, the primary conclusion of this study is that there is enough evidence to encourage further investigations at Avoca particularly with respect to combining resource extraction with a remediation or rehabilitation project, thus mitigating the cost of environmental protection.

7. COMPARISON OF CURRENT RESULTS TO HMS STUDY

The results obtained in this study were compared with the commercial laboratory results obtained during the original HMS study. This enabled a further QA/QC check to be made on the samples. There is good reproduction of results between the two studies for most elements, however improvements in analytical techniques can clearly be seen in some of the data (e.g. Figure 23; improved lower detection limits for tin).

Comparison of the data from this study with the HMS XRF results supports many of the conclusions reached in that report regarding the accuracy and precision of the XRF unit used. In particular, high lead values can affect the accuracy of other elements, e.g. arsenic. It was also noted that there are some distinct geographical populations visible in the handheld XRF data. Figure 24 shows an excellent reproduction of results for most of the mine sites with the exception of Glendalough, Caim and Keeldrum (Donegal Pb). This may be related to the high lead content at each of these sites as suggested by the HMS report however the clear geographic divide may indicate that the poor XRF performance is related to specific mineralogy at these locations.

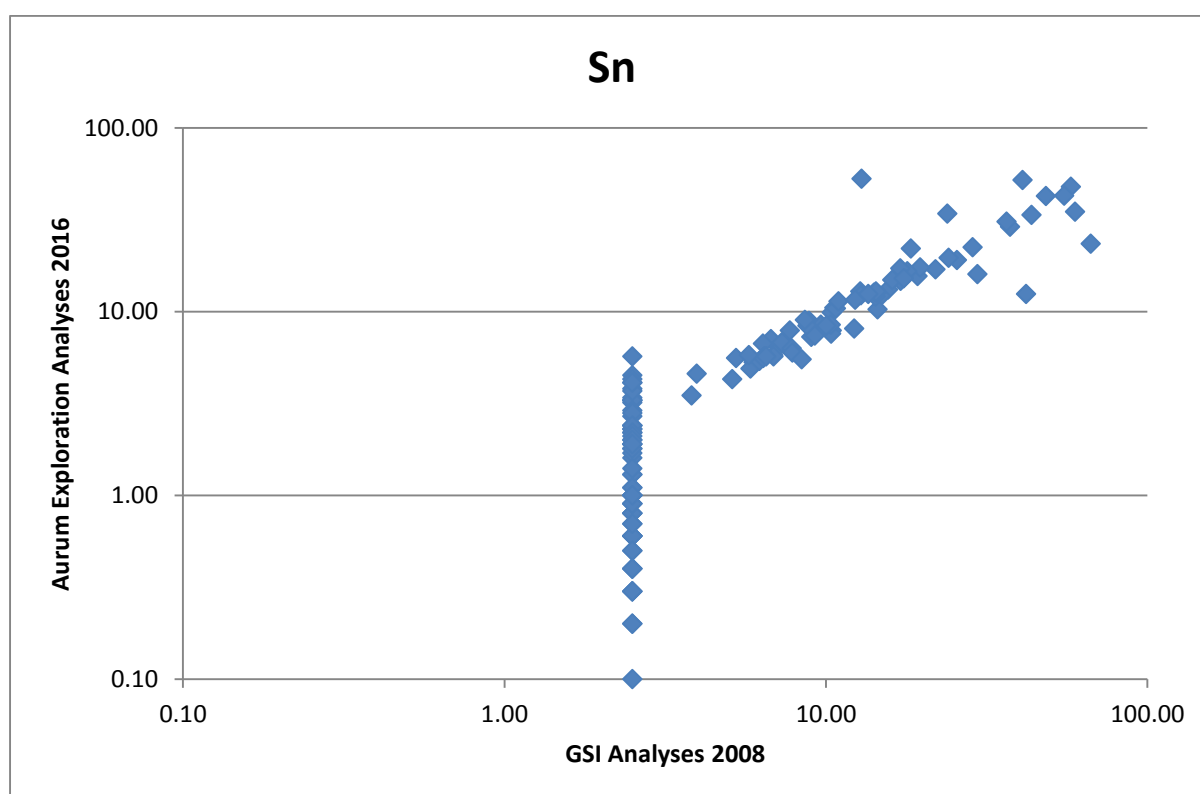


Figure 23 Sn lab values from this study compared to lab results from HMS study

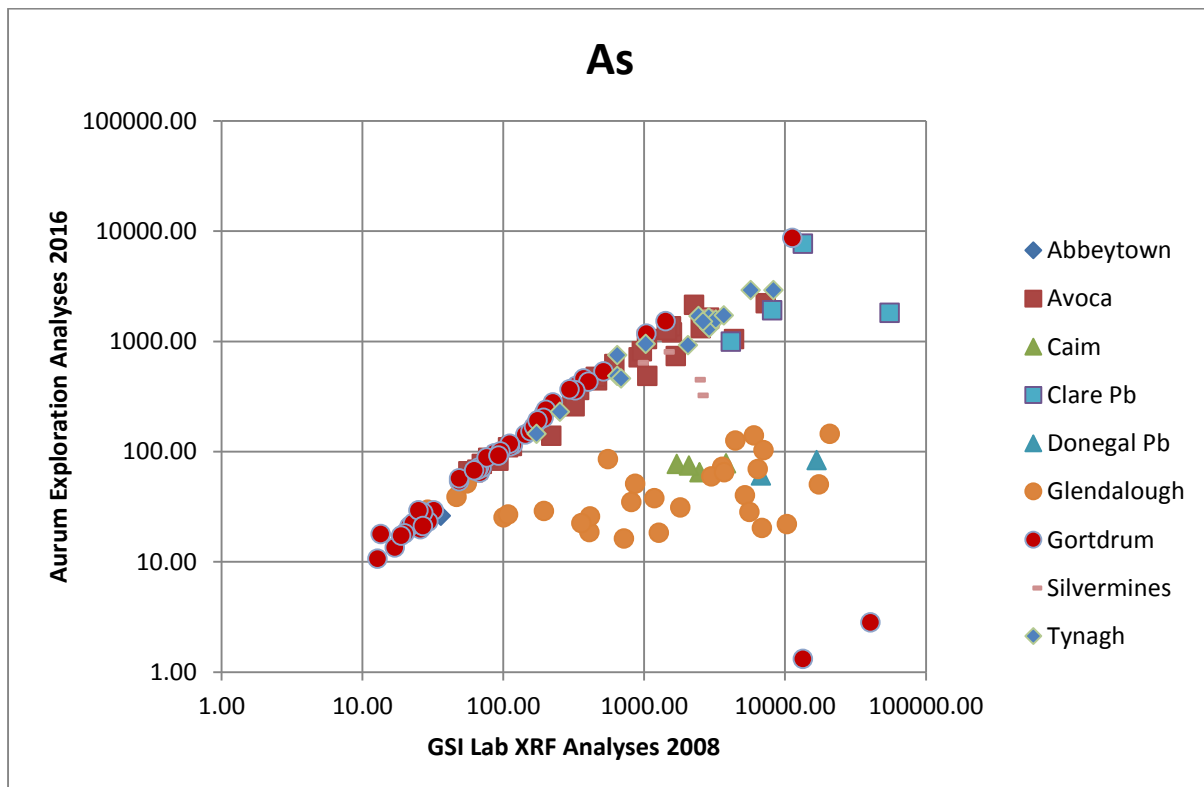


Figure 24 As lab values from this study compared to XRF values from HMS study

8. CONCLUSIONS

- The majority of historic Irish Mine Waste stockpiles included in this study can be dismissed as of no economic value.
- Avoca is the mine site which this study found to have the greatest economic potential.
- The spoil material at Avoca has significantly more potential than the tailings material.
- Further work is needed to fully assess the quantity and value of the Avoca material
- Combining resource extraction with a remediation or rehabilitation project may allow sub-economic resources to be reclaimed, thus mitigating the cost of environmental protection

9. RECOMMENDATIONS

- This project was limited by the sample suite available from the HMS study. It is recommended that the Avoca historic mine waste is studied further to fully assess the value and quantity of material present.
- There are significant mine waste stockpiles not included in this project. These include Lisheen, Galmoy and Navan lead zinc mines and the waste material from Aughinish Alumina in Foynes, Co. Limerick. It is recommended that they should be similarly examined and their economic potential assessed.
- State and semi-state bodies in Ireland make a vast quantity of data available to users at no charge. It is recommended that these available datasets (e.g. soil, rock and water geochemistry) from the Geological Survey, the EPA, EMD, Teagasc, Tellus Project etc., are compared to the results from this project to ascertain if they can provide any additional pertinent information.
- It is recommended that the data generated from this project regarding the Rare Earth distribution in the study areas is further examined to improve knowledge of the mineralisation present in the specific districts.

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